Sveriges lantbruksuniversitet

Markanvändning på organogena jordar i Sverige – en översikt av markanvändningen inom jord- och skogsbruk samt förändringar i markanvändning under perioden 1983-2014

Land use on organic soils in Sweden – a survey on the land use of organic soils within agriculture and forest lands during 1983-2014

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ABSTRACT

Data from the Geological Survey of Sweden (SGU), the Swedish Board of Agriculture and the Swedish National Forest Inventory were used in a GIS analysis to evaluate the distribution of organic soils (OS) used for agriculture and forestry in Sweden. The status of agricultural soils and agricultural land use changes were also studied, based on the most recent data available from the SGU. The total surface area of OS in Sweden was estimated to be 6 207 284 ha (15.2% of the land surface area), which is less than reported in previous assessments (Berglund and Berglund, 2008; Berglund et al., 2009). Of the total OS area 98.2% was peat, of which 4.7% was shallow peat and 2.5% ^{40}K peat (peat determined using gamma radiation data). The remaining 1.8% were gyttja soils.

Total agricultural area under EU regulations (i.e. on the EU agriculture block map) in Sweden was 3 232 039 ha (7.9% of the land surface area) and most of this was arable land (82.8%). Pasture occupied approx. 16% of the area, the land use on the remaining 1.2% is unknown. Agricultural area on OS (AOS) based on SGU-data and the EU agriculture block map was estimated to be 225 722 ha which is 7% of the total agricultural area based on EU agriculture block maps and 9.0% based on the national maps over agricultural land areas provided by the Swedish Board of Agriculture.

More than 50% of AOS was arable land whereas approx. 40% was divided between pasture and unmanaged arable land. The remaining area was wetland, unknown or other land use type. In comparison to previously studies in 2003 (Berglund and Berglund, 2008) and 2008 (Berglund et al., 2009), both the total agricultural area and AOS area have decreased, probably due to structural changes in agriculture. The decline has been sharper for the surface area of AOS than for the total agricultural area.

Among the Swedish National Forest Inventory plots, 12.3% were located on OS. Land use changes recorded on the Forest Inventory plots were mostly from arable land to other land uses rather than from other land uses to arable land both in total area and in OS.

REFERAT

Databaser från Sveriges Geologiska Undersökning (SGU), Jordbruksverket och Riksskogstaxeringen användes i en GIS-analys för att utvärdera hur mycket av jord- och skogsmark som ligger på organogen jord. Markanvändningen samt markanvändnings-förändringar undersöktes också baserat på SGUs senast tillgängliga data. Den totala arealen organogen jord i Sverige uppskattas till 6 207 284 ha (15,2% av Sveriges landyta) vilket är mindre än föregående utvärdering (Berglund och Berglund, 2008; Berglund et al., 2009). Av den totala arealen organogen jord var 98.2% torv (varav 4.7% var ytlig torv och 2.5% ”40K-torv”) och de resterande 1.8% gyttjejordar.

Den totala arealen jordbruksmark i Sverige under EUs regelverk (jordbruksblocken) var 3 232 039 ha (7,9% av Sveriges landyta) och största delen, 82.8% var odlad jord. Ungefär 16% var bete och resterande 1,2% var okänd markanvändning. Enligt analysen baserad på blockdatabasen samt SGUs jordartsdatabas låg 225 722 ha jordbruksmark på organogen jord vilket var ca 7% av arealen i blockdatabasen och 9% baserat på kartor över jordbruksmark från jordbruksverket.

Drygt 50% av den organogena jorden på jordbruksmark användes för öppen odling, 40% var beten och permanenta grödor och den resterande delen var våtmarker och okänd markanvändning. Jämfört med föregående studier 2003 (Berglund and Berglund, 2008) och 2008 (Berglund et al., 2009) har både den totala arealen jordbruksmark och jordbruksmark på torvjord minskat, troligen pga. strukturella förändringar inom jordbruket. Arealen jordbruksmark på organogen jord har minskat i snabbare takt än den totala minskningen jordbruksmark.

I riksskogstaxeringen låg 12,3% av provpunkterna på organogen jord. När man studerar hur markanvändningen förändrats på dessa punkter så är det en större andel av punkterna, både på torvjord och när man inkluderar alla punkter, som förändras från jordbruk till annan mark än tvärt om.

INTRODUCTION

Peatlands in their natural state are reservoirs of organic matter and carbon. They are utilised widely for farming, forestry and peat extraction, but also have great importance as a source of biodiversity. Peatland exploitation requires drainage to lower the watertable and this accelerates the decomposition process, which in general leads to increased greenhouse gas emissions (van der Molen, 1975; Sorteberg, 1978; Armentano, 1980; Martikainen et al., 1995; Minkkinen and Laine, 1998) and nutrient loads to nearby water systems (Holden et al., 2004). In particular, agriculture on peatlands is estimated to contribute a noteworthy amount of CO_2 and N_2O emissions (Berglund and Persson, 1996; Kasimir-Klemedtsson et al., 1997; Berglund and Berglund, 2011). It is thus critical to have accurate information about peatland surface area, distribution and characteristics in order to evaluate and predict the environmental impacts of drainage. Such detailed information about peat resources also supports planning of sustainable land use.

The aim of this study was to re-evaluate the surface area of organic soils in Sweden, based on the most recent data available from the Geological Survey of Sweden (SGU), and to determine the proportions currently used for agriculture and forestry. In this study, the term organic soils (OS) refers to a combination of peat and gyttja soil types. The outcomes of the present analysis are discussed and compared with those of earlier studies (Berglund et al., 2009; Berglund and Berglund, 2008). In addition, the organic soil data from SGU were compared against information in the Swedish National Forest Inventory database and soil data from the Swedish Board of Agriculture.

MATERIAL

The data on OS used in this work were based mainly on the soil type data in the SGU database. These data are comprehensive with minor gaps in spatial coverage. The Swedish Board of Agriculture provide information about agriculture in Sweden as agricultural block maps and as soil quality data. Data on forestry were taken from basic surveys by the Swedish National Forest Inventory. Moreover, data from the National Land survey were used to establish national and county borders. All the data maps use the SWEREF99 coordinate system.

Organic soils of Sweden

Geological Survey of Sweden (SGU) soil type data

The Geological Survey of Sweden (SGU) geological data include geographical information about soil types in Sweden with different accuracy and scales, provided as map layers applicable for geographical information systems (GIS). The SGU soil maps are constructed using multiple techniques, such as aerial photography, field visits and different types of mapping methods. Of these methods, physical field visits are the most reliable. However, in some more remote parts of Sweden, especially in Norrland, field visits are only made along the road network to support aerial mapping.

Map layers are separated according to the quality of the data, soil depth and spatial location. In this study the following soil type layers were used: *base layer* (>0.5 m depth), *thin or non-uniform layer* (<0.5m or 0.5-1.0 m depth) and the *uppermost thin or non-uniform layer* (<0.5 m depth). These layers contain data for all soil types, but for the purposes of this study geographical information on only organic soil types was used. The difference between the *thin or non-uniform layer* and the *base layer* lies in the occurrence and extent of the surveyed soil layers and their depths. Fragmental deposits with an average depth of 0.5-1.0 m are categorized as *thin*

or non-uniform layer despite occasionally deeper soil layers. For example, in areas where bedrock is near the soil surface the overlaying deposit is defined as thin layer and the bedrock itself as base layer.

In the base layer, organic soil types are defined more accurately than in the other two thin layers. In the base layer, the organic soil types are peat (*torv*), sphagnum peat (*mossetorv*), fen peat (*kärrtorv*), gyttja, gyttja clay (*gyttjelera/lergyttja*) and peat occasionally under water (*torv, tidvis under vatten*). On Gotland, calcareous gyttja (*kalkgyttja*) and lake marl (*bleke*) soil types are common and are also included as OS in SGU maps. Peat in the thin layers is not subclassified, and to distinguish this peat from the peat in the base layer, it was reclassified here as thin peat. The available map scales are 1:25 000-1:100 000, 1:200 000, 1:250 000 and 1:750 000, but not all scales are available for all regions of Sweden.

^{40}K radiation data from the Geological Survey of Sweden

All soils contain small amounts of unstable isotopes that degenerate spontaneously and emit energy, which can be measured as radiation. Airborne gamma radiation data have been used for a long time in geological surveys, such as in bedrock surveys (Cook et al., 1996). The potassium isotope, ^{40}K, is one of the most commonly used radiation emitters and is used by SGU as part of its geological surveys. Water reduces gamma radiation and this information can be used when determining the soil type. Organic soils are often moist and thus they show low radiation levels in gamma spectrometric measurements. Wet peat layers deeper than 0.5 m block all gamma radiation (Ek et al., 1992). The ^{40}K-method is considered as accurate as a country-scale map in the scale 1:1 000 000 (Monserud and Leemans, 1992). In this study, samples with a value of 1.4 or lower were treated as organic soil according to earlier studies (Berglund et al., 2009; Berglund and Berglund, 2008). The abbreviation ^{40}K peat is used here to refer to gamma radiation survey data.

SGU has been performing airborne gamma radiation measurements since 1967 (SGU, 2015). Point measurements are made at an altitude of 60 m and the airplane flies in straight lines at 200-800 m intervals, either from east to west or from north to south. Along the lines, the distance between the samples is approximately 18 m.

Agriculture in Sweden

Agriculture block database

Farmers in EU countries, including Sweden, must report their land use to be entitled to EU farming subsidies. This information from Swedish farmers is combined into an agriculture block database regulated by the Swedish Board of Agriculture (Jordbruksverket, 2010). The database contains only blocks that meet the EU regulations. Each block is a relatively uniform area with a defined agriculture type and clear borders. Block borders are defined either by natural barriers such as rivers, lakes and forest, by human-made barriers such as roads or ditches or by barriers based on land ownership. All the blocks have individual coordinates and identification codes. A block can be divided into sectors containing different crops.

The database includes information about the land use in the blocks, geographical location, block size, mapping time and method, together with other detailed information. These data are presented as block maps that are updated regularly. The data used in this study was the most recent agriculture block database, from 2015. Defined agricultural land use options are pasture (*betesmark*), wetland (*våtmark*), arable land (*åker*), two additional types of arable land (*åkermark*: permanent (*långliggande vall*) and unmanaged (*permanenta grödör*) for > 5 years), unknown (*okänt*) and other land use types (*övrig mark*). In general, a block is defined as pasture if it is (i) not suitable for ploughing, (ii) used for pasture and (iii) grows plants suitable for grazing (e.g. grass, herbs or twigs) (Jordbruksverket, 2010). Entire blocks with natural lay are also defined as pasture. Blocks with forest and tree seedling stands are not categorised as pasture. A block is recognised as arable land

if it is easy to plough and if it is used for plant production. Permanent arable land mainly hosts willow (*Salix* sp.) cultivation (90%). If a farmer has not applied for EU subsidies for a certain parcel of arable land in five consecutive years, it is categorised as unmanaged arable land. Unknown blocks are under investigation.

Total agricultural area under EU regulations in Sweden (Figure 1) in 2015 was 3 232 039 ha. Most of the blocks were arable land (66.3%), which together with the two subtypes made up 82.8%. Pasture occupied approx. 16% of the agricultural area (Table 1A-1B). The Swedish Board of Agriculture provides more detailed information about block definitions and mapping methods on its website (Jordbruksverket.se) or e.g. in its manual on block mapping (Jordbruksverket, 2010).

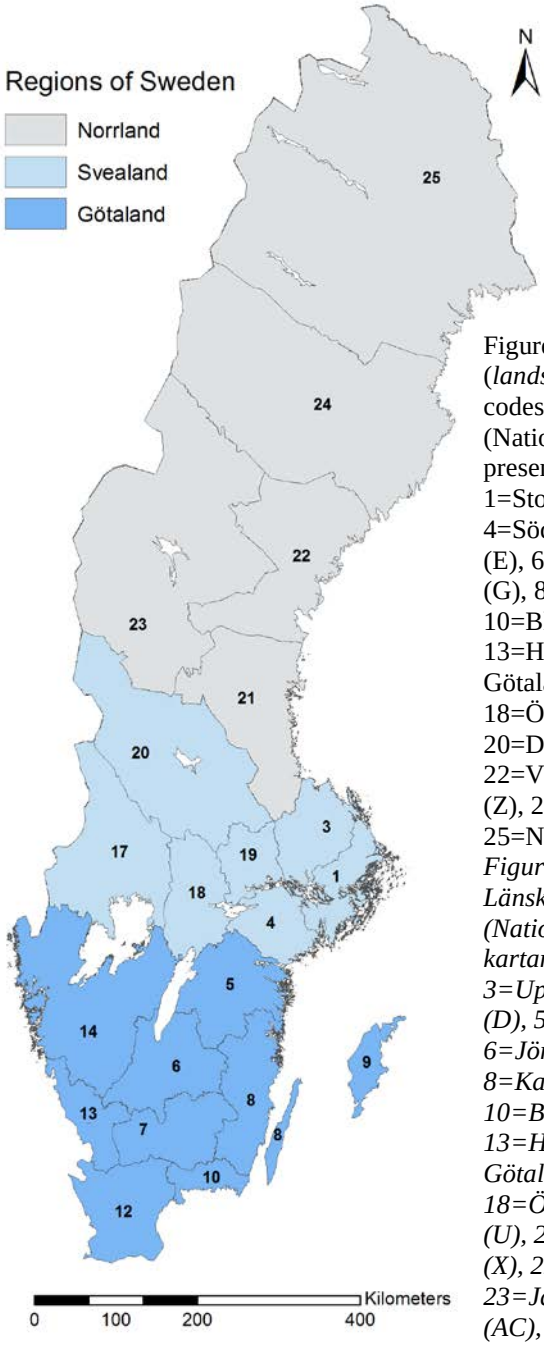


Figure 1. Counties (*län*) and regions (*landsdelar*) of Sweden. The county codes and letters (Nationalencyklopedin, 2016) presented on the map are 1=Stockholm (AB), 3=Uppsala (C), 4=Södermanland (D), 5=Östergötland (E), 6=Jönköping (F), 7=Kronoberg (G), 8=Kalmar (H), 9=Gotland (I), 10=Blekinge (K), 12=Skåne (M), 13=Hallands (N), 14=Västra Götaland (O), 17=Värmland (S), 18=Örebro (T), 19=Västmanland (U), 20=Dalarna (W), 21=Gävleborg (X), 22=Västernorrland (Y), 23=Jämtland (Z), 24=Västerbotten (AC), 25=Norrbotten (BD).
Figur 1. Sveriges län och landsdelar. Länskoderna och länsbokstav (Nationalencyklopedin, 2016) på kartan är: 1=Stockholm (AB), 3=Uppsala (C), 4=Södermanland (D), 5=Östergötland (E), 6=Jönköping (F), 7=Kronoberg (G), 8=Kalmar (H), 9=Gotland (I), 10=Blekinge (K), 12=Skåne (M), 13=Hallands (N), 14=Västra Götaland (O), 17=Värmland (S), 18=Örebro (T), 19=Västmanland (U), 20=Dalarna (W), 21=Gävleborg (X), 22=Västernorrland (Y), 23=Jämtland (Z), 24=Västerbotten (AC), 25=Norrbotten (BD).

Table 1A. Agricultural blocks (ha) in the 21 counties of Sweden in 2015. Counties are presented as codes and letters (Nationalencyklopedin, 2016).

Tabell 1A. Arealen jordbruksblock (ha) i Sveriges 21 län 2015, länsnummer och länsbokstav.

County code/letter	Arable land (AL)	AL s.t.*	AL s.t.**	Pasture	Wetland	Other	Unknown	Total
1/AB	65 858	19 396	343	12 900	334	17	1 174	100 021
3/C	131 591	16 541	1 560	18 509	192	52	1 487	169 933
4/D	106 111	20 671	1 299	18 874	926	2	741	148 624
5/E	170 692	32 800	1 113	46 106	899	14	1 202	252 825
6/F	60 865	29 162	126	42 348	241	1	343	133 085
7/G	30 151	19 406	95	23 812	227	33	509	74 233
8/H	93 091	30 861	175	78 686	674	18	3 265	206 770
9/I	72 646	14 500	58	29 007	363	73	4 550	121 196
10/K	23 811	8 129	123	13 118	164	8	1 068	46 420
12/M	401 715	47 568	2 960	60 945	2 120	21	3 045	518 375
13/N	93 373	18 667	315	19 008	641	22	1 550	133 576
14/O	399 358	77 918	893	71 593	1 340	47	5 141	556 290
17/S	77 127	34 241	179	9 215	124	29	1 640	122 556
18/T	88 316	17 558	1 127	10 586	411	27	1 765	119 790
19/U	108 453	13 469	1 070	9 221	247	61	574	133 095
20/W	43 671	19 258	209	15 677	43	79	2 930	81 865
21/X	48 952	21 354	34	7 048	49	20	2 037	79 494
22/Y	31 020	21 591	44	3 061	0	20	1 319	57 055
23/Z	24 621	18 096	28	13 326	0	0	1 324	57 396
24/AC	48 994	24 723	23	3 106	48	62	743	77 699
25/BD	23 045	14 081	105	3 482	0	19	1 008	41 740

*Arable land subtype, unmanaged for >5 years, **Arable land subtype, permanent arable crop

Table 1B. Table 1. Agricultural blocks (ha) in the regions of Sweden and in Sweden as a whole in 2015. Counties are presented as codes and letters (Nationalencyklopedin, 2016).

Tabell 1B. Arealen jordbruksblock (ha) i Sveriges landsdelar samt hela Sverige 2015.

Region	Arable land (AL)	AL s.t.*	AL s.t.**	Pasture	Wetland	Other	Unknown	Total
Norrland	176 631	99 845	234	30 022	97	122	6 432	313 383
Svealand	621 129	141 134	5 786	94 981	2 278	266	10 310	875 885
Götaland	1 345 703	279 011	5 857	384 624	6 669	235	20 672	2 042 771
Total ha	2 143 463	519 990	11 878	509 627	9 044	623	37 414	3 232 039
Total %	66.3	16.1	0.4	15.8	0.3	0.02	1.2	

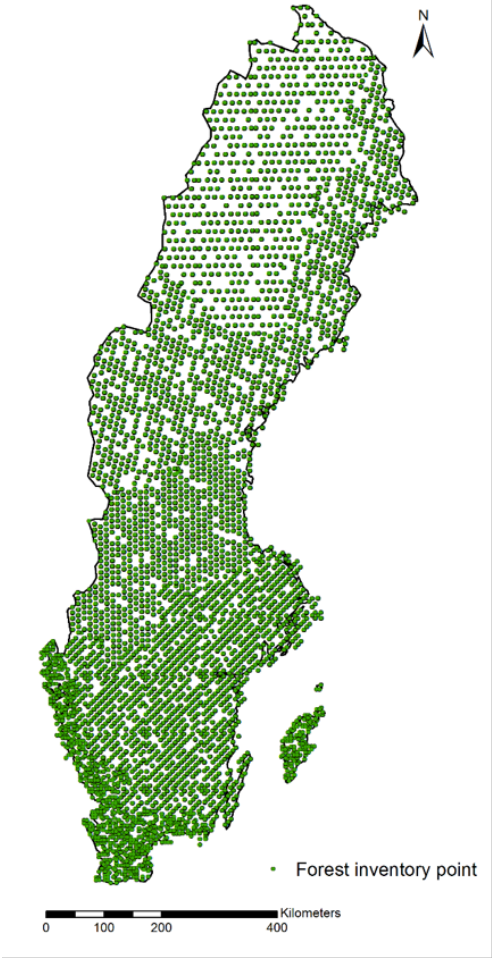
*Arable land subtype, unmanaged for >5 years, **Arable land subtype, permanent arable crop

Soil quality of agricultural land

The Swedish Board of Agriculture surveys and monitors the status of agricultural land in Sweden. In 2006, it initiated a project to improve knowledge about arable land and to provide comprehensive data and soil maps about the quality of agricultural land (Paulsson et al., 2015). During the project, almost 12 600 new soil sampling points were created in Sweden, excluding the four northernmost counties (Norrbotten, Västerbotten, Jämtland, and Västernorrland). Soil samples were analysed for plant nutrients, pH and soil texture. These data from the Swedish Board of Agriculture were published in 2015 and can be found on the website jordbruksverket.se or in the SLU environment database (http://miljodata.slu.se/mvm/). In the present study, the amount of organic matter (% of soil, <2 mm) in the sampling plots was compared spatially and quantitatively against the SGU soil type maps.

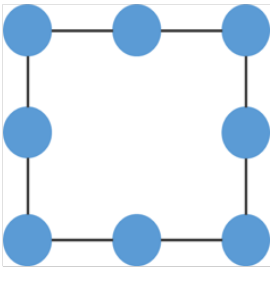
National data on forests

The Swedish National Forest Inventory is a plot sampling inventory designed to provide information on forestry and land use in Sweden (Figure 2, A). The inventory is performed in circular sampling plots that are clustered in a rectangle (Figure 2, B).



A

Most of the sample plots are mapped physically on field visits. Those that are difficult to reach due to their location, e.g. on mountains, islands, farmland or harsh terrain, are surveyed by aircraft or maps. Each plot point is marked with individual coordinates and a number. This inventory was originally conducted during the period 1983-1987 and sample points are re-surveyed every five years (Nilsson et al., 2013).



B

Figure 2. a) Illustration of sampling plots and b) clustered circular sample plots used in the Swedish National Forest Inventory.
Figur 2. a) Riksskogstaxeringens provplatser i Sverige och b) utformningen av klustrade cirkulära provplatser.

The density of the forest inventory grid is varying over Sweden due to landscape variability with a denser grid in the south and a less dense grid in the north. (Figure 2, A).

Development of agricultural areas in the National Forest Inventory

The Swedish National Forest Inventory monitors land use and land use changes that have taken place on the inventory sample plots. Plots that were or became arable land in the period 1983-2014 are included in this study. The distribution of these sample plots is presented in Figure 3. Most of these plots were located in southern Sweden. In northern Svealand and Norrland, the plots were mainly near the coast. The data cover the following types of changes: from forest to arable land and vice versa; from pasture to arable and vice versa; and from other land use type to arable and vice versa. Plots with no changes are also included. In addition to land use changes, the database includes information about soil moisture, soil type (peat, well sorted and poorly sorted sediments, moraine, and bedrock) and peat coverage. This

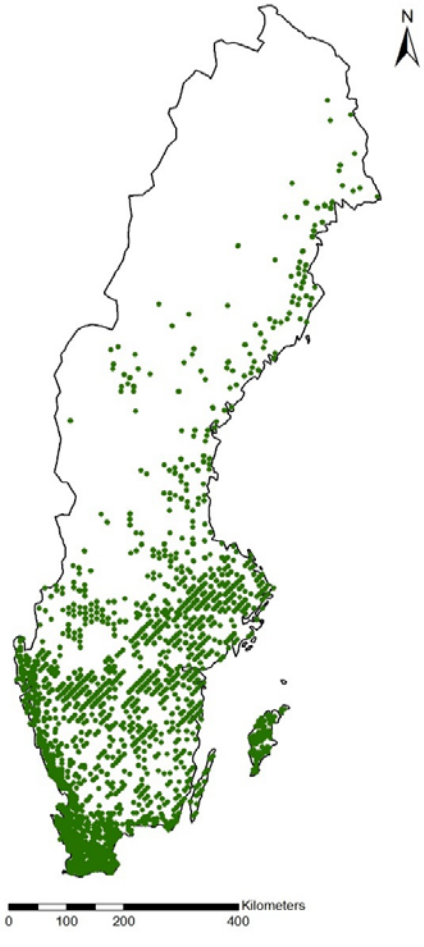


Figure 3. Distribution of sample plots containing information about agricultural land use changes in Sweden. The data is based on the Swedish National Forest Inventory.

Figur 3. Riksskogstaxeringens provplatser som var eller blev klassificerad som jordbruksmark 1983-2014.

information is determined only for plots that are classified as forest or pasture, but not for plots that are classified as arable land. The peat coverage is defined as: plots without peat; plots with <50% of the area covered with peat; plots with >50% of the area covered with peat; and plots with 100% peat.

METHODS

The data was analysed with ArcGIS 10.3.1 software. First, a map of organic soils in Sweden was created. Then datasets on agriculture and forestland use were combined individually with the organic soil base map.

Organic soil base map

The organic soil types included in the SGU-dataset were selected from the soil type maps in each layer and these different layers were combined with GIS tools. The smallest scale (1:25 000-1:100 000) together with the peat base layer (>0.5 m) was given the highest priority to construct the most accurate organic soil presentation possible. Remaining areas were represented by maps with increasing scale and decreasing soil depth (0.5-1.0 m and <0.5 m), and the very last gaps were filled with the ^{40}K radiation data. In some regions gyttja soils are covered by a shallow peat layer and these areas were deducted from the total surface area of OS.

Since the ^{40}K data are point-based, the points were interpolated using the Kriging method to create 10 m x 10 m raster-based data. This made it possible to combine ^{40}K radiation data with other layers. The created raster data were then reclassified according to radiation value (<1.4 for organic soil) and raster cells with organic soils were classified as 1 and without as 0. Finally, peat rasters were converted and dissolved into polygons.

Most of the land surface area is covered with the most detailed maps (Figure 4). However, in northern Sweden map accuracy is lower than in the southern and central parts. Gamma radiation data were used for central parts of Sweden and a few counties of Götaland.

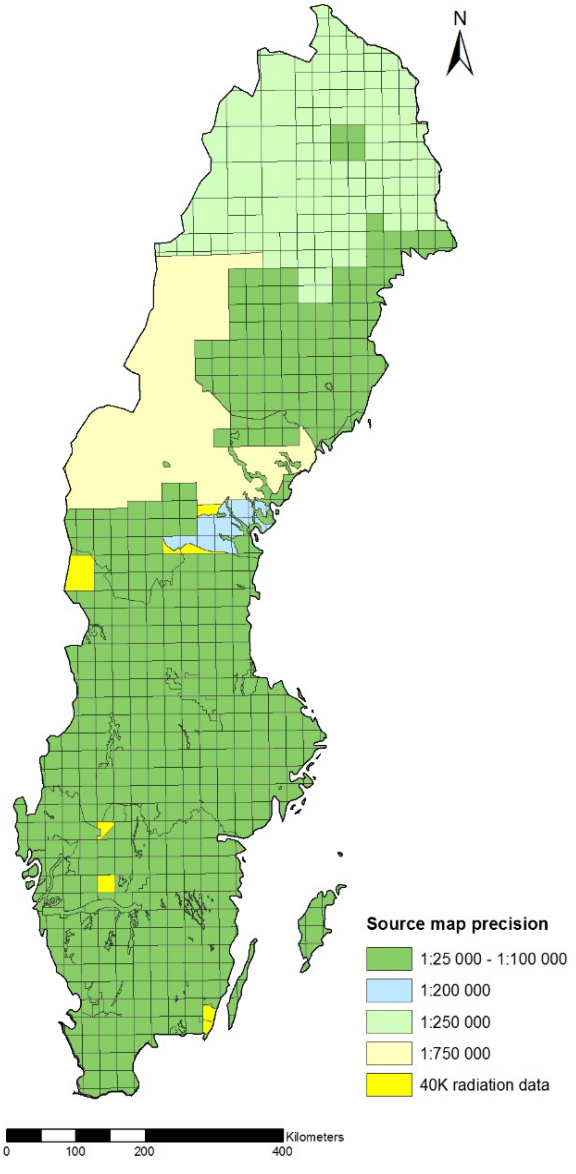


Figure 4. The precision in the soil database varies over the country. The green areas have high precision, the yellow lower precision.
Figur 4. Noggrannheten i jordartsdatabasen varierar över landet. De gröna områdena har hög noggrannhet och de gula lägre noggrannhet.

Organic soils (OS) in agriculture and in national forest inventory plots

The organic soil base map was used to study the distribution of agriculture and forestry on OS and to investigate the agricultural land use changes on OS. In the case of the plot-based Swedish National Forestry Inventory data, the representative map of the plot inventory was simply overlaid with the OS base map, except for the calcareous gyttja and lake marl soil types, and the data were joined spatially. Gyttja on top of peat (overlaying gyttja) and surface peat layers were treated as one layer. A similar procedure was performed with the agricultural data of the National Forest Inventory (inventory plots that were always or have become arable land).

The agriculture block data and the OS base maps are both polygon-based layers. Therefore these two layers were intersected and the overlaying polygons were exported in a separate file as agriculture blocks on organic soil. Figure 5 illustrates agriculture block and OS polygons and areas where they overlay. The intersection method creates fractions of polygons when two polygons do not overlap seamlessly. To reduce noisy and meaningless data, fractions smaller than 0.1 ha were removed from the agriculture dataset. The same method has been used in previous studies (Berglund et al., 2009). Point-based soil quality data from the Swedish Board of Agriculture was treated similarly as the inventory plot data from the National Forest Inventory.

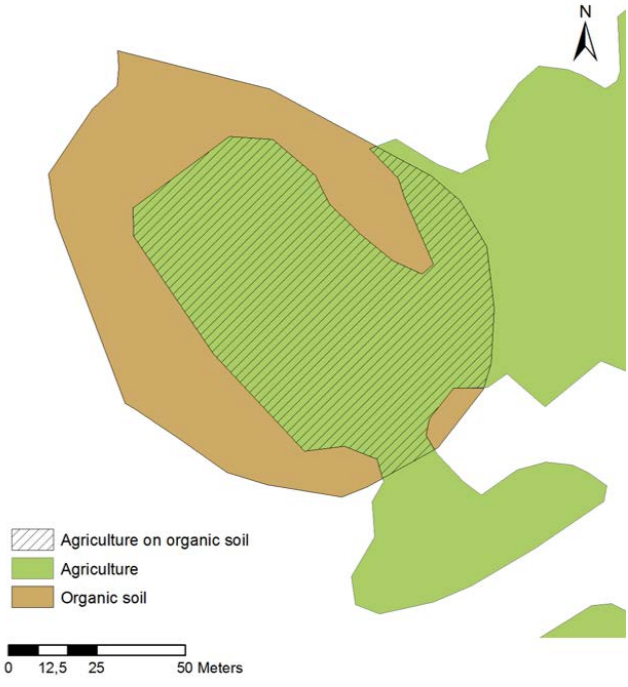


Figure 5. Illustration of agriculture block (green) and organic soil (brown) polygons. Hatched area represents overlaying areas and hence agriculture on organic soils (AOS).
Figur 5. Polygoner med jordbruksblock (grön) och organogen jord (brun). De streckade ytorna innehåller både jordbruksblock och organogen jord och är således torvblock.

RESULTS AND DISCUSSION

Organic soils in Sweden

The total surface area of organic soils (peat and gyttja types) based on SGU data was found to be 6 207 284 ha, which corresponded to 15.2% of the total land surface area in Sweden (Table 2A–2B). The highest proportion of peat soils was found in northern Sweden and in the counties of Kronoberg and Jönköping. The proportion of OS was lowest in south-east Sweden, in Blekinge, Kalmar and Gotland (Figure 6). Most of the peat was deeper than 0.5 m (91.0%). Surface peat corresponded to 4.7%, and 1.8% of the OS was defined as gyttja type (Table 2B). The highest proportions of gyttja (including gyttja, gyttja clay, calcareous gyttja and lake marl) were found in Gotland (41.5% of total OS surface area in the county) and Stockholm (38.0%). A shallow peat layer covered 21.4% (24 081 ha)

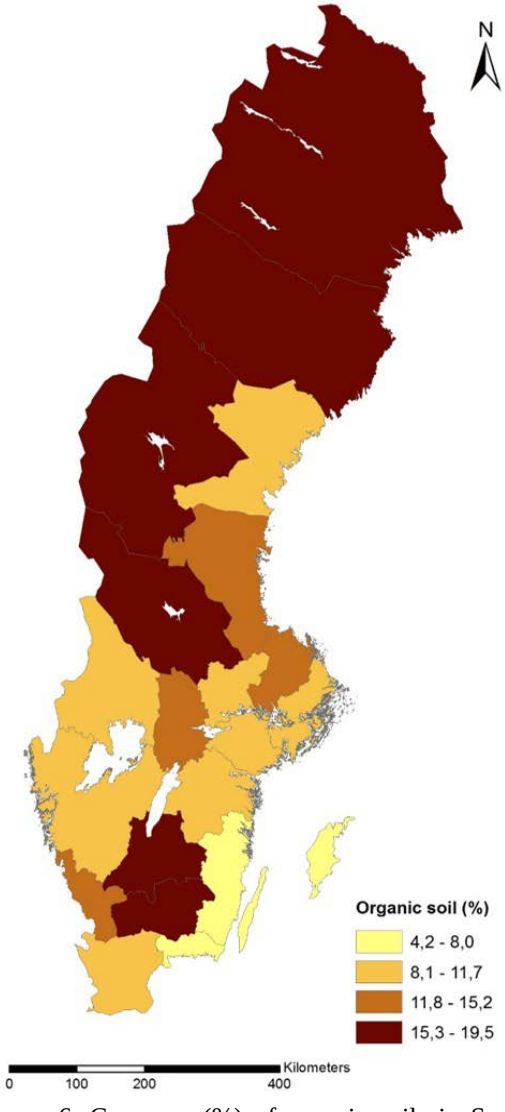


Figure 6. Coverage (%) of organic soils in Swedish counties in comparison to total land surface area.

Figur 6. Andelen (%) organogen jord jämfört med den totala landytan per län

of the total area of gyttja soils. At county level, peat covering gyttja was the most common OS type in Örebro (40.8%), Uppsala (40.2%) and Västmanland (36.0%).

The total area of OS determined for Sweden is in line with a previous approximation of 6 368 000 ha (peat thickness >0.3 m), representing 15.5% of land surface area (Hånell, 1990) based on the National Forest Inventory. Franzén (2006) has presented a similar approximation. In the study by Hånell (1990), 3 711 000 ha of thin peat (<0.3 m) were also classified as peat soil. This thin peat is found in open mires/mires with low forest production (361 000 ha) or under paludifying forests with relevant forest production (3 350 000 ha). The total peat surface area presented by Hånell (1990) including these thin peat areas thus amounted to 10 079 000 ha being 25% of the Swedish land surface. This area is notably different from the present results but has been widely used to describe the distribution of peatlands in Sweden.

In the OS base map constructed in the present study, thin and non-uniform OS covered 291 299 ha (4.7%) of land area, which is similar to the area of shallow peat mires defined by Hånell (1990). Therefore, it can be deduced that the shallow peat areas under paludifying forest reported in that previous investigation are no longer defined as peatlands. If these areas were drained, it could have led to peatland area reduction and mineralisation. By definition, a soil is defined as a peat if the peat layer is more than 0.3 m deep (Joosten and Clarke, 2002; Eriksson et al., 2005). Thus it is debatable whether the inclusion of shallow peat areas in wet forests as actual peatland area should be reconsidered, or whether the importance and impacts of shallow peatlands should be evaluated in a different manner. A solution could be to present shallow organic soils as a subclass together with total area.

Table 2A. Distribution (ha) of organic soil (OS) types and their depth in counties of Svealand and Götaland and total area and percentage of OS in each of the counties. Soil types are presented as absolute surface areas without excluding overlaying gyttja and shallow peat areas. Overlaying areas are deducted from the total area of OS. Counties are presented as codes and letters (Nationalencyklopedin, 2016).

Tabell 2A. Länsvis fördelning (ha) av torv, ytlig torv, torv enligt ^{40}K metoden samt gyttja i Svealand och Götaland. Arealen angiven i kolumnerna för de olika jordtyperna är oberoende av varandra, men i summan för de organogena jordarna är överlagrade ytorna borttagna för att inte dubbelräkna samma yta.

County code/letter	Peat*	Surface peat**	^{40}K peat	Sum of peat	Gyttja***	Tot. surface area of OS	OS (%) of land area
1/AB	29 642	6 563	0	36 205	19 486	52 255	8.1
3/C	83 103	22 506	0	105 609	17 340	115 980	14.2
4/D	40 809	7 968	0	48 777	14 774	60 169	10.0
5/E	78 998	12 104	0	91 102	8 749	97 841	9.3
6/F	153 296	12 126	6	165 428	1 037	166 460	15.9
7/G	130 310	9 382	0	139 691	4 920	144 612	17.1
8/H	62 209	10 241	7 409	79 859	8 003	86 927	7.8
9/I	8 334	4 515	0	12 849	8 060	19 402	6.4
10/K	12 626	1 088	5 207	18 921	2 422	21 343	7.5
12/M	80 250	13 546	0	93 796	5 435	99 173	9.0
13/N	74 056	2 851	0	76 907	1 515	78 392	14.4
14/O	212 201	14 475	29 178	255 854	4 350	259 868	10.9
17/S	155 673	5 352	0	161 026	1 611	162 538	9.3
18/T	93 854	13 302	0	107 156	8 488	112 178	13.1
19/U	47 606	7 931	0	55 537	4 412	58 358	11.4
20/W	382 314	17 128	73 653	473 095	943	473 982	16.8

*Peat, fen peat or sphagnum peat in base layer (>0.5 m), **Peat in surface layers (0.5-1.0 m or <0.5 m), ***Gyttja, gyttja clay or clay-gyttja type of organic soil in base layer (>0.5 m). For Gotland, lake marl and calcareous gyttja soils are included.

Table 2B. Distribution (ha) of organic soil (OS) types and their depth in counties of Norrland and total area and percentage of OS in each of the counties. Sum of OS types in all the counties of Sweden are presented as total hectare and %. Soil types are presented as absolute surface areas without excluding overlaying gyttja and shallow peat areas. Overlaying areas are deducted from the total area of OS. Counties are presented as codes and letters (Nationalencyklopedin, 2016).

Tabell 2B. Länsvis fördelning (ha) av torv, ytlig torv, torv enligt ^{40}K metoden samt gyttja. Arealen angiven i kolumnerna för de olika jordtyperna är oberoende av varandra, men i summan för de organogena jordarna är överlagrade ytorna borttagna för att inte räkna samma yta flera gånger.

County code/letter	Peat*	Surface peat**	^{40}K peat	Sum of peat	Gyttja***	Tot. surface area of OS	OS (%) of land area
21/X	190 333	20 752	11 887	222 972	856	223 640	12.3
22/Y	214 141	17 096	83	231 321	230	231 535	10.8
23/Z	751 616	11 601	26 977	790 194	0	790 194	16.0
24/AC	997 758	48 887	0	1 046 646	13	1 046 658	19.0
25/BD	1 873 817	31 883	0	1 905 700	77	1 905 777	19.4
Total ha	5 672 945	291 299	154 401	6 118 644	112 721	6 207 284	
Total %	91.0	4.7	2.5	98.2	1.8		15.2

*Peat, fen peat or sphagnum peat in base layer (>0.5 m), **Peat in surface layers (0.5-1.0 m or <0.5 m), ***Gyttja, gyttja clay or clay-gyttja type of organic soil in base layer (>0.5 m). For Gotland, lake marl and calcareous gyttja soils are included.

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Agriculture on organic soils

Agriculture blocks

In 2015, EU-regulated agriculture (3 232 039 ha) in Sweden covered 7.9% of the total land area (Table 3). Cultivation was most intensive in Götaland, where 23.5% of the land area was used for agriculture. The agricultural area in Norrland was clearly smaller by total area and in percentage terms in comparison with Svealand and Götaland. Comparing individual counties, Skåne and Gotland had the largest proportions of agricultural area, while in the northern counties the proportions were small. Agricultural area has been also surveyed by the Swedish National Forest Inventory and the reported area in 2014 was 3 149 000 ha (SEPA, 2016), which is 83 000 ha (2-3%) less than evaluated by the Swedish Board of Agriculture. Results can be considered to be similar and the difference mainly originates from definitions used in the studies.

Table 3. Total area of organic soils (OS), agricultural area and agriculture on organic soils (AOS) in the different counties of Sweden, presented as hectares and as percentage of total land surface area. Percentage AOS is in relation to total agricultural area. The area of overlaying soil horizons have been deducted from the total area of OS and AOS. Counties are presented as codes and letters (Nationalencyklopedin, 2016).

Tabell 3. Total areal organogena jordar (OS), jordbruksmark och jordbruksmark på organogena jordar (AOS) länsvis (ha) och (%) av total landyta. Procentuell AOS i relation till total jordbruksareal. Den totala arealen OS och AOS är reducerad med överliggande ytliga organogena jordarter.

County code/letter	OS (ha)	OS (%)	Agr. (ha)	Agr. (%)	AOS (ha)	AOS (%)
1/AB	52 255	8.1	100 021	15.5	11 935	11.9
3/C	115 980	14.2	169 933	20.8	18 659	11.0
4/D	60 169	10.0	148 624	24.6	16 622	11.2
5/E	97 841	9.3	252 825	23.9	17 073	6.8
6/F	166 460	15.9	133 085	12.7	11 004	8.3
7/G	144 612	17.1	74 233	8.8	7 983	10.8
8/H	86 927	7.8	206 770	18.6	16 495	8.0
9/I	19 402	6.4	121 196	39.7	12 687	10.5
10/K	21 343	7.5	46 420	16.4	5 057	10.9
12/M	99 173	9.0	518 375	47.0	24 747	4.8
13/N	78 392	14.4	133 576	24.5	5 288	4.0
14/O	259 868	10.9	556 290	23.3	30 930	5.6
17/S	162 538	9.3	122 556	7.0	1 725	1.4
18/T	112 178	13.1	119 790	14.0	14 003	11.7
19/U	58 358	11.4	133 095	25.9	11 912	8.9
20/W	473 982	16.8	81 865	2.9	3 764	4.6
21/X	223 640	12.3	79 494	4.4	4 140	5.2
22/Y	231 535	10.8	57 055	2.7	642	1.1
23/Z	790 194	16.0	57 396	1.2	2 432	4.2
24/AC	1 046 658	19.0	77 699	1.4	4 231	5.4
25/BD	1 905 777	19.4	41 740	0.4	4 395	10.5
Norrland	4 197 804	17.3	313 383	1.3	15 840	5.1
Svealand	1 035 461	12.9	875 885	10.9	78 619	9.0
Götaland	974 018	11.2	2 042 771	23.5	131 263	6.4
Sum	6 207 284	15.2	3 232 039	7.9	225 722	7.0

Agriculture on organic soils (AOS) corresponded to 7.0% of the total agriculture area and most of these areas were concentrated to southern Sweden (Table 3, Figure 7). Furthermore, of the total AOS area of 225 722 ha, more than half was in Götaland and a very small proportion in Norrland (Table 3). However, due to Norrland's greater area of OS and the smaller area in Götaland, their percentage AOS areas were similar (5.1 and 6.4%, respectively), whereas the AOS percentage was higher in Svealand (9.0%) (Table 3). Organic soils were used most intensively for agriculture in eastern and central Svealand and in the south-east of Götaland (Figure 7). Surface area of OS in agriculture was mainly deeper than 0.5 m (73.0% including gyttja type).

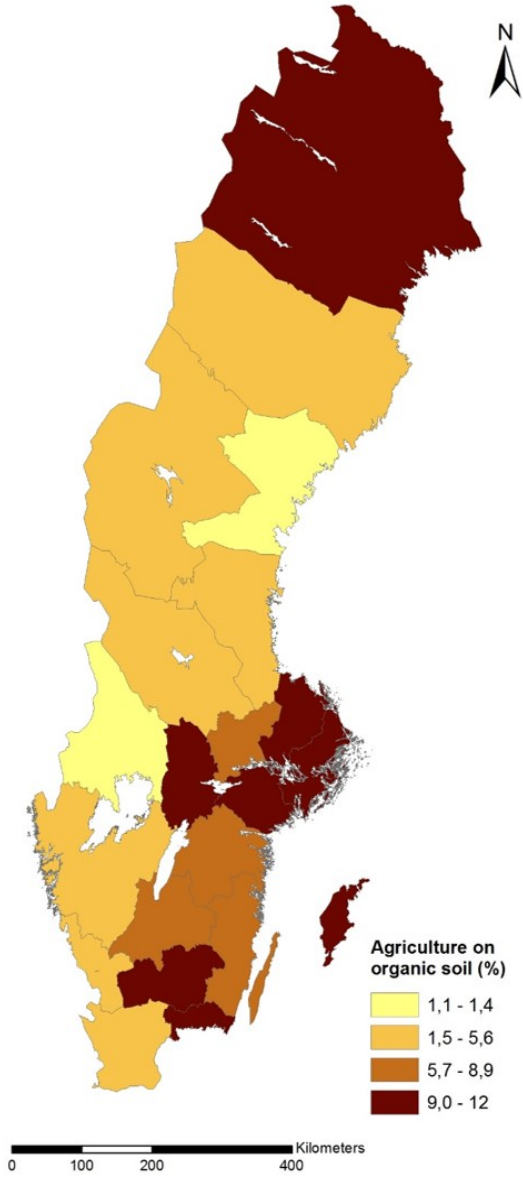

Figure 7. Distribution (%) of agriculture on organic soils (AOS) in Sweden in comparison to total agriculture area in each county.
Figur 7. Andel jordbruksmark på organogen jord (AOS) i förhållande till den totala jordbruksarealen länsvis.

The shallow peat (0.5m–1.0m and <0.5m) corresponded to 21.1% and ^{40}K peat data accounted for 5.9% (Appendix 1, Table A2).

In contrast to the general distribution of gyttja type soils in Sweden (1.8%), their occurrence was clearly higher in AOS, representing almost 27% of the total area. This is similar to the previous estimate of 29.5% in 2008 (Berglund et al., 2009). Cultivation intensity on gyttja soils, including gyttja covered by peat, varied from 66.3% in Stockholm to 0% in Jämtland, Västerbotten and Norrbotten. In Svealand, 44.4% of AOS was gyttja soils. Of the total AOS area of gyttja soils, 25.5% were overlaid by surface peat. Most of these areas were in Svealand, especially in Uppsala (40.3%), Västmanland (39.6%) and Örebro (40.3%). In Norrland, 56.9% of Gävleborg's gyttja soils were covered by peat, but in general the area of gyttja soils was very low. While there are some studies describing greenhouse gas emissions from AOS (Kasimir-Klemedtsson et al., 1997; Berglund et al., 2007; Berglund et al., 2010), but studies targeting the impacts of gyttja soils are scarce. In view of the distribution of gyttja soils in agriculture, which may expand in future due to mineralisation of overlying peat, the effects of these soils on the environment should be investigated.

More than half (58.4%) of the agriculture on OS was arable land, while pasture and unmanaged arable land covered most of the remaining area (approx. 20% each) (Table 4A-4B). These ratios followed the total area of each agriculture block type presented earlier. Wetlands were typically organic soils, which was directly reflected in the high percentage in AOS (Table 5). The proportion of arable land was lower on OS and higher proportions of other land use types were located on peat soils, whereas arable land had a tendency to be on mineral soil or other non-organic soil type (Table 5). Intensive and successful crop cultivation on peat requires good drainage and management. However, pasture or permanent grassland usually does not demand resource-consuming management, which might be the reason for the higher proportion of pasture on OS.

Table 4A. Areal (ha) distribution of different agricultural land use options on organic soils (AOS) in Svealand and Götaland. Land use options are presented as absolute surface area including areas with shallow organic soils. Overlaying area has been deducted from the total area of AOS. Counties are presented as codes and letters (Nationalencyklopedin, 2016).
Tabell 4A. Areal (ha) av olika markanvändning på organogen jordbruskmark i Svealand och Götaland. Arealen total organogen jordbruksmark har reducerats med överlappande areal av ytliga organogena jordarter.

County code/letter	Arable land (AL)	AL s.t.*	AL s.t.**	Pasture	Wetland	Other	Unknown	Total AOS	Total AOS – overlaying gyttja
1/AB	8 506	2 817	89	1 886	204	2	225	13 729	11 935
3/C	16 829	3 394	243	2 010	84	1	350	22 911	18 659
4/D	13 135	2 662	244	2 286	489	0	167	18 983	16 622
5/E	9 865	4 519	101	3 196	469	2	159	18 311	17 073
6/F	4 190	3 509	7	3 153	120	0	28	11 007	11 004
7/G	2 989	2 347	24	2 425	119	13	64	7 983	7 983
8/H	7 668	3 649	24	4 828	380	0	421	16 969	16 495
9/I	11 032	2 171	2	460	220	1	109	13 995	12 687
10/K	2 834	758	1	1 331	37	0	96	5 057	5 057
12/M	11 119	4 372	169	8 126	713	6	280	24 785	24 747
13/N	3 186	945	20	897	139	1	125	5 313	5 288
14/O	17 118	6 352	58	6 728	392	4	543	31 196	30 930
17/S	1 008	385	4	320	6	4	80	1 808	1 725
18/T	14 153	1 226	97	1 189	206	1	144	17 015	14 003
19/U	10 529	1 217	99	1 476	167	5	74	13 567	11 912
20/W	884	305	9	2 280	16	11	271	3 776	3 764

*Arable land subtype, unmanaged for >5 years, **Arable land subtype, permanent arable crop

Table 4B. Areal (ha) distribution of different agricultural land use options on organic soils (AOS) in counties of Norrland, in different regions and in total in Sweden. Land use options are presented as absolute surface area including areas with shallow organic soils. Overlaying area has been deducted from the total area of AOS. Counties are presented as codes and letters (Nationalencyklopedin, 2016).

Tabell 4B. Areal (ha) av olika markanvändning på organogen jordbruskmark i Norrland, samt för alla landsdelar och hela Sverige. Arealen total organogen jordbruksmark har reducerats med överlappande areal av ytliga organogena jordarter.

County code/letter	Arable land (AL)	AL s.t.*	AL s.t.**	Pasture	Wetland	Other	Unknown	Total AOS	Total AOS – overlaying gyttja
21/X	2 084	754	0	1 249	37	4	127	4 256	4 140
22/Y	247	213	0	125	0	1	59	644	642
23/Z	479	375	0	1 521	0	0	58	2 432	2 432
24/AC	2 442	1 152	1	509	12	33	82	4 231	4 231
25/BD	1 317	1 103	0	1 789	0	6	180	4 395	4 395
Norrland	6 569	3 596	1	5 192	49	45	506	15 957	15 840
Svealand	65 044	12 007	784	11 447	1 172	25	1 311	91 790	78 619
Götaland	70 001	28 623	404	31 144	2 589	28	1 825	134 616	131 263
Total ha	141 614	44 226	1 190	47 783	3 810	98	3 642	242 363	**225 722**
Total %	58.4	18.2	0.5	19.7	1.6	0.04	1.5		**7.0**

*Arable land subtype, unmanaged for >5 years, **Arable land subtype, permanent arable crop

Table 5. Proportional (%) distribution of different agricultural land use options on organic soils (AOS) in Sweden relative to total agricultural area of each option and each county. Land use options are presented as absolute surface area without deducting overlaying gyttja and shallow peat areas. Overlaying areas are deducted from the total area of AOS. Counties are presented as codes and letters (Nationalencyklopedin, 2016).

Tabell 5. Andel (%) olika markanvändning på organogen jordbruksmark i förhållande till den totala jordbruksmarken per län. Andelen total jordbruksmark har reducerats med överlappande andel av ytliga organogena jordarter.

County code/letter	Arable land (AL)	AL s.t.*	AL s.t.**	Pasture	Wetland	Other	Un	Tot. (%) AOS
1/AB	12.9	14.5	25.9	14.6	61.2	14.0	19.2	11.9
3/C	12.8	20.5	15.6	10.9	43.4	1.3	23.5	11.0
4/D	12.4	12.9	18.8	12.1	52.8	7.9	22.5	11.2
5/E	5.8	13.8	9.0	6.9	52.2	12.0	13.2	6.8
6/F	6.9	12.0	5.2	7.4	49.9	28.6	8.2	8.3
7/G	9.9	12.1	25.4	10.2	52.5	41.4	12.6	10.8
8/H	8.2	11.8	13.8	6.1	56.3	0.0	12.9	8.0
9/I	15.2	15.0	3.4	1.6	60.5	1.1	2.4	10.5
10/K	11.9	9.3	0.4	10.1	22.4	3.6	9.0	10.9
12/M	2.8	9.2	5.7	13.3	33.6	27.2	9.2	4.8
13/N	3.4	5.1	6.4	4.7	21.8	6.1	8.0	4.0
14/O	4.3	8.2	6.5	9.4	29.3	9.5	10.6	5.6
17/S	1.3	1.1	2.0	3.5	5.0	15.3	4.9	1.4
18/T	16.0	7.0	8.6	11.2	50.0	3.5	8.1	11.7
19/U	9.7	9.0	9.2	16.0	67.8	7.8	12.9	8.9
20/W	2.0	1.6	4.4	14.5	37.2	14.3	9.2	4.6
21/X	4.3	3.5	0.5	17.7	76.5	22.2	6.2	5.2
22/Y	0.8	1.0	0.0	4.1	0.0	5.8	4.5	1.1
23/Z	1.9	2.1	0.0	11.4	0.0	0.0	4.3	4.2
24/AC	5.0	4.7	4.1	16.4	24.0	53.6	11.0	5.4
25/BD	5.7	7.8	0.0	51.4	0.0	30.4	17.9	10.5
Norrland	3.7	3.6	0.5	17.3	50.4	36.9	7.9	5.1
Svealand	10.5	8.5	13.5	12.1	51.5	9.2	12.7	9.0
Götaland	5.2	10.3	6.9	8.1	38.8	11.9	8.8	6.4
Total	6.6	8.5	10.0	9.4	42.1	15.6	9.7	7.0

*Arable land subtype, unmanaged for >5 years, **Arable land subtype, permanent arable crop

Total area of agriculture and AOS in 2015 had decreased compared to estimations made in 2003 and 2008 (Figure 8). The agriculture block area in 2015 (3 232 039 ha) was also 8.3% less than the corresponding area in 2008 (3 525 259 ha) presented in the earlier study by Berglund et al. (2009) (Table 6). The agricultural area had decreased most in Norrland, while in Svealand and Götaland the cultivated area had declined at a lower rate. Surface area of AOS decreased almost two-fold faster than the total area and the rate was highest in southern Sweden (Table 6). At county level, Dalarna and Halland showed the greatest decrease. Jämtland differed from the other counties with a notable increase in AOS area.

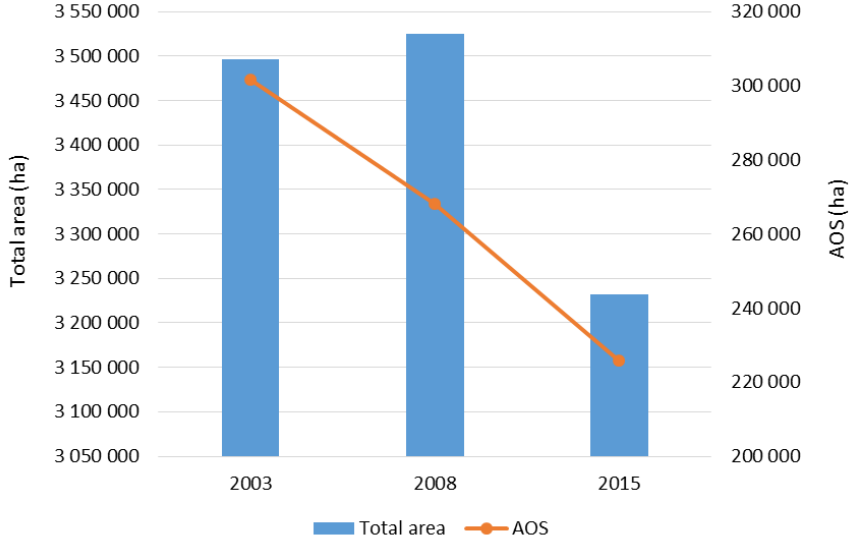

Figure 8. Total area of agricultural land (ha) and area of agriculture on organic soil (AOS) (ha) in Sweden in 2003, 2008 and 2015. Data from 2003 and 2008 are from Berglund and Berglund (2008) and Berglund et al. (2009).
Figur 8. Total areal jordbruksmark (ha) och areal jordbruksmark på organogen jord i Sverige 2003, 2008 och 2015 (Berglund and Berglund, 2008., Berglund et al., 2009).

Some of the changes in agricultural area can be explained by improved OS data precision, for example Jämtland's (95.7%) and Dalarna´s (-46.4%) notable changes in AOS. In the previously done

study (Berglund et al., 2009) there were unmapped areas especially in central-west part of Sweden (mainly Dalarna, Jämtland and Gävleborg), which mostly explains the observed changes in these counties.

However, both total agricultural area and AOS area in Sweden have declined since 2003. Generally the declining total agricultural area is probably connected to changes happened in agricultural policy, economy and land use practices in Sweden. Economic viability of agriculture has declined since 2000 leading e.g. to smaller number of livestock and thus lesser fodder production (Eurostat, 2012). These changes might be connected to the EU Common Agricultural Policy (CAP) that came into effect in 2005 changing the structure of agriculture in Sweden (Government Offices of Sweden, 2007). Moreover, during 2007-2013 the Rural Development Programme of the Swedish Ministry of Agriculture guided cultivation towards sustainable, productive and efficient options. Abandoning non-efficient arable land would enhance the efficiency of cultivation and could be thus one explanation for the observed declining area of agricultural land.

Table 6. Agricultural surface area and agricultural area on organic soils (AOS) in Sweden in 2008 (Berglund et al., 2009) and 2015. Change in agricultural area is presented as a percentage of the total. Overlaying gyttja and peat soil area has been deducted from the total area of AOS in 2015. Counties are presented as codes and letters (Nationalencyklopedin, 2016).
Tabell 6. Jordbruksmark och jordbruksmark på organogen jord i Sverige 2008 (Berglund et al., 2009) och 2015. Förändringen av jordbruskarealen presenteras som procent av den totala arealen. Arealen total organogen jordbruksmark har reducerats med överlappande areal av ytliga organogena jordarter 2015.

	2008		2015		Change	
County code/letter	Agr. (ha)	AOS (ha)	Agr. (ha)	AOS (ha)	Agr. (%)	AOS (%)
1/AB	114 720	13 925	100 021	11 935	-12.8	-14.3
3/C	184 938	20 618	169 933	18 659	-8.1	-9.5
4/D	158 449	18 280	148 624	16 622	-6.2	-9.1
5/E	276 678	20 205	252 825	17 073	-8.6	-15.5
6/F	146 144	14 448	133 085	11 004	-8.9	-23.8
7/G	84 359	10 188	74 233	7 983	-12.0	-21.6
8/H	233 914	18 747	206 770	16 495	-11.6	-12.0
9/I	134 121	13 450	121 196	12 687	-9.6	-5.7
10/K	54 117	6 670	46 420	5 057	-14.2	-24.2
12/M	548 556	28 338	518 375	24 747	-5.5	-12.7
13/N	147 057	7 659	133 576	5 288	-9.2	-31.0
14/O	597 775	39 302	556 290	30 930	-6.9	-21.3
17/S	134 851	2 370	122 556	1 725	-9.1	-27.2
18/T	128 290	16 480	119 790	14 003	-6.6	-15.0
19/U	138 273	12 570	133 095	11 912	-3.7	-5.2
20/W	90 441	7 024	81 865	3 764	-9.5	-46.4
21/X	86 783	5 072	79 494	4 140	-8.4	-18.4
22/Y	65 590	844	57 055	642	-13.0	-23.9
23/Z	57 624	1 243	57 396	2 432	-0.4	95.7
24/AC	90 038	5 674	77 699	4 231	-13.7	-25.4
25/BD	52 540	4 883	41 740	4 395	-20.6	-10.0
Norrland	352 575	17 716	313 383	15 840	-11.1	-10.6
Svealand	949 962	91 267	875 885	78 619	-7.8	-13.9
Götaland	2 222 721	159 007	2 042 771	131 263	-8.1	-17.4
Total	3 525 259	267 990	3 232 039	225 722	-8.3	-15.8

Distribution of organic soils in agriculture and comparison to SGU soil type data

Within the national soil inventory on agricultural land, 1135 (9.0%) points had more than 10% organic matter (OM). This was 2 percentage points higher than the percentage of AOS in Sweden based on SGU soil maps. The soil inventory did not cover Norrland, and comparing AOS in Svealand, the SGU-based and inventory values were identical. Götaland, in contrast, had 2.6 percentage points lower AOS in the inventory data.

There were 801 soil inventory points located on the OS base map constructed here, which represented 6.4% of the total number of points (Table 7). Most of these points had more than 20% OM. However, some of the soil inventory points with high OM did not fall within the OS base map, although the number of such points was low (4.5% of total) and most had OM between 10 and 20%. Overall, however, these results together with the comparison of total points on OM presented above might indicate a lack of precision in some parts of the SGU soil type maps. In addition, inaccuracies may arise when deciding to categorise points with low OM (usually gyttja soils) as OS or not.

Table 7. Distribution of organic matter (OM) (% of soil, <2mm) in agricultural soil inventory (A.) points and in points located on the constructed OS base map. Points that were not located on OS map are presented separately.
Tabell 7. Fördelning av punkterna i jordinventeringen i klasser beroende på angiven halt organiskt material och lokalisering i förhållande till kartan med de organogena jordarna. Punkter som inte är lokaliserade på torvjord presenteras separat.

Type of points	OM ≥20%	20% > OM ≥ 10%	OM <10%	Total
	Points / %	Points / %	Points / %	Points / %
A. points	603 / 4.8	532 / 4.2	11 463 / 91.0	12 598
A. points on OS	428 / 53.4	135 / 16.9	238 / 29.7	801 / 6.4
A. points not on OS	175 / 1.5	397 / 3.7	11 225 / 95.2	11 797 / 93.6

Forests on organic soils

A total of 4 533 of the 36 924 national forest inventory point plots were located on OS, which represented 12.3%. In general, the distribution of forests on organic soil (FOS) followed the original forest inventory sample plot distribution in Sweden. There were small concentrations of FOS in the south-west and centre of Sweden. Despite the large areas of OS in Norrland, the number of FOS plots was sparse, especially in the north-west, and plots were concentrated on the coast (Figure 9). A similar distribution of forest was reported in Hånell's (2006) study of drained forest lands and mires, according to which the area of forest on peat (> 1 m thickness) was 735 000 ha, divided relatively equally between undrained and drained areas.

Peat types found in FOS in this study are presented in Table 8. The distribution of these peat types corresponded to that of the OS base map.

Figure 9. The inventory sample plots of the Swedish National Forest Inventory located on organic soil.

Figur 9. Punkterna från riksskogstaxeringen lokaliserade på organogen jord.

More than 90% of the OS represented the base peat layer (>0.5 m). Gyttja type and peat from the gamma radiation data together were found in less than 4% of the plots, while 5.5% was surface peat type (0.5-1.0 m or <0.5 m).

Table 8. Distribution of peat types in national forest inventory sample points.
Tabell 8. Fördelningen av riksskogstaxeringens provpunkter på olika typer av organogen jord från kartan med de organogena jordarna.

Peat type	Peat*	Surface peat**	^{40}K peat	Sum of peat	Gyttja***	Total
No. points	4127	249	38	4414	119	4533
No. points %	91.0	5.5	0.8	97.4	2.6	

*Peat, fen peat, sphagnum peat and peat occasionally under water in base layer (>0.5 m)
**Peat in surface layers (0.5-1.0 m or <0.5 m)
***Gyttja, gyttja clay or clay gyttja type of organic soil in base layer (>0.5 m).

Land use changes in agriculture and characteristics of cultivation

A total of 4 258 forest inventory plots were located in areas that have been in agricultural use since 1983 (Table 9). In most of the plots (78.5%), no changes in surface area or land use form had occurred during the inventory period. Transformation from/to arable land, forest or pasture had occurred in 14.3% of the plots (Table 9). When plots without changes and with other land use changes were excluded, *most of the plots had changed from arable land to forest.* This may be due to increased demand for silviculture or to these plots of arable lands having been abandoned and thereafter afforested naturally. Though it should be noted that according to forest classification an abandoned arable land is by default categorized as forest, since it is likely that forest will be established either spontaneously or by planting. The change from arable land to pasture and vice versa were approximately similar, with a slightly higher number of plots turning to pasture. This is logical, since pasture and arable land are similar land use forms and changing between them is relatively easy. The most infrequent change was from forest to arable land, probably due to the heavy workload that clearcutting and field preparation requires.

Table 9. Number and percentage of Swedish National Forest Inventory sample plots in which the land use form had changed from/to arable land in the period 1983-2014. Changes to/from forest, or pasture are presented separately.
Tabell 9. Antal och andel (%) av riksskogstaxeringens provpunkter som ändrat markanvändning till eller från jordbruksmark 1983-2014. Förändringar till och från skog eller bete presenteras separat.

Change	No. plots	%	Excluding no change and other land use changes %
Forest -> Arable land	96	2.3	15.8
Arable land -> Forest	228	5.4	37.5
Pasture -> Arable land	132	3.1	21.7
Arable land -> Pasture	152	3.6	25.0
No changes	3 341	78.5	
Other land use -> Arable land	124	2.9	
Arable land -> Other land use	185	4.3	
Total	4 258		
Excluding no change and other land use changes	608	14.3	

When the constructed OS base map was combined with the inventory plot data set, 273 (6.4%) of 4 258 plots were found to be on OS and most of these plots were deep peat (>0.5 m). Gyttja type organic soil was found in 20% of the plots, which was a relatively high proportion when taking into account the mean distribution (1.8%) of gyttja soils in Sweden.

In general, the number of land use changes on OS followed the total distribution of changes (Table 10). However, on OS the percentage of “no change” was lower, indicating a higher probability of change. More plots on OS changed from arable land than to arable land, which may refer to a tendency for abandoning OS.

Table 10. Total number and percentage of Swedish National Forest Inventory sample plots where the land use type had changed from/to arable land during the period 1983-2014 and number of these plots on organic soils (OS). Information on OS is based on the constructed OS base map.
Tabell 10. Totalt antal och andel (%) av riksskogstaxeringens provpunkter som ändrat markanvändning till eller från jordbruksmark 1983-2014 jämfört med provpunkter lokaliserade på organogen jord.

Change	Total no. change	%	Change on OS	%
Forest -> Arable land	96	2.3	11	4.0
Arable land -> Forest	228	5.4	23	8.4
Pasture -> Arable land	132	3.1	13	4.8
Arable land -> Pasture	152	3.6	13	4.8
No changes	3 341	78.5	199	72.9
Other land use type -> Arable land	124	2.9	6	2.2
Arable land -> Other land use type	185	4.3	8	2.9
Total	4 258		273	6.4

The Swedish National Forest Inventory data defined soil characteristics for 608 inventory plots out of 4 258 that are not in the categories no change or other land use type. The soil types in these plots were mostly highly sorted sediments (36.5%), moraine (28.0%) or sediment (21.1%) (Table 11). Peat soil covered 36 inventory plots entirely (Table 11), while 14 plots had peat on only part of their surface area. Thus according to the forest inventory, a total of 50 (8.2%) plots out of 608 had peat soil. The corresponding number according to the OS base map was 60 (9.9%). Plots with only peat soil had changed from arable land to forest in 44.4% of cases and from arable land to pasture in 22.2% of cases (Table 12). A change from forest to arable land on peat soils was the most infrequent change. Arable land on peat seemed to be abandoned or transferred to other use rather than taken into cultivation from another land use type, which is in line with results obtained with the OS base map.

Table 11. Soil types found in the inventory plots, presented as absolute number of plots and percentage, in comparison to the number of land use changes.
Tabell 11. Jordtyper från riksskogstaxeringens provytor som ändrat markanvändning, antal samt andel (%) av totala antalet punkter.

Soil type	Forest -> Arable land	Arable land -> Forest	Pasture -> Arable land	Arable land -> Pasture	Total
	Plots / %	Plots / %	Plots / %	Plots / %	Plots / %
Peat	5 / 5.2	16 / 7.0	7 / 5.3	8 / 5.3	36 / 5.9
Sediment	29 / 30.2	29 / 12.7	52 / 39.4	18 / 11.8	128 / 21.1
Sediment high sort.	35 / 36.5	106 / 46.5	29 / 22.0	52 / 34.2	222 / 36.5
Sediment low sort.	4 / 4.2	23 / 10.1	8 / 6.1	15 / 9.9	50 / 8.2
Moraine	23 / 24.0	54 / 23.7	36 / 27.3	57 / 37.5	170 / 28.0
Bedrock	0 / 0.0	0 / 0.0	0 / 0.0	2 / 1.3	2 / 0.3
Total	96 / 15.8	228 / 37.5	132 / 21.7	152 / 25.0	608

Table 12. Land use changes for each OS type, presented as absolute number of plots and percentage of total number of each OS type.
Tabell 12. Ändrad markanvändning för varje typ av organogen jord, antal provpunkter och andel (%) av totala antalet provpunkter per jordtyp.

Soil type	Forest -> Arable land	Arable land -> Forest	Pasture -> Arable land	Arable land -> Pasture	Total
	Plots / %	Plots / %	Plots / %	Plots / %	Plots / %
Peat	5 / 13.9	16 / 44.4	7 / 19.4	8 /22.2	36 / 5.9
Sediment	29 / 22.7	29 / 22.7	52 / 40.6	18 / 14.1	128 / 21.1
Sediment high sort.	35 / 15.8	106 / 47.7	29 / 13.1	52 / 23.4	222 / 36.5
Sediment low sort.	4 / 8.0	23 / 46.0	8 / 16.0	15 / 30.0	50 / 8.2
Moraine	23 / 13.5	54 / 31.8	36 / 21.2	57 / 33.5	170 / 28.0
Bedrock	0 / 0.0	0 / 0.0	0 / 0.0	2 / 100	2 / 100
Total	96 / 15.8	228 / 37.5	132 / 21.7	152 / 25.0	608

Accuracy of the used data sources

In comparison with earlier studies, the accuracy and coverage of the soil data used in this study were better. The soil type data were based on the most accurate maps available. There are still areas of low precision, especially in northern Sweden, but nevertheless the maps represent an improvement on the previous situation, when there were no data available for many parts of Norrland. The least accurate source of data, the gamma radiation survey, was used only for a fraction of the land area. In comparison to the soil data from the Swedish Board of Agriculture, some inaccuracies were observed in the constructed OS base map. These inaccuracies were not critical for the results, but should be taken into account when developing and updating the soil type maps.

Despite some sources of uncertainty in the SGU soil type data, the overall precision was good and the results can be considered reliable. In the future, the precision could be improved by extending the field survey area. This would improve data quality and perhaps increase the peatland area, in Norrland in particular. The quality of the agriculture and forest inventory data has remained consistent over the years, and thus the data uncertainty is low and the results reflect the real change in Swedish cultivation activity.

CONCLUSIONS

The area of organic soils in Sweden estimated in this study was approx. 6.2 million ha, which is similar to values reported earlier. However, if the shallow, paludifying peatland forests defined in earlier study are taken into account, the present areal values are markedly smaller. This difference may be due to differences in soil type determination. Soils with a shallow peat layer (<0.3 m) do not meet the definition of organic soils and thus accounting for these soils in total area of organic soils should be reconsidered. In fact, these shallow peatlands possess peat soil characteristics and are probably as suitable for cultivation and forestry as any "true" peatland, but their environmental impact may be less or different. Shallow peatlands are also more vulnerable to watertable changes and mineralisation and may thus rapidly transform into mineral soil. Organic soils that do not meet the peatland depth definition could be subclassified and mentioned among total area of OS. This would ensure that all the organic soils are taken under consideration, but that the total area is not overestimated.

Sometimes shallow peatlands cover gyttja soils. In this study, 21.4% of gyttja soils had a peat cover. Gyttja soils were clearly more common in AOS relative to their total distribution in Sweden and 25.5% of them were under peat. Studies on the environmental impacts of gyttja soils are scarce but in light of the high distribution of gyttja soils in agriculture, which may even expand in future due to mineralisation of overlying peat, there is a need for further research on these soils.

The area of agricultural land in Sweden has declined since 2003, and in 2015 it covered 7.9% of the total land area. A similar decline, but sharper trend, was observed for the surface area of AOS. In general, arable land was the most frequent land use type, but its frequency decreased on OS. Land use changes on forest inventory plots showed partly similar results, with more plots changing from arable land to forest or pasture than vice versa. A similar trend was evident for OS. This development might be partly an outcome of Swedish agricultural policy, which aims for

sustainable and productive cultivation together with the CAP (The EU Common Agricultural Policy) reform. Also decreasing economic viability of agriculture has influenced the number of livestock among other changes and together with the ongoing reforms in cultivation practices it can explain the observed changes in agriculture area and land use types.

REFERENCES

ARMENTANO, T. V. 1980. Drainage of organic soils as a factor in the world carbon cycle. *Bioscience,* 30**,** 825-830.

BERGLUND, K. & PERSSON, L. 1996. Water repellence of cultivated organic soils. *Acta Agriculturae Scandinavica Section B-Soil and Plant Science,* 46**,** 145-152.

BERGLUND, O. & BERGLUND, K. 2011. Influence of water table level and soil properties on emissions of greenhouse gases from cultivated peat soil. *Soil Biology & Biochemistry,* 43**,** 923-931.

BERGLUND, O., BERGLUND, K. & PERSSON, L. 2007. Effect of drainage depth on the emission of CO2 from cultivated organic soils. *Wetlands: Monitoring, Modelling and Management***,** 133-137.

BERGLUND, Ö. & BERGLUND, K. 2008. Odlad organogen jord i Sverige 2003 - Areal och grödfördelning uppskattad med hjälp av digitaliserade databaser. *Rapport.* Rapport 7 ed. Uppsala: SLU, Inst. för Markvetenskap, avd. för hydroteknik.

BERGLUND, Ö., BERGLUND, K. & KLEMEDTSSON, L. 2010. A lysimeter study on the effect of temperature on CO_2 emission from cultivated peat soils. *Geoderma,* 154**,** 211-218.

BERGLUND, Ö., BERGLUND, K. & SOHLENIUS, G. 2009. Organogen jordbruksmark i Sverige 1999-2008. *Rapport.* Sveriges Lantbruksuniversitet, Mark och Miljö.

COOK, S. E., CORNER, R. J., GROVES, P. R. & GREALISH, G. J. 1996. Use of airborne gamma radiometric data for soil mapping. *Australian Journal of Soil Research,* 34**,** 183-194.

EK, B.-M., AARO, S. & NÄSLUND-LANDENMARK, B. 1992. Utnyttjande av flygradiometriska data och IR-bilder vid inventering

av sumpskogar och andra våtmarker. Uppsala: SGU och Lantmäteriverket.

ERIKSSON, J., NILSSON, I. & SIMONSSON, M. 2005. *Wiklanders marklära*, Studentlitteratur.

EUROSTAT. 2012. *Agricultural census in Sweden - Statistics Explained* [Online]. Available: http://ec.europa.eu/eurostat/statistics-explained/index.php/Agricultural_census_in_Sweden#Further_Eurostat_information [Accessed 2016-07-11].

FRANZÉN, L. G. 2006. Increased decomposition of subsurface peat in Swedish raised bogs: Are temperate peatlands still net sinks of carbon? *Mires and Peat,* 1**,** 1-16.

GOVERNMENT OFFICES OF SWEDEN, G. 2007. Rural Development Programme for Sweden – the period 2007-2013. The Swedish Ministry of Agriculture.

HOLDEN, J., CHAPMAN, P. J. & LABADZ, J. C. 2004. Artificial drainage of peatlands: hydrological and hydrochemical process and wetland restoration. *Progress in Physical Geography,* 28**,** 95-123.

HÅNELL, B. 1990. Torvtäckta marker, dikning och sumpskogar i Sverige. *In:* ZIMMERMAN, J. (ed.) *Skogsfakta, Inventering och ekonomi*. Skogsvetenskapliga fakulteten.

JOOSTEN, H. & CLARKE, D. 2002. Wise use of mires and peatlands. International mire conservation group.

JORDBRUKSVERKET 2010. Instruktion för fältinventering av brukarblock.

KASIMIR-KLEMEDTSSON, A., KLEMEDTSSON, L., BERGLUND, K., MARTIKAINEN, P., SILVOLA, J. & OENEMA, O. 1997. Greenhouse gas emissions from farmed organic soils: a review. *Soil Use and Management,* 13**,** 245-250.

MARTIKAINEN, P. J., NYKANEN, H., ALM, J. & SILVOLA, J. 1995. Change in Fluxes of Carbon-Dioxide, Methane and Nitrous-Oxide Due to Forest Drainage of Mire Sites of Different Trophy. *Plant and Soil,* 169**,** 571-577.

MINKKINEN, K. & LAINE, J. 1998. Long-term effect of forest drainage on the peat carbon stores of pine mires in Finland. *Canadian Journal of Forest Research,* 28**,** 1267-1275.

MONSERUD, R. A. & LEEMANS, R. 1992. Comparing Global Vegetation Maps with the Kappa-Statistic. *Ecological Modelling,* 62**,** 275-293.

NATIONALENCYKLOPEDIN. 2016. *Länsbokstav, http://www.ne.se/uppslagsverk/encyklopedi/lång/länsbokstav* [Online]. [Accessed 2016-10-12].

NILSSON, P., CORY, N., FRIDMAN, J. & KEMPE, G. 2013. Skogsdata 2013.

PAULSSON, R., DJODJIC, F., CARLSSON ROSS, C. & HJERPE, K. 2015. Nationell jordartskartering, Matjordens egenskaper i åkermarken.

SEPA 2016. Swedish Environmental Protection Agency. National Inventory Report Sweden 2016, Greenhouse Gas Emission Inventories 1990-2014, Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol.

SGU. 2015. *Geological Survey of Sweden* [Online]. Available: http://www.sgu.se/en/products/data/use-data-from-sgu/ [Accessed 2016-10-12].

SORTEBERG, A. 1978. Subsidence in peat soil after drainage. *International peat society proceedings*.

VAN DER MOLEN, W. H. 1975. Subsidence of peat soils after drainage. *IAHS-AISH-UNESCO publications 105, Paris*.

APPENDIX

Table A1. Distribution (ha and %) of peat, surface peat, ^{40}K peat and gyttja in agriculture blocks in Svealand and Götaland. Overlaying gyttja and peat soil area is deducted from the total area of AOS. Counties are presented as codes and letters (Nationalencyklopedin, 2016).

Tabell A1. Fördelningen (ha och %) av torv, ytlig torv, ^{40}K torv och gyttja på jordbruksblock i Svealand och Götaland. Arealen total organogen jordbruksmark har reducerats med överlappande area av ytliga organogena jordarter.

County code/letter	Peat (ha)	Peat (%)	Surface (ha)	Surface (%)	Gyttja (ha)	Gyttja (%)	^{40}K (ha)	^{40}K (%)	Total AOS	Total AOS without gyttja
1/AB	2 478	18.0	2 149	15.7	9 102	66.3	0	0.0	11 935	2 832
3/C	5 117	22.3	7 241	31.6	10 553	46.1	0	0.0	18 659	8 105
4/D	6 040	31.8	4 035	21.3	8 909	46.9	0	0.0	16 622	7 713
5/E	9 435	51.5	3 913	21.4	4 963	27.1	0	0.0	17 073	12 110
6/F	8 706	79.1	2 109	19.2	192	1.7	0	0.0	11 004	10 813
7/G	6 222	77.9	1 487	18.6	274	3.4	0	0.0	7 983	7 709
8/H	8 385	49.4	3 346	19.7	3 806	22.4	1 432	8.4	16 495	12 689
9/I	3 907	27.9	3 389	24.2	6 700	47.9	0	0.0	12 687	5 987
10/K	1 956	38.7	433	8.6	1 438	28.4	1 229	24.3	5 057	3 619
12/M	16 076	64.9	5 542	22.4	3 167	12.8	0	0.0	24 747	21 580
13/N	3 554	66.9	607	11.4	1 152	21.7	0	0.0	5 288	4 136
14/O	14 760	47.3	2 717	8.7	2 531	8.1	11 187	35.9	30 930	28 399
17/S	646	35.7	394	21.8	768	42.5	0	0.0	1 725	956
18/T	5 147	30.3	4 853	28.5	7 015	41.2	0	0.0	14 003	6 989
19/U	5 143	37.9	4 245	31.3	4 179	30.8	0	0.0	11 912	7 732
20/W	2 900	76.8	338	8.9	274	7.2	265	7.0	3 764	3 491

Table A2. Distribution (ha and %) of peat, surface peat, ^{40}K peat and gyttja in agriculture blocks in the counties of Norrland and in different regions and in total in Sweden. Overlaying gyttja and peat soil area is deducted from the total area of AOS. Counties are presented as codes and letters (Nationalencyklopedin, 2016).

Tabell A2. Fördelningen (ha och %) av torv, ytlig torv, ^{40}K torv och gyttja på jordbruksblock i Norrland, samt för alla landsdelar och hela Sverigek. Arealen total organogen jordbruksmark har reducerats med överlappande area av ytliga organogena jordarter.

County code/letter	Peat (ha)	Peat (%)	Surface (ha)	Surface (%)	Gyttja (ha)	Gyttja (%)	^{40}K (ha)	^{40}K (%)	Total AOS	Total AOS without gyttja
21/X	2 452	57.6	1 592	37.4	203	4.8	9	0.2	4 140	3 937
22/Y	476	74.0	151	23.5	16	2.5	0	0.0	642	626
23/Z	2 242	92.2	95	3.9	0	0.0	94	3.9	2 432	2 432
24/AC	2 758	65.2	1 472	34.8	0	0.0	0	0.0	4 231	4 230
25/BD	3 434	78.1	961	21.9	1	0.0	0	0.0	4 395	4 394
Norrland	11 362	71.2	4 271	26.8	220	1.4	104	0.6	15 840	15 619
Svealand	27 470	29.9	23 254	25.3	40 800	44.4	265	0.3	78 619	37 819
Götaland	73 001	54.2	23 543	17.5	24 222	18.0	13 849	10.3	131 263	107 041
Total	111 833	46.1	51 069	21.1	65 243	26.9	14 218	5.9	225 722	160 479

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