Towards new reporting of drained organic soils under the UNFCCC

– assessment of emission factors and areas in Sweden.

Rapportering av utsläpp från dränerade organiska jordar under UNFCCC

– utvärdering av emissionsfaktorer och arealer för Sverige.

Foto: Lars Lundin

Amelie Lindgren and Mattias Lundblad

Sveriges lantbruksuniversitet
Institutionen för mark och miljö

Swedish University of Agricultural Sciences
Department of Soil and Environment

Rapport 14.
Uppsala 2014
ISBN
978-91-576-9222-1

Preface

This is the final report of a project, initiated and funded by the Swedish Environmental Protection agency to assess how to improve and/or to expand the reporting of drained organic soils and wetlands.

The work was conducted at the Department of Soil and Environment at the Swedish University of Agricultural Sciences (SLU) by Amelie Lindgren, together with supervisor and co-author Mattias Lundblad.

Several contacts with researchers at the SLU and other universities as well as experts at interested national agencies have been taken to reconcile the proposals put forward in the report.

The authors are solely responsible for the statements and proposals made in the report.

Uppsala 2014-04-25

Table of Contents

Sammanfattning

I oktober 2013, under IPCCs 37:e session, antogs “The 2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands” (hädanefter kallat WL GL). Dessa antogs också av Klimatkonventionens (UNFCCC) 19:e partsmöte att användas som en del av metodriktlinjerna för rapportering av växthusgaser inom markanvändningssektorn (LULUCF) till UNFCCC. I samband med dessa nya riktlinjer uppstod behovet av att utreda hur dessa skulle kunna användas för svenska förhållanden och för Sverige tillgängliga datakällor. Detta arbete inkluderar både att utreda de befintliga emissionsfaktorerna, de nya angivna i WL GL och i särskilda fall ta fram ytterligare alternativ om behovet, eller kunskapen finns. Dessutom innebär arbetet även att ta fram relevant aktivitetsdata för de markanvändningskategorier som ingår i WL GL. Denna rapport fokuserar på utsläpp av växthusgaser från dränerad organogen mark, torvbrytning och återvätning av organogen mark.

I tabell 1 summeras de emissionsfaktorer som rekommenderas att användas inom svensk klimatrapportering av dränerad organogen mark, torvbrytning och återvätning. Varje enskild rekommendation diskuteras i respektive kapitel (Forest land till Rewetting). Emissionsfaktorerna gäller generellt för mark som inte genomgår någon markanvändningsförändring utom för återvätning.

I tabell 1 visas även en total emissionsfaktor i CO_2-C ekvivalenter som beskriver den sammanlagda belastningen på utsläppen från en markanvändningskategori per hektar (implied emission factor, IEF). Resultaten visar att dränerad organogen jordbruksmark har den högsta belastningen per ytenhet, däremot står dränerad organogen skogmark för de största totala utsläppen på grund av dess areal. Den sammanlagda emissionen från dränerad organogen mark, torvbrytning och återvätning baserat på de arealuppskattningar som gjorts i denna studie uppgår till 10,63 Mt $CO_{2\text{-ekv}}$ (tabell 1).

Tabell 1 a) Summering av rekommenderade emissionsfaktorer (EF) för nationell rapportering av organogen mark. Alla EF gäller dränerad organogen mark eller återvätt organogen mark. EF står beskrivna så som i rapporten och gäller per hektar. Den totala emissionsfaktorn (IEF) är en summering av enskilda emissionsfaktorer multiplicerad med deras globala uppvärmningspotential (GWP -100 år) i ton CO_2 ekvivalenter per hektar. b) Utsläpp för varje kategori i kiloton CO_2 ekvivalenter uträknade med respektive EF och area, samt totalt utsläpp i M ton CO_2 ekvivalenter.

***Table 1** a) Summary of recommended emission factors for the Swedish national reporting of GHG emissions from drained or rewetted organic soils in accordance with the new method guidance given in the WL GL. The emission factors are given per hectare and the impact on total emission is the sum of the individual emission factors multiplied with their Global warming potential (GWP - 100 year) to create a sum in CO_2 equivalents which is called the implied emission factor (IEF). b) Emissions (area times EF) in k ton CO_2 equivalents for each category, total emission given in M ton CO_2 equivalents.*

1a Typ av mark	Klimat	Närings-status	Emissionsfaktorer (viktenhet per hektar)					IEF	IEF
			ton CO_2-C	kg N_2O-N	kg CH_4	dike kg CH_4	DOC ton CO_2-C	(ton CO_2-C $_{eq}$/ha)	(ton CO_2 $_{eq}$/ha)
Dränerad Skogsmark	Boreal	Rik	0,93	3,2	2	5,4	0,12	1,51	5.53
		Fattig	0,25	0,22	7	5,4	0,12	0,48	1.77
	Tempererad	Rik	2,6	2,8	2,5	5,4	0,12	3,13	11.48
		Fattig	2,6	2,8	2,5	5,4	0,12	3,13	11.48
Dränerad Jordbruksmark	Boreal/ Tempererad		6,1	13	0	58,3	0,12	8,28	30.35
Dränerad Gräsmark	Boreal	Rik	0,93	3,2	1,4	5,4	0,12	1,54	5.65
		Fattig	0,25	0,22	1,4	5,4	0,12	0,48	1.76
	Tempererad	Rik	2,6	2,8	2,5	5,4	0,12	3,17	11.62
		Fattig	2,6	2,8	2,5	5,4	0,12	3,17	11.62
Torvbrytning			2,8	0,3	6,1	26,2	0,12	3,18	11.67
Återvätning	Boreal	Rik	-0,55	0	55	0	0,08	-0,10	-0.35
		Fattig	-0,34	0	183	0	0,08	0,99	3.62
	Tempererad	Rik	0,5	0	123	0	0,08	1,42	5.20
		Fattig	-0,23	0	288	0	0,08	1,81	6.65

1b Typ av mark	Klimat	Närings-status	Sveriges Nationella Emissioner i kiloton $CO_{2\ eq}$					Totalt utsläpp (M ton $CO_{2\ eq}$)
			CO_2	N_2O	CH_4	dike CH_4	DOC CO_2	
Dränerad Skogsmark	Boreal	Rik	1067,4	469,1	15,3	42,5	137,7	1,73
		Fattig	222,0	24,9	41,3	32,8	106,5	0,43
	Tempererad	Rik	2576,2	354,3	16,5	36,7	118,9	3,10
		Fattig	498,0	68,5	3,2	7,1	23,0	0,60
Dränerad Jordbruksmark	Boreal/ Tempererad		3243,2	882,7	0,0	211,2	0,12	4,40
Dränerad Gräsmark	Boreal	Rik	3,4	1,5	0,0	0,3	0,4	0,01
		Fattig	0,0	0,0	0,0	0,0	0,0	0,00
	Tempererad	Rik	208,1	28,6	1,3	5,9	9,6	0,25
		Fattig	0,0	0,0	0,0	0,0	0,0	0,00
Torvbrytning			92,1	1,3	1,3	6,1	3,9	0,10
Återvätning	Boreal	Rik	0,0	0,0	0,0	0,0	0,0	0,00
		Fattig	0,0	0,0	0,0	0,0	0,0	0,00
	Tempererad	Rik	2,4	0,0	4,0	0,0	0,4	0,01
		Fattig	0,0	0,0	0,0	0,0	0,0	0,00
Totalt			7912,8	1830,9	82,9	342,5	464,3	**10,63**

Summary

The 2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement), hereafter called WL GL, was adopted and accepted at the 37th Session of the IPCC in October 2013. This study assesses how to adapt the WL GL for Swedish conditions and available data sources. This includes both the assessment of emission factors and the possibility to obtain relevant activity data for the categories included in the WL GL. The report focuses on land use categories in the Land use, Land use change and Forestry sector (LULUCF) where emissions from drained organic soils occur, and the rewetting of these organic soils.

Table 2 summarizes the recommended emission factors described throughout the sections in this report, and the total impact of the new emission factors on the emissions from a land-use area (IEF). See relevant sections for discussion on the choice of emission factors. The emission factors presented here are only representative for land remaining within a category and not for land use change between categories, except rewetting.

These results show that drained organic Cropland has the highest impact per area. Swedish Forest land contributes with the highest $CO_{2\ \text{-eq}}$ emissions due to the large area. The total emissions from the land-use categories described in table 2 are 10.63 Mt $CO_{2\ \text{eq}}$ (table 2).

Table 2 a) Summary of recommended emission factors for the Swedish national reporting of GHG emissions from drained or rewetted organic soils in accordance with the new method guidance given in the WL GL. The emission factors are given per hectare and the impact on total emission is the sum of the individual emission factors multiplied with their Global warming potential (GWP - 100 year) to create a sum in CO_2 equivalents which is called the implied emission factor (IEF). b) Emissions (area times EF) in k ton CO_2 equivalents for each category, total emission given in M ton CO_2 equivalents.

Tabell *2 a) Summering av rekommenderade emissionsfaktorer (EF) för nationell rapportering av organogen mark. Alla EF gäller dränerad organogen mark eller återvätt organogen mark. EF står beskrivna så som i rapporten och gäller per hektar. Den totala emissionsfaktorn (IEF) är en summering av enskilda emissionsfaktorer multiplicerad med deras globala uppvärmningspotential (GWP -100 år) i ton CO_2 ekvivalenter per hektar. b) Utsläpp för varje kategori i kiloton CO_2 ekvivalenter uträknade med respektive EF och area, samt totalt utsläpp i M ton CO_2 ekvivalenter.*

2a Land category	Climate	Nutrient status	Emission Factors (unit mass per hectare)					IEF (ton CO_2-C $_{eq}$/ha)	IEF (ton CO_2 $_{eq}$/ha)
			ton CO_2-C	kg N_2O-N	kg CH_4	ditch kg CH_4	DOC ton CO_2-C		
Forest	Boreal	rich	0.93	3.2	2	5.4	0.12	1.51	5.53
		poor	0.25	0.22	7	5.4	0.12	0.48	1.77
	Temperate	rich	2.6	2.8	2.5	5.4	0.12	3.13	11.48
		poor	2.6	2.8	2.5	5.4	0.12	3.13	11.48
Cropland	Boreal/ Temperate		6.1	13	0	58.3	0.12	8.28	30.35
Grassland	Boreal	rich	0.93	3.2	1.4	5.4	0.12	1.54	5.65
		poor	0.25	0.22	1.4	5.4	0.12	0.48	1.76
	Temperate	rich	2.6	2.8	2.5	5.4	0.12	3.17	11.62
		poor	2.6	2.8	2.5	5.4	0.12	3.17	11.62
Peat Extraction			2.8	0.3	6.1	26.2	0.12	3.18	11.67
Rewetting	Boreal	rich	-0.55	0	55	0	0.08	-0.10	-0.35
		poor	-0.34	0	183	0	0.08	0.99	3.62
	Temperate	rich	0.5	0	123	0	0.08	1.42	5.20
		poor	-0.23	0	288	0	0.08	1.81	6.65

2b Land category	Climate	Nutrient status	Sweden's National Emissions in kilo ton $CO_{2\ eq}$					Total Emission (M ton $CO_{2\ eq}$)
			CO_2	N_2O	CH_4	ditch CH_4	DOC CO_2	
Forest	Boreal	rich	1067.4	469.1	15.3	42.5	137.7	1.73
		poor	222.0	24.9	41.3	32.8	106.5	0.43
	Temperate	rich	2576.2	354.3	16.5	36.7	118.9	3.10
		poor	498.0	68.5	3.2	7.1	23.0	0.60
Cropland	Boreal/ Temperate		3243.2	882.7	0.0	211.2	0.12	4.40
Grassland	Boreal	rich	3.4	1.5	0.0	0.3	0.4	0.01
		poor	0.0	0.0	0.0	0.0	0.0	0.00
	Temperate	rich	208.1	28.6	1.3	5.9	9.6	0.25
		poor	0.0	0.0	0.0	0.0	0.0	0.00
Peat Extraction			92.1	1.3	1.3	6.1	3.9	0.10
Rewetting	Boreal	rich	0.0	0.0	0.0	0.0	0.0	0.00
		poor	0.0	0.0	0.0	0.0	0.0	0.00
	Temperate	rich	2.4	0.0	4.0	0.0	0.4	0.01
		poor	0.0	0.0	0.0	0.0	0.0	0.00
Total			7912.8	1830.9	82.9	342.5	464.3	**10.63**

Introduction

The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent and reduce dangerous human-induced interference with the climate system.

One way to track whether the international community is on its way to achieve this objective and to verify if Parties with commitments under the Kyoto protocol fulfill their binding obligations to decrease emissions of greenhouse gases (GHG) is the annual greenhouse gas inventories submitted by Annex I Parties. Annex I Parties are required to annually report anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol to the secretariat of the UNFCCC.

The national GHG inventory includes emission/removal estimates in the Common Reporting Format (CRF) and a National Inventory Report (NIR), which comprise a description of the national system for reporting as well as descriptions of methods and references to data sources used in the inventory. The reporting is regulated in the UNFCCC reporting guidelines[1] and is based on methodological reports from the IPCC.

Until now, Parties have reported the direct greenhouse gases CO_2, CH_4, N_2O, HFC, PFC, SF6 and the indirect greenhouse gases NOX, CO, NMVOC and SO_2 divided into six sectors: Energy, Industrial processes, Solvents and other products use, Agriculture, Land use Land use Change and Forestry (LULUCF) and Waste.

Revision of UNFCCC reporting guidelines

With the second commitment period of the Kyoto Protocol in sight and new methodology guidelines from the IPCC not yet implemented in real reporting, a work program to revise the UNFCCC reporting guidelines was initiated in 2010. This started with a discussion of the usability of, and how to implement the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[2] , hereafter called 2006 IPCC GL. One of the major concerns raised by several Parties was related to the description of methods to report emissions from Wetlands under the AFOLU-section. IPCC was therefore invited by SBSTA33 to “undertake further methodological work on Wetlands, focusing on the rewetting and restoration of peatlands, with a view to filling in the gaps in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories”. The 2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014), hereafter called WL GL, was adopted and accepted at the 37th Session of the IPCC in October 2013.

Since the revised UNFCCC reporting guidelines were adopted at COP19 in Warsaw[3] Parties needs to implement some changes in their reporting to fulfill the reporting obligations. Basically these relate to the implementation of the IPCC 2006 GL and the implementation of the WL GL.

---

[1] FCCC/SBSTA/2006/9

[2] IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

[3] FCCC/SBSTA/2013/L.29/Add.1 and http://unfccc.int/files/meetings/warsaw_nov_2013/decisions/application/pdf/cop19_inv_rep_gdln.pdf

Implementation of the Wetland supplement

This report assesses how to adapt the WL GL for Swedish conditions and data sources, which includes both the assessment of emission factors and the possibilities to obtain relevant activity data for the categories included in the WL GL. The report focuses on land use categories in the LULUCF-sector[4] where emissions from drained organic soils occur.

The report should be read in conjunction with the WL GL. The methods in the WL GL are presented at different levels of complexity (so called tiers, which is standard for IPCC methodological reports) which gives the countries the flexibility to select methods, activity data and emission factors as appropriate for national circumstances. No attempts were made within this project to find optional methods to report the relevant emissions (with the exception of the evaluation of the C:N ratio model).

Today, the reporting of the LULUCF-sector includes estimates of CO_2 emissions/removals from Forest land, Cropland, Grassland, Wetland, Settlements and Other land, and land use changes between these categories. However, reporting is only required for managed land which in the Swedish reporting exempts Wetlands and Other land. Only emissions associated with peat extraction is reported under Wetlands. Consequently, in the current Swedish inventory, emissions from organic soils are reported for Forest land, Cropland and Grassland, and a small area under Wetlands. Until now, only CO_2 emissions have been reported. Non-CO_2 gases have only been reported for agricultural soils (in the Agricultural sector) since they have not been mandatory to report for other land use categories, and since methods have been considered too juvenile to be used for reporting to the UNFCCC. In future reporting, emissions of non-CO_2 gases from organic soils are mandatory for all managed land use categories and there are possibilities to expand the reporting of Wetlands under the UNFCCC. It is also possible to include the new activity: Wetland drainage and rewetting (WDR) in the accounting of LULUCF under the Kyoto protocol.

This report presents options on how to improve the Swedish reporting on organic soils, and how to expand the reporting to categories not already included in the reporting to the UNFCCC and under the Kyoto Protocol.

---

[4] Note that when adopting the UNFCCC reporting guidelines it was also decided to continue with the division between the Agriculture and the LULUCF reporting sectors and not adapting the concept in the IPCC 2006 GL with an all-encompassing agriculture and land use sector (AFOLU).

Drained organic soils

The definition of organic soils within the WL GL is consistent with the definition in 2006 IPCC GL (Annex 3A.5, Chapter 3, Volume 4).

Soil that satisfies the requirements 1 and 2, or 1 and 3 below:

1. *Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm;*
2. *Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter); and*
3. *Soils are subject to water saturation episodes and have either:*
   - *a) At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or*
   - *b) At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60 percent or more clay; or*
   - *c) An intermediate proportional amount of organic carbon for intermediate amounts of clay.*

Apart from the 10 cm criterion in requirement 1 above, the definition in the WL GL does not define the minimum thickness for organic soils as to allow for country-specific definitions. The definition of histosols according to FAO, and which has been adopted within the Swedish National Forest Inventory and the National Forest Soil Inventory (hereafter jointly referred to as the NFI), applies a minimum depth of 40 cm unless the soil directly overlays bedrock, whereby a 10 cm soil organic horizon is sufficient.

The thickness criterion of 40 cm was applied when finding the areas of organic soils on Forest land and Grassland in Sweden. The area of organic soils on Cropland was estimated with the geo-referenced soil maps available at Swedish Geological Survey (SGU) where the soils defined as deep or shallow histosols were included.

The WL GL defines drainage as “an artificial lowering of the soil water table”, and “a drained soil is a soil that formerly has been a *wet soil* but as a result of human intervention is tending to become a *dry soil”* (IPCC 2014). As all organic soils are assumed to have been wet in their pristine state, a dry organic soil is also per definition a drained soil according to these guidelines.

In the Swedish estimate of drained organic forest soils the information on the presence of a ditch (<25 m from the inventory plot) was used to distinguish between drained and undrained organic soils. This measure probably causes a slight underestimation of the drained organic soil area in Forest land, as soils may be well drained even though the ditch is located more than 25 m away. However, it is also likely that some of these ditches do not drain the soils satisfactorily. The alternative to this method is to use soil moisture conditions as a proxy for drainage level. Although this has some benefits, it is also an uncertain proxy as the soil moisture condition at a site in NFI at the time of the inventory doesn’t necessarily represent the average condition.

Emission factors – and the use of categories

The emissions from soils at the simplest level (Tier 1) are calculated by multiplying activity data (areas) with emission factors. Emission factors quantify the emissions or removals per unit activity. For instance the activity can relate to the amount of fuel burned or to the area associated with the activity. Here, emission factors are used to calculate emissions or uptake of greenhouse gases (GHGs) from land-use areas.

As an individual area might behave significantly different from another area within the same land-use category in terms of GHG emissions, categorization within a land-use category may be applied to improve estimates (see figure 1). These categories can be assigned different emission factors which should correspond to variations in variables that influence GHG fluxes. In the case of drained organic soils, fluxes of GHGs have been found to depend on nutrient status, drainage level and climate (IPCC, 2014). These variables are used to categorize land-areas within land-uses on the Tier 1 level in the WL GL and also within this report. Drainage level is only used as a category variable for Temperate, Nutrient rich Grasslands in the WL GL.

Land-use	Climate	Nutrient status	EF
Forest	Boreal	rich	X
		poor	X
	Temperate	rich	X
		poor	X

Figure 1 Scheme of land-use categorization used in the WL GL at Tier 1 and in this report. Emission factors (EF) are given for each category.
Figur 1 *Schema för den markanvändningskategorisering som används i WL GL på Tier 1 nivå och i denna rapport. Emissionsfaktorer (EF)anges för varje kategori.*

It is necessary to assess the feasibility of using these categories within the reporting. This is largely determined by the data availability. In Sweden, nutrient status of land-use areas can be assessed by using the data collected within the NFI. There are two options to assess nutrient status: 1) C:N ratio, which is a measure of nitrogen availability and 2) the type of ground vegetation present which can be seen as a proxy for nutrient status. Drainage level can be estimated within the NFI through presence of a ditch (<25 m from the plot) together with soil moisture status, and has been used in previous submissions of the national inventory report (Swedish Environmental Protection Agency 2013). The NFI collects this type of data from Swedish Forest land and semi-natural pastures (Grasslands). Presently there are no data available for this kind of categorization on Croplands, however all Croplands on organic soils are assumed to be drained. This assumption is also made for Swedish semi-natural pastures occurring on organic soils.

Gases

Carbon dioxide - CO_2

The emissions of CO_2 from drained organic soils mainly originate from the loss of soil carbon due to respiratory oxidation, leaching of dissolved organic carbon (DOC) to runoff, and combustion due to fire. Additional losses comes from leaching of inorganic carbon (DIC) and from erosion (particulate organic carbon: POC), however these are not treated in the WL GL.

The soil carbon in organic soils accumulates over time, during the peatland's pristine phase, as long as water levels are sufficiently high to lower respiration rates due to oxygen limitation. On the scale of hundreds of years and longer, peatlands have acted to cool the climate because of this carbon storage despite their relatively high CH_4 emissions (Whiting and Chanton, 2001). When the water table is lowered, the soil slowly loses the stored carbon as outputs typically exceed inputs in drained conditions.

The aerobic soil microorganisms that break down the soil organic matter into CO_2, require substrate, moisture and oxygen. When these requirements are fulfilled the rate of respiration is largely determined by soil temperature (Lloyd and Taylor 1994). At any given location one or many of these parameters may be the limiting factor, and respiration rates may therefore vary both temporally and spatially.

Based on this understanding of the processes controlling CO_2 emissions, the emission factors in the WL GL apply to a certain climate, drainage depth and nutrient status if applicable.

The CO_2 emissions from drained organic soils must be separated from those emissions that occur due to autotrophic respiration from roots and ground vegetation.

Nitrous oxide - N_2O

Production of N_2O in soils occurs both during nitrification and denitrification. These processes are controlled by several factors, such as; soil moisture content, temperature and concentration of mineral nitrogen (IPCC, 2014). Emissions of this gas are often erratic, and large bursts have been recorded after large rain events, freezing, thawing or after nutrient application. The emissions related to nutrient applications are not treated in the WL GL as these are already covered by the 2006 IPCC Guidelines (Chapter 11 vol. 4). The erratic behavior of production and release of N_2O also influences the estimations of annual averages, and variations around the averages are therefore typically large.

Based on this understanding of the processes controlling N_2O emissions, the emission factors in the WL GL apply to a certain climate, drainage depth and nutrient status if applicable.

Methane - CH_4

CH_4 is produced by respiring bacteria (methanogens) in anaerobic conditions. CH_4 is also oxidized in soils by aerobic microbes (methanotrophs) in the unsaturated soil layers. A lowering of the water table increases the size of the aerobic zone which means that CH_4 emissions typically are reduced when drainage is applied. The soil can eventually turn from a CH_4 source into a sink. However, the emissions of CH_4 from drainage ditches may be considerable (Minkkinen and Laine, 2006) and the emissions from a drained area, when including emissions from ditches, are not likely to be negative (CH_4 sink) based on the results in the WL GL.

The rate of emissions of CH_4 from the soil surface depends on the balance between respiration and oxidation of CH_4. This balance is determined not only by respiration and oxidation rates but also upon the transport pathway of CH_4 through the soil profile. A large part of the CH_4 is transported towards the atmosphere by diffusion through the soil. If the pathway through the aerobic layer is longer (deep drainage), the methane oxidizers have a better opportunity to lower CH_4 net emissions at the soil surface, or even make them negative (uptake). This support the assumption that both water table depth (determines the size of the aerobic soil layer) and temperature (respiration and oxidation rates) can explain variations in net CH_4 emissions.

Based on this understanding of the processes controlling the CH_4 emission the emission factors in the WL GL apply to a certain climate, drainage depth and nutrient status if applicable.

Another important control of methane emissions, which is not yet included in the Tier 1 methodology in the WL GL is the vegetation community which can influence production and oxidation through its influence on substrate, and the transport pathway. Some plants augment the emissions from the soil by providing a direct transport route from the root to the atmosphere through the aerenchyma, thus providing a possible release of CH_4 that has bypassed the methanotrophs.

Methodology

Emission factors

This report covers literature used within the WL GL, as well as additional references which were found relevant for Swedish conditions. This literature was used to calculate the presented emission factors. More attention was given to literature connected to those categories that potentially have a large influence on the total emissions of GHGs from drained organic soils in Sweden.

Annual averages of fluxes from individual studies were used to calculate a single average for one land-use category. If possible, each site and each year reported in a study was included in the finale average. By this method a study that has been running for more than one year, or extensive studies covering many sites, becomes more important. This also ensures the inclusion of both temporal and spatial variation. This method differs slightly from the one used in the WL GL where studies running for a number of years have been averaged into one estimate before including it in the calculation. It is important to note the difference between these methods. This is indicated in presented tables as “number of sites” in tables for the WL GL and “number of samples” in tables created for this report.

One exception was made from this general method when calculating averages for this current study. Only half of the studied sites in Ojanen et al. (2010, 2013) were used as this dataset otherwise would have had a disproportionately high influence on the results due to its many study sites (68) despite having comparatively low temporal resolution.

No corrections were made regarding overrepresentation of certain vegetation types in the datasets, instead the studies were assumed to form a representative average. As an example this means that studies from deciduous and coniferous forests were combined without corrections for the fact that the amount of studies from coniferous forest was higher.

When heterotrophic respiration of CO_2 was derived from measurements of ecosystem respiration, a value of 50% was assumed (von Arnold et al. 2005a), meaning that the ecosystem respiration was roughly divided into heterotrophic respiration and autotrophic respiration. This partitioning between heterotrophic and autotrophic varies from study to study but 50 % was chosen as to not underestimate the heterotrophic part.

When calculating CO_2 equivalents, IPCC’s recommended Global Warming Potentials at a 100 year horizon were used: 25 for CH_4 and 298 for N_2O.

Land-use categorization

If the emission factors from the WL GL are to be used it is necessary to categorize Swedish land-use areas according to climate, nutrient status and possibly drainage level.

Sweden was roughly divided into two climate zones so that each county south of Värmland, Gävleborg, and Dalarna belongs to the temperate zone and the remaining counties belong to the boreal zone. This corresponds to how IPCC treated studies from the southern region of Sweden in calculations of temperate averages within the WL GL. However, it should be noted that this zone more often is referred to as the hemi-boreal zone.

The limit between nutrient poor and nutrient rich drained organic soils should be drawn between ombrotrophic and minerotrophic conditions according to the WL GL. This measure is not available in the NFI. However, there are two other possible ways to separate between different nutrient conditions with the data available within the NFI. The first one is to simply set a C:N ratio threshold value. The second alternative is to determine the categories based on ground vegetation community. This may sound straightforward and simple; however, data on C:N ratio is not available from all sample plots within the NFI, which decreases the quality of the area analysis by allowing less sites for statistical up-scaling. The vegetation proxy does not suffer from this constraint, but on the other hand vegetation classes are not easily divided into only two classes. Some vegetation groups are found on both nutrient rich and nutrient poor conditions, or to be more concrete – they are found when the conditions are between rich and poor. Björn Hånell (pers. comm.) suggests three nutrient status classes as the coarsest scale, which unfortunately cannot be used together with the current emission factors from the WL GL. It is clear that assumptions must be made on how to divide between classes, thus increasing the uncertainties in the estimates.

If information on the ground vegetation community from the NFI is used to set the limit between nutrient poor and nutrient rich, the intermediate class vegetation (group 12 and 13) should most likely be located in the nutrient rich group (Lundin, L. pers. comm.). This also ensures to avoid underestimation of GHG emissions as nutrient rich conditions most often are associated with higher emission factors in the WL GL.

Nutrient rich
01 – Tall herbs without shrubs
02 – Tall herbs with shrubs/blueberry
03 – Tall herbs with shrubs/lingonberry
04 – Low herbs without shrubs
05 – Low herbs with shrubs/blueberry
06 – Low herbs with shrubs/lingonberry
07 – Without field layer (no plants, just mosses)
08 – Broad grasses
09 – Narrow grasses
12 – Horsetail
13 – Blueberry

Nutrient poor
10 – Tall carex
11 – Low carex
14 – Lingonberry
15 – Crowberry/calluna
16 – Poor shrubs

Drainage level was used to separate drained organic soil Forest land into two different categories in previous national inventory reports (Swedish Environmental Protection Agency 2013). The drainage level was assessed by using information in the NFI, with wet and moist soil moisture conditions indicating poorly drained soil, and dry, mesic and mesic-moist indicating well drained soil. This measure is also available on Swedish Grasslands (semi-natural pastures).

Results

Forest land

The definition of Forest land in the Swedish NIR follows the FAO definition[5], which states:

Forest land:

Land with tree crown cover (or equivalent stocking level) of more than 10 percent and area of more than 0.5 hectares (ha). The trees should be able to reach a minimum height of 5 meters (m) at maturity in situ. May consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground; or open forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 percent. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 percent or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but which are expected to revert to forest.

Areas

The area of drained organic Forest land was estimated by using data available in the NFI. The criteria for area calculation in this report were set to a) International Forest land, b) histosols, c) presence of a ditch, d) a soil moisture criterion that excluded wet and moist soils. This last criterion (d) is questionable as these wetter soils have been included in previous submissions. It should be discussed further, how to best apply the information within the NFI to find the drained organic soils.

The area of drained organic Forest land was categorized into two climate regions (temperate and boreal zones) with the limits discussed in section; Methods – Land use categorization. It was also divided into nutrient rich and nutrient poor according to ground vegetation communities (page 15).

The total area of drained organic Forest land was estimated to 877 000 ha in this report. This is lower than estimates used in the current reporting, which also includes wet and moist drained organic soils. Of this estimated total area, 313 000 ha is considered nutrient rich and 242 000 ha nutrient poor in the boreal climate zone. Moreover it was found that 270 000 ha is nutrient rich, and 52 000 ha nutrient poor in the temperate zone.

Each of these choices for categorisation may be made differently and affects the total area within each category, and thereby the total emissions. The effect of the choices on the total emission of GHGs from drained organic soils could therefore be assessed by conducting a sensitivity analysis.

CO_2

Read in conjunction with section 2.2.1.1, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

Sweden already reports emissions of CO_2 from drained organic Forest land. This means that instead of developing an alternative emission factor, this report presents a comparison between the currently used emission factors and those presented within the WL GL. The currently used emission factors were developed by von Arnold et al. (2005a). These were estimated to 3 ton CO_2-C ha^{-1} yr^{-1} (range 2.49-3.51) for well drained conditions and to 1.9 ton CO_2-C ha^{-1} yr^{-1} (range 1.45-2.35) for poorly drained conditions. These emission factors are different from the emission factors presented in the WL GL as the former do not include the carbon gain from litter and root mortality. These inputs of carbon are incorporated into the

---

[5] http://www.fao.org/docrep/006/ad665e/ad665e06.htm

calculations of total emissions rather than in the emission factors themselves in the Swedish methodology (Swedish Environmental Protection Agency, 2013 Annexes, 1.1.6). The emission factors also differ as von Arnold et al. (2005a) categorize land-use areas according to drainage level rather than to nutrient status which is used in the WL GL.

The national emissions of CO_2 from drained organic Forest land in Sweden was reported as 2.5 Mt C in 2011 (Swedish Environmental Protection Agency, 2013), resulting in an implied emission factor of 2.02 ton CO_2-C ha^{-1} yr^{-1}. This implied emission factor includes carbon input to the soil from both above- and belowground litter production and includes both drainage categories that are used in the Swedish methodology. When the emission factors from the WL GL are used with the area categorization suggested in section; Methods – Land use categorization, the implied emission factor is 1.35 ton CO_2-C ha^{-1} yr^{-1}. By looking at implied emission factors for the total forest area it is possible to compare emission factors, and it shows that emission factors from the WL GL results in lower total emissions.

The emission factors presented in the WL GL should provide a more robust result than von Arnold et al. (2005a). It is therefore recommended to use the emission factors presented in table 3. However, the currently used emission factors are considered to be a reasonable alternative.

Table 3 Emission factors in ton CO_2-C ha^{-1} yr^{-1} from drained organic Forest land, categorized by climate and nutrient status as given in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.
Tabell 3 *Emissionsfaktorer i ton CO_2-C ha^{-1} år^{-1} från dikad organogen Skogsmark, kategoriserade efter klimat och näringsstatus som de anges i WL GL. Emissionsfaktorerna bygger på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	Nutrient Rich			Nutrient Poor			Nutrient Rich + Poor		
	EF	95 % conf.	n	EF	95 % conf.	n	EF	95 % conf.	n
Temperate							**2.6**[a]	2.0 – 3.3	8
Boreal	**0.93**[b]	0.54 – 1.3	62	**0.25**[c]	-0.23 – 0.73	59			

[a] Glenn et al., 1993, Minkkinen et al., 2007a, von Arnold et al., 2005b, von Arnold et al., 2005c, Yamulki et al., 2013.
[b] Laurila et al., 2007, Lohila et al., 2007, Minkkinen and Laine, 1998, Minkkinen et al., 2007a, Minkkinen et al., 1999, Ojanen et al., 2010, Ojanen et al., 2013, Simola et al., 2012.
[c] Lohila et al., 2011, Minkkinen et al., 1999, Ojanen et al., 2010, Ojanen et al., 2013, Simola et al., 2012.

N_2O

Read in conjunction with section 2.2.2.2, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

Sweden has not yet included emissions of N_2O from drained organic Forest land in the reporting to the UNFCCC. The knowledge within this field has improved and reporting is to be expected in submission 2015. Even though Sweden has not reported these numbers there have been attempts to calculate emissions on a national scale (von Arnold et al.2005a, Ernfors et al. 2007). The first study by von Arnold et al. (2005a) used two different emission factors for coniferous and deciduous forest, and based those emission factors on averages collected from several studies. Ernfors et al. (2007) estimated the size of the emissions as a function of the soil C:N ratio. This model was developed by Klemedtsson et al. (2005).

The implied emission factors in these studies are 1.4 kg N_2O-N ha^{-1} yr^{-1} in von Arnold et al. (2005a) if the categories deciduous and coniferous forests are merged, and 1.9 kg N_2O-N ha^{-1}

yr^{-1}in Ernfors et al. (2007). Both of these are lower than the emission factor calculated within this study including all categories (2.6 kg N_2O-N ha^{-1} yr^{-1} see table 4), and also lower than the resulting implied emission factor (2.2 kg N_2O-N ha^{-1} yr^{-1} see table 6) if the emission factors for different climate and nutrient status from the WL GL are used.

Table 4 Emission factors in kg N_2O-N ha^{-1} yr^{-1} from drained organic Forest land, categorized by climate and nutrient status as synthesized in this report. The emission factors (EF) are based on several studies from the Nordic countries. Range (min and max-value) and number of samples (n) are also displayed.
***Tabell 4** Emissionsfaktorer i kg N_2O-N ha^{-1} $år^{-1}$ från dikad organogen Skogsmark, kategoriserade efter klimat och näringsstatus enligt denna rapport. Emissionsfaktorerna bygger på flera studier från de nordiska länderna. Min och max-värde och antal prover (n) redovisas också i tabellen.*

Climate	Nutrient Rich			Nutrient Poor			Nutrient Rich + Poor		
	EF	range	N	EF	range	n	EF	range	n
Temperate	**6.2**[a]	0.5 – 28.3	18	**0.0**[c]	0.0 – 0.5	2	**5.9**	0.0 – 28.3	20
Boreal	**2.9**[b]	0.1 – 25.5	53	**0.2**[d]	0.0 – 0.6	30	**1.9**	0.0 – 25.5	83
Temp+Bor	**3.7**	0.1 – 28.3	71	**0.2**	0.0 – 0.6	32	**2.6**	0.0 – 28.3	103

[a] Klemedtsson et al., 2010, Sikström et al., 2009, von Arnold et al., 2005c, von Arnold et al., 2005b, Weslien et al., 2009
[b] Maljanen et al., 2010a, Martikainen et al., 1993, Martikainen et al., 1995a, Mäkiranta et al., 2007, Ojanen et al., 2010, Regina et al., 1996, Regina et al., 1998, Saari et al., 2009.
[c] Sikström et al., 2006, Yamulki et al., 2013.
[d] Lohila et al., 2011, Martikainen et al., 1995a, Regina et al., 1996, Ojanen et al., 2010, Mäkiranta et al., 2007, Pearson et al., 2012, Martikainen et al., 1993.

Climate seems to be less important in the case of N_2O emissions than for CH_4 and CO_2 as the processes behind the formation of N_2O are less dependent on temperature. It is therefore not necessary to use emission factors categorized by climate (Kasimir-Klemedtsson, Å. Pers. Comm.), nor is it recommendable in this case as the number of studies within the temperate zone are comparably low. However, there is a significant difference ($p<0.05$) between the emissions from nutrient rich organic soil compared to nutrient poor. It is therefore recommended to use different emission factors for nutrient rich and nutrient poor conditions.

The two emission factors for temp+bor -nutrient rich (3.7 kg N_2O-N ha^{-1} yr^{-1}) and nutrient poor (0.2 kg N_2O-N ha^{-1} yr^{-1}) are very close to those recommended within the WL GL for boreal climate of 3.2 and 0.22 kg N_2O-N ha^{-1} yr^{-1} for nutrient rich and nutrient poor conditions respectively (table 5). It is therefore recommended to use the emission factors presented within the WL GL as these should be considered as more robust emission factors. It is also recommended to use the emission factor from the WL GL for the temperate climate zone for the same reason.

Table 5. Emission factors in kg N_2O-N ha^{-1} yr^{-1} from drained organic Forest land, categorized by climate and nutrient status as reported in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.

Tabell 5. *Emissionsfaktorer i kg N_2O-N ha^{-1} år^{-1} från dikad organogen Skogsmark, kategoriserade efter klimat och näringsstatus som de anges i WL GL. Emissionsfaktorerna bygger på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	Nutrient Rich			Nutrient Poor			Nutrient Rich + Poor		
	EF	95 % conf	n	EF	95 % conf.	n	EF	95 % conf	n
Temperate							**2.8**[a]	-0.57-6.1	13
Boreal	**3.2**[b]	1.9-4.5	75	**0.22**[c]	0.15-0.28	43			

[a] Sikström et al., 2009, von Arnold et al., 2005b, von Arnold et al., 2005c, Weslien et al., 2009, Yamulki et al., 2013.

[b] Mäkiranta et al., 2007, Maljanen et al., 2001a, Maljanen et al., 2003b, Maljanen et al., 2006b, Maljanen et al., 2010a, Martikainen et al., 1993, Martikainen et al., 1995a, Ojanen et al., 2010, Ojanen et al., 2013, Pihlatie et al., 2004, Regina et al., 1998, Saari et al., 2009.

[c] Lohila et al., 2011, Maljanen et al., 2006a, Martikainen et al., 1995a, Martikainen et al., 1993, Ojanen et al., 2010, Ojanen et al., 2013, Regina et al., 1996.

Note: Maljanen et al. (2001) only presents measurements for the summer season, which could not be used in the present study. Maljanen et al. (2003a) presents results from an organic soil other than histosol. Maljanen et al. (2006) only have measurements from six occasions over a 2 year period.

A second alternative is to use the model based on the relationship between N_2O emissions and the C:N ratio, developed by Klemedtsson et al. (2005), and later used in Ernfors et al. (2007). The appropriateness of this model for other land use categories than Forest land can be questioned as indicated in the review of GHG fluxes from drained organic soil made by Maljanen et al. (2010b). However, the model seems to be working satisfactory on Forest land. Despite the advantages of the model, care should be taken when utilizing this model. As the model uses an exponential relationship, the uncertainty at low C:N ratios is problematic to explore (Ernfors et al. 2007). If this model is to be used it is recommended to set a limit for the emissions factor at low C:N ratios.

One issue to consider when using emission factors based on different nutrient status levels, is that the total emissions becomes sensitive to where the limit between the two categories is set. This is especially important, in this case, as the difference between the N_2O emission factors for nutrient rich and nutrient poor is large for Forest lands. This problem does not arise when using the C:N-model, where no categorization is needed.

Table 6 is included to show how the use of different methods to calculate the emission factors produces different total emissions of N_2O from drained organic Forest land by comparing implied emission factors. It shows that using the estimates from von Arnold et al (2005a) would produce the lowest total emissions, while the emission factors in this study (table 4) would produce the highest. The resulting total emissions from the C:N model (Ernfors et al. 2007) and the emission factors from the WL GL lies in between the other two estimates.

Table 6 Implied emission factors in kg N_2O-N ha^{-1} yr^{-1} for the different methods discussed.
Tabell 6 *Implicita emissionsfaktorer i kg N_2O-N ha^{-1} $år^{-1}$ för olika metoder.*

Reference	IEF
Von Arnold et al.	1.4
Ernfors et al. 2007	1.9
This study	2.6
WL GL	2.2

The implied emission factors from this study and the WL GL are comparable as they both are related to the same area categorization and total area. This direct comparison is not possible to do with von Arnold et al. (2005a) or Ernfors et al. (2007) as the area estimates were different compared to the area used in this study.

It is recommended to use the emission factors from the WL GL, however, the C:N-model is considered to be a reasonable alternative.

CH_4

Read in conjunction with section 2.2.2.1, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

Sweden has not yet reported emissions of CH_4 from drained organic Forest land. The knowledge within this field has improved and reporting is to be expected in submission 2015.

Due to the influence of water table on CH_4 emissions, drainage of soil has been assumed to cause 0-emissions from soils (IPCC 2006 GL, Vol 4, Chap 11). This emission factor has been revised in the WL GL. Both climate and nutrient status have been used for categorization (see table 7). Drainage level has not been included despite the importance of water table depth on CH_4 emissions.

The results from the literature review, which are based on Swedish measurements and other relevant literature for Swedish conditions of CH_4 from drained organic Forest lands, are very different from the ones presented in the WL GL, see table 7 and 8. One reason for the large differences could be that the fluxes (emission factors) are very low in general, and could be argued as being close to the detection limit (Nilsson, M. pers. comm.).

Table 7. Emission factors in kg CH_4 ha^{-1} yr^{-1} for methane emissions from drained organic Forest land categorized by climate and nutrient status as reported in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.

Tabell 7. *Emissionsfaktorer i kg CH_4 ha^{-1} $år^{-1}$ för metanutsläpp från dikad organogen Skogsmark kategoriserade efter klimat och näringsstatus som de redovisas i WL GL. Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	Nutrient Rich			Nutrient Poor			Nutrient Rich + Poor		
	EF	95 % conf.	n	EF	95 % conf.	n	EF	95 % conf.	n
Temperate							**2.5**[a]	-0.6–5.7	13
Boreal	**2.0**[b]	-1.6–5.5	83	**7.0**[c]	2.9–11.0	47			

[a] Glenn et al., 1993, Moore and Knowles, 1990, Sikström et al., 2009, von Arnold et al., 2005c, von Arnold et al., 2005b, Weslien et al., 2009, Yamulki et al., 2013.

[b] Komulainen et al., 1998, Laine et al., 1996, Mäkiranta et al., 2007, Maljanen et al., 2001a, Maljanen et al., 2003a, Maljanen et al., 2006b, Martikainen et al., 1992, Martikainen et al., 1995b, Minkkinen and Laine, 2006, Minkkinen et al., 2007b, Nykänen et al., 1998, Ojanen et al., 2010, Ojanen et al., 2013.

[c] Komulainen et al., 1998, Lohila et al., 2011, Maljanen et al., 2006b, Martikainen et al., 1992, Martikainen et al., 1995b, Minkkinen and Laine, 2006, Minkkinen et al., 2007b, Nykänen et al., 1998, Ojanen et al., 2010, Ojanen et al., 2013.

Note: Maljanen et al. (2003a) presents results from an organic soil other than histosol, Maljanen et al. (2006) only presents results from six measurement occasions during two years. Reference not found: Martikainen et al.(1992, 1995b)

Table 8. Emission factors in kg CH_4 ha^{-1} yr^{-1} for methane emissions from drained organic Forest land categorized by climate and nutrient status as synthesized in this report. The emission factors are based on several studies from the Nordic countries and the EF, range (min-max) and number of samples (n) are displayed.

Tabell 8*. Emissionsfaktorer i kg CH_4 ha^{-1} $år^{-1}$ för metanutsläpp från dikad organogen Skogsmark kategoriserade efter klimat och näringsstatus enligt denna rapport. Emissionsfaktorerna bygger på flera studier från de nordiska länderna och flera EF. Min-max intervall och antal prover (n) redovisas också i tabellen.*

Climate	Nutrient Rich			Nutrient Poor			Nutrient Rich + Poor		
	EF	Range	n	EF	range	n	EF	range	n
Temperate	**2.0**[a]	-4.6–16.0	18	**5.8**[c]	1.4–11.4	7	**3.1**	-4.6–16	25
Boreal	**-1.2**[b]	-6.4–10.0	53	**16.0**[d]	-6.9–78.9	33	**5.5**	-6.9–78.9	86
Temp+Bor	**-0.3**	-6.4–16.0	71	**14.2**	-6.9–78.9	40	**4.9**	-6.9–78.9	111

[a] Klemedtsson et al., 2010, Sikström et al., 2009, von Arnold et al., 2005c, von Arnold et al., 2005b, Weslien et al., 2009

[b] Komulainen et al., 1998, Laine et al., 1996, Mäkiranta et al., 2007, Maljanen et al., 2010a, Martikainen et al., 1995a, Minkkinen and Laine, 2006, Minkkinen et al., 2007b, Nykänen et al., 1998, Ojanen et al., 2010, Saari et al., 2009

[c] Sikström et al., 2006, Sikström et al., 2009, Yamulki et al., 2013.

[d] Komulainen et al., 1998, Lohila et al., 2011, Martikainen et al., 1995a, Minkkinen and Laine, 2006, Minkkinen et al., 2007b, Nykänen et al., 1998, Pearson et al., 2012, Ojanen et al., 2010.

Due to the differences in table 7 and 8 and the fact that the results presented in the WL GL are based on more studies it is recommended to use the emission factors for CH_4 for drained organic Forest land from the WL GL. One exception could be to use the national estimate presented here for temperate conditions, and if so, for nutrient rich and poor conditions together (3.1 kg CH_4 ha^{-1} yr^{-1}) due to the limited number of studies.

Cropland

Cropland is defined as regularly tilled agricultural land in the Swedish NIR. It also includes lands that could potentially be classified as Grasslands according to the 2006 IPCC GL, this is discussed in section: Grasslands.

Areas

The area of drained organic Cropland was determined by Berglund et al. (2009) to 268 000 ha of which 198 000 ha was classified as histosols (peat soils). The areal estimate was calculated in ArcMap with the help of georeferenced soil maps from Swedish Geological Survey (*Jordartskartan*) and maps of ^{40}K together with the georeferenced data of agricultural fields (*Blockdatabasen)*. A detailed methodological discussion can be found in Berglund et al. (2009).

The total area of Cropland histosols reported to the UNFCCC (145 000 ha, Swedish Environmental Protection Agency, 2013) is less than the area of histosols estimated by Berglund et. al. (2009) because of modifications made for land-use areas belonging to Grassland, Forest land and Wetlands categories.

The Cropland area cannot be categorized further into drainage or nutrient status levels as these soils have not been surveyed in such detail at a national scale. Currently the categorization is based on different crops. This kind of categorization is discussed within the next section.

CO_2

Read in conjunction with section 2.2.1.1, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

Sweden already reports emissions of CO_2 from drained organic agricultural soils. The emissions are based on soil subsidence rates reported by Berglund (1989). In Berglund (1989) it was concluded that the subsidence rates differ between cropping systems and different subsidence rates have been used for grass, cereal and row crops respectively. Later findings have indicated that these differences might not be as clear as previously thought (Norberg, L. unpublished, accepted data 2013).

The WL GL does not define emission factors for different categories of Cropland other than for different climate zones. However, the same emission factor (7.9 ton CO_2-C ha^{-1} yr^{-1}) is suggested for both temperate and boreal climate regions. This is much higher than the implied emission factor of 3.59 ton CO_2-C ha^{-1} yr^{-1} that is currently reported within the Swedish NIR (submission 2013). In fact 3.59 is not even within the 95% confidence interval presented in the WL GL (see table 9).

Table 9 Emission factors in ton CO_2-C ha^{-1} yr^{-1} from drained organic Cropland as presented in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.

Tabell 9 *Emissionsfaktorer i ton CO_2-C ha^{-1} $år^{-1}$ från dränerad organogen Åkermark som de presenteras i WL GL. Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	All Cropland		
	EF	95 % conf.	n
Temperate + Boreal	**7.9**[a]	6.5-9.4	39

[a] Drösler et al., 2013, Elsgaard et al., 2012, Grønlund et al., 2008, Kasimir-Klemedtsson et al., 1997, Leifeld et al., 2011, Maljanen et al., 2004, Maljanen et al., 2001b, Maljanen et al., 2007, Morrison et al., 2013, Petersen et al., 2012.

If Sweden continues to use the emission factors from Berglund (1989) the difference between those emission factors and the emission factor from the WL GL must be explained and justified. One argument for continued use of the old emission factors is that the level of detail of the current emission factors is higher as they are adapted for different crop systems, and are based on subsidence rates in Sweden only. Another point to note is that it is unlikely that the oxidation rates of CO_2 are similar in the temperate zone and the boreal zone due to their strong dependence on temperature, and the occurrence of frost during winter. The temperature dependence has been noted in several studies, and also for two Swedish organic agricultural soils by Berglund (2011). Oxidation rates are most likely lower in boreal drained organic soils than in temperate drained organic soils if other soil conditions are similar. Thus it can be questioned if oxidation rates occurring in Germany are relevant for Sweden.

Due to recent research results, the use of different emission factors for different crops may be questioned (Berglund, K. pers. communication). Until the drivers of CO_2 emissions from drained organic agricultural soils are better understood, the use of a single emission factor is preferable as to not give the impression that one crop is better than the other in the perspective of CO_2 emissions. If this modification is done by using an average of the measured subsidence rates in Berglund (1989) the implied emission factor is changed from 3.59 to 5.24 ton CO_2-C ha^{-1} yr^{-1} . This is still not within the confidence interval presented in the WL GL (see table 9). However, the Swedish modified estimate of 5.24 ton CO_2-C ha^{-1} yr^{-1} is close to the emission factors used in the Finnish NIR(2013) of 4.1 (grass) and 5.7 ton CO_2-C ha^{-1} yr^{-1} (other crops).

A literature review containing many of the references within the WL GL was made and the result was a lower emission factor (6.1 ton CO_2-C ha^{-1} yr^{-1}) than the one presented in the WL GL (compare table 9 and 10) . This emission factor was developed using Swedish, Norwegian and Finnish studies. The studies have not been treated with the same care as within the WL GL review, as the authors of the WL GL made corrections based on method differences. These adjustments are not covered in detail within the WL GL and thus it was impossible to use exactly the same method. Despite method differences it is recommended to use the emission factor from table 10 as to avoid studies from countries with temperature conditions that are not fully representable for Sweden as temperature exerts a strong control on emissions.

Table 10. Emission factors in ton CO_2-C ha^{-1} yr^{-1} from drained organic Cropland as synthesized in this report. The emission factors are based on several studies from the Nordic countries and the EF, range (min-max) and number of samples (n) are displayed.
***Tabell 10**. Emissionsfaktorer i ton CO_2-C ha^{-1} $år^{-1}$ från dränerad organogen Åkermark enligt sammanställningen i denna rapport. Emissionsfaktorerna bygger på flera studier från de nordiska länderna och flera EF. Min-max intervall och antal prover (n) redovisas också i tabellen.*

Climate	All Cropland		
	EF	Range	n
Temperate + Boreal	**6.1**[a]	0.8 – 8.3	45

[a] Berglund et al. 2011, Grønlund et al. 2006, Grønlund et al. 2008, Maljanen et al. 2007, Maljanen et al. 2010b, Nykänen et al. 1995.

N_2O

Read in conjunction with section 2.2.2.2, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

Emissions of N_2O from drained organic agricultural soils are reported in the Agricultural sector and have been estimated using a Tier 1 method with an emission factor of 8 kg N_2O-N ha^{-1} yr^{-1} estimated for temperate conditions. In the WL GL this emission factor has been increased to 13 kg N_2O-N ha^{-1} yr^{-1} both for temperate and boreal climate (table 11.). However, this emission factor only applies to the background mineralization of nitrogen in the soil, thereby excluding bursts of N_2O release caused by nutrient application. Table 12 presents results from this study.

Table 11. Emission factors in kg N_2O-N ha^{-1} yr^{-1} from drained organic Cropland as presented in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.
***Tabell 11**. Emissionsfaktorer i kg N_2O-N ha^{-1} $år^{-1}$ från dränerad organogen Åkermark som de presenteras i WL GL. Emissionsfaktorerna baseras på flera studier och emissionsfaktorer. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	All Cropland		
	EF	95 % conf.	n
Boreal + Temperate	**13**[a]	8.2 – 18	36

[a] Augustin et al. 1998, Drösler et al. 2013, Elsgaard et al. 2012, Flessa et al. 1998, Kasimir-Klemetsson et al. 2009, Maljanen et al. 2003a, Maljanen et al. 2003b, Maljanen et al 2004, Maljanen et al. 2007a, Petersen et al. 2012, Regina et al. 2004, Taft et al. 2013.

Table 12. Emission factors in kg N_2O-N ha^{-1} yr^{-1} from drained organic Cropland, categorized by climate and crop type or together as synthesized for this report. The emission factors are based on several studies and the EF, range (min and max-value) and number of samples (n) are displayed.

Tabell 12*. Emissionsfaktorer i kg N_2O-N ha^{-1} $år^{-1}$ från dränerad organogen Åkermark, kategoriserade efter klimat och gröda eller tillsammans enligt sammanställningen i denna rapport. Emissionsfaktorerna bygger på flera studier från de nordiska länderna. Min-max intervall och antal prover (n) redovisas också i tabellen.*

Climate	Cereal+Row crop			Grass lay			Cereal+Row crop+Grass lay		
	EF	range	n	EF	range	n	EF	range	n
Temperate	**26**[a]	6.3-67.0	8	**12**[b]	2.5-29.0	8	**16**	2.5-67.0	16
Boreal	**11**[c]	2.9-37.0	23	**8**[d]	0.7-34.8	25	**10**	0.7-37.0	48
Temp+Bor	**15**	2.9-67.0	31	**9**	0.7-34.8	33	**12**	0.7-67.0	64

[a] Flessa et al., 1998, Kasimir Klemedtsson et al., 2009, Langeveld et al., 1997, Petersen et al., 2012.

[b] Berglund and Berglund, 2011, Flessa et al., 1998, Langeveld et al., 1997, Petersen et al., 2012.

[c] Kløve et al., 2010, Maljanen et al., 2003b, Maljanen et al., 2004, Maljanen et al., 2012, Nykanen et al., 1995, Regina et al., 2004.

[d] Berglund and Berglund, 2011, Kløve et al., 2010, Maljanen et al., 2003b, Maljanen et al., 2004, Maljanen et al., 2009, Maljanen et al., 2010a, Nykänen et al., 1995, Regina et al., 1996, Regina et al., 2004.

When looking at table 12 it becomes apparent that the estimated emission factors for N_2O emissions without climate or crop categorization from drained organic soil on Cropland is very close to the corresponding emission factor in the WL GL; 13 kg N_2O-N ha^{-1} yr^{-1}. Therefore it is recommended to use the emission factor from the WL GL.

It is not recommended to categorize the emissions based on crop type as the present knowledge within this field of study is fairly limited. Differences can be seen in table 12 but these are just as likely to arise from the fact that some crops are better suited for a certain kind of soil condition. Soil conditions such as pH (Weslien et al., 2009) and nutrient status (Klemedtsson et al., 2005) seem to play a role and if these are correlated with crop type correlations between crop type and N_2O emissions may be incorrect. More knowledge is evidently needed in this area.

CH_4

Read in conjunction with section 2.2.2.1, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

Sweden has not yet reported emissions of CH_4 from drained organic Cropland, and if Sweden chooses to use the default emission factor from the WL GL no emissions of this gas will be reported as the emission factor is set to 0 (see table 13).

Table 13. Emission factors in kg CH_4 ha^{-1} yr^{-1} from drained organic Cropland as presented in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.
***Tabell 13**. Emissionsfaktorer i kg CH_4 ha^{-1} $år^{-1}$ för metanutsläpp från dränerad organogen Åkermark som de presenteras i WL GL. Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate		All Cropland	
	EF	95 % conf.	n
Temperate + Boreal	**0**[a]	-2.8 – 2.8	38

[a] Augustin 2003 (unknown reference) Autustin et al. 1998, Drösler et al. 2013, Elsgaard et al. 2012, Flessa et al. 1998, Kasimir-Klemedtsson et al. 2009, Maljanen et al. 2003a,b, 2004, 2007a, Petersen et a. 2012, Regina et al. 2007, Taft et al. 2013.

The literature review within this study does show emissions of CH_4 from drained Cropland (see table 14). However, two high annual estimates from Norway have a considerable influence on the results and the robustness of the boreal emission factor and Temperate+Boreal emission factor can be questioned. Median values are below 0. It is therefore recommended to use the emission factor from the WL GL.

Table 14. Emission factors in kg $CH4_4$ ha^{-1} yr^{-1} from drained organic Cropland as synthesized for this report. The emission factors are based on several studies from the Nordic countries and the EF, range (min-max) and number of samples (n) are displayed.
***Tabell 14**. Emissionsfaktorer i kg CH_4 ha^{-1} $år^{-1}$ för metanutsläpp från dränerad organogen Åkermark enligt sammanställningen i denna rapport. Emissionsfaktorerna bygger på flera studier från de nordiska länderna och flera EF. Min-max intervall och antal prover (n) redovisas också i tabellen.*

Climate		All Cropland	
	EF	Range	n
Temperate	**-0.2**[a]	-1.8 – 3.8	16
Boreal	**2.3**[b]	-2.2 – 54.6	24
Temperate + Boreal	**1.3**	-2.2 – 54.6	40

[a] Berglund et al. 2011, Kløve et al. 2010, Maljanen et al. 2004, Maljanen et al. 2010b, Maljanen et al. 2012, Nykänen et al. 1995, Regina et al. 2007.
[b] Berglund et al. 2011, Flessa et al. 1998, Kasimir-Klemedtsson et al. 2009, Langeveld et al. 1997, Petersen et al. 2012.

Grassland

The definition of Grasslands varies between countries. In the Swedish NFI Grasslands are defined as semi-natural pastures. These are distinguished by the presence of grazing and the absence of regular ploughing. Cultivated pastures that are sometimes ploughed are categorized as Cropland within the NFI. These areas could be categorized as Grassland within the reporting to UNFCCC, but Sweden has chosen to include those under Cropland. Within the WL GL it becomes apparent that studies from fields with cultivation of grass (meadows/grass lays) have been included when calculating emission factors for Grasslands (see references tables 15, 16, 18). These cultivated Grasslands may be unsuitable as representatives for Swedish semi-natural pastures.

There is a need for discussing the definition of Grassland used in the reporting to the UNFCCC further as cultivated pastures could be included. If they would be included it is proposed to use the emission factors from the WL GL on these areas. Such a discussion should be finished before the implementation of the reporting methods to be used for the second commitment period of the Kyoto Protocol.

In Sweden it is uncommon to fertilize pastures, partly because environmental support funding in Sweden does not allow fertilization (Ståhlberg et al. 2010). Therefore it is debatable whether the emission factors within the WL GL should be considered as representative as many of the used studies, especially in the temperate zone, focus their measurements on fertilized grasslands with intensive grazing (see references for tables 15, 16, 18).

The emission factors for temperate, nutrient rich conditions in the WL GL are given for deep-drained and shallow-drained conditions. This might be possible to assess indirectly with the moisture data available in the data from the NFI. Otherwise deep-drained conditions should be used as default when drainage level is unknown according to the WL GL (section 2.2.1.1).

Areas

The areas of drained organic semi-natural pastures (Grasslands) can be estimated by using the data within the NFI. All semi-natural pastures on organic soils are assumed to be drained (Karltun, E. pers. com.). If additional lands are to be transferred from Cropland, the methodology described in section; Cropland, should be applied for these additional areas. If the selection approaches that were described in section; Forest land – Areas, are used for semi-natural pastures, the entire area of drained organic Grassland is 23 000 ha. All of these are considered nutrient rich if the vegetation type criterion is applied, which does not mean that they should be comparable to fertilized Grasslands. Only 1000 ha of these are located in the boreal climate zone, while 22 000 are located in the temperate climate zone.

CO_2

Read in conjunction with section 2.2.1.1, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

Sweden already reports emissions of CO_2 from drained organic Grasslands by assuming that the emission factors from von Arnold et al. (2005a) are representative not only for Forest land but for semi-natural pastures (Grasslands) as well. Consequently the emission factors have been set to 3 ton CO_2-C ha^{-1} yr^{-1} (range 2.49-3.51) for well drained conditions and 1.9 ton CO_2-C ha^{-1} yr^{-1} (range 1.45-2.35) for poorly drained conditions. These emission factors are different from the emission factors presented in the WL GL as the former do not include the carbon gain from litter and root mortality. In the Swedish methodology, these inputs of carbon are incorporated into the calculations of total emissions rather than in the emission factors themselves (Swedish Environmental Protection Agency, Annexes, 1.1.6).

The implied emission factor in the 2013 submission was 1.77 ton CO_2-C ha^{-1} yr^{-1}. This emission factor is lower than the emission factors presented in the WL GL regardless of climate, nutrient or drainage conditions (see table 15).

Since few or no studies were found outside of those already assessed in either von Arnold (2005a) or the WL GL, a comparison was made rather than a new estimate.

Table 15. Emission factors in ton CO_2-C ha^{-1} yr^{-1} from drained organic Grassland, categorized by climate, drainage level and nutrient status as reported in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.

Tabell 15. *Emissionsfaktorer i ton CO_2-C ha^{-1} $år^{-1}$ från dränerad organogen Gräsmark, kategoriserade efter klimat, dräneringsnivå och näringsstatus som de redovisas i WL GL. Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	Nutrient Rich			Nutrient Poor			Nutrient Rich + Poor		
	EF	95 % conf.	n	EF	95 % conf.	n	EF	95 % conf.	n
Temperate				**5.3**[a]	3.7 – 6.9	7			
Temperate Deep drained	**6.1**[b]	5.0 – 7.3	39						
Temperate Shallow drained	**3.6**[c]	1.8 – 5.4	13						
Boreal							**5.7**[d]	2.9 – 8.6	8

[a] Drösler et al. 2013, Kuntze 1992.

[b] Augustin 2003 – reference not found, Augustin et al. 1996, Czaplak and Dembek 2000, Drösler et al. 2013, Elsgaard et al. 2012, Höper 2002, Jacobs et al. 2003, Kasimir-Llemedtsson et al. 1997, Langeveld et al. 1997, Leifeld et al. 2011, Lorenz et al. 1992, Meyer et al. 2001, Nieveen et al. 2005, Okruszko 1989, Schothorst 1977, Schrier-Uijl 2010a,c, Veenendaal et al. 2007, Weinzierl 1997.

[c] Drösler et al. 2013, Jacobs et al. 2003, Lloyd 2006.

[d] Grønlund et al. 2006, Kreshtapova and Maslov 2004, Lohila et al. 2004, Maljanen et al. 2001b, Maljanen et al. 2004, Nykänen et al. 1995, Shurpali et al. 2009.

As discussed, it is doubtful whether studies from temperate, fertilized, intensively grazed grasslands in Netherlands are representative for Swedish temperate semi-natural pastures. Since no studies of this kind were found in current literature for Swedish Grassland soils, it is reasonable to consider using the emission factors for Forest land on semi-natural pastures from either the WL GL or from von Arnold et al. (2005a). It is recommended to use the same emission factors that are chosen for Forest land.

N_2O

Read in conjunction with section 2.2.2.2, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

N_2O emissions are especially sensitive to nutrient status (Klemedtsson et al., 2005) and fertilization often causes bursts of emissions during a short period after application (Kroon et al., 2010). Therefore it would be reasonable to use studies from grasslands that are not fertilized to account for N_2O emissions from Swedish semi-natural pastures as they are commonly not fertilized. Since no studies of N_2O emissions were found from semi-natural pastures it was not possible to compute new emission factors. Therefore it is recommended to use the emission factors for Forest land (table 17). An option that might be considered is to use the C:N-model (described under the Forest land section).The emission factors for Grasslands presented in the WL GL (table 16) are considerably higher than the emission factors presented for Forest land (table 17).

Table 16. Emission factors in kg N_2O-N ha^{-1} yr^{-1} from drained organic Grassland, categorized by climate, drainage level and nutrient status as reported in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.

***Tabell 16**. Emissionsfaktorer i kg N_2O-N ha^{-1} år^{-1} från dränerad organogen Gräsmark, kategoriserade efter klimat, dräneringsnivå och näringsstatus som de redovisas i WL GL. Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	Nutrient Rich			Nutrient Poor			Nutrient Rich + Poor		
	EF	95 % conf.	n	EF	95 % conf.	n	EF	95 % conf.	n
Temperate				**4.3**[a]	1.9 – 6.8	7			
Temperate Deep drained	**8.2**[b]	4.9 – 11	47						
Temperate Shallow drained	**1.6**[c]	0.56 –2.7	13						
Boreal							**9.5**[d]	4.6 – 14	16

[a] Drösler et al., 2013, Kasimir Klemedtsson et al., 2009.

[b] Augustin and Merbach, 1998, Augustin et al., 1996, Augustin et al., 1998, Drösler et al., 2013, Flessa and Beese, 1997, Flessa et al., 1998, Jacobs et al., 2003, Kroon et al., 2010, Langeveld et al., 1997, Meyer et al., 2001, Nykanen et al., 1995, Petersen et al., 2012, Teh et al., 2011, van Beek et al., 2010, Velthof et al., 1996, Wild et al., 2001.

[c] Drösler et al., 2013, Jacobs et al., 2003.

[d] Grønlund et al., 2006, Hyvönen et al., 2009, Jaakkola, 1985, Maljanen et al., 2001a, Maljanen et al., 2004, Maljanen et al., 2003b, Maljanen et al., 2009, Nykanen et al., 1995, Regina et al., 1996, Regina et al., 2004.

Table 17. Emission factors in kg N_2O-N ha^{-1} yr^{-1} for drained organic grasslands, directly taken from table 6 (N_2O on Forest land), categorized by climate and nutrient status as given in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.

***Tabell 17**. Emissionsfaktorer i kg N_2O-N ha^{-1} år^{-1} för dränerad organogen Gräsmark, direkt från tabell 6 (N_2O för Skogsmark), kategoriserade efter klimat och näringsstatus som de redovisas i WL GL. Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	Nutrient Rich			Nutrient Poor			Nutrient Rich + Poor		
	EF	range	n	EF	range	n	EF	range	n
Temperate							**2.8**	-0.57– 6.1	13
Boreal	**3.2**	1.9–4.5	75	**0.22**	0.15–0.28	43			

For references see table 5

CH_4

Read in conjunction with section 2.2.2.1, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

As discussed in section 4 it is debatable if studies from temperate, fertilized, intensively grazed Grasslands in Netherlands are representative for Swedish semi-natural pastures. However, if these studies are removed from the literature study very few measurements remain, and this made it impossible to calculate robust averages. As in the case with CO_2 and N_2O, it might be possible to consider using the emission factor from Forest land on temperate Swedish Grasslands. The studies from the boreal zone used in the WL GL for Grasslands seem to better represent Swedish Boreal Grasslands than the temperate studies, and it is recommended to use the emission factor from table 18 for areas within that climate zone.

Table 18. Emission factors in kg CH_4 ha^{-1} yr^{-1} from drained organic Grassland, categorized by climate, drainage level and nutrient status as reported in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.

Tabell 18. *Emissionsfaktorer i kg CH_4 ha^{-1} år^{-1} från dränerad organogen Gräsmark, kategoriserade efter klimat, dräneringsnivå och näringsstatus som de redovisas i WL GL. Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	Nutrient Rich			Nutrient Poor			Nutrient Rich + Poor		
	EF	95 % conf.	n	EF	95 % conf.	n	EF	95 % conf.	n
Temperate				**1.8**[a]	0.72 – 2.9	9			
Temperate Deep drained	**16**[b]	2.4 – 29	44						
Temperate Shallow drained	**39**[c]	-2.9 – 81	16						
Boreal							**1.4**[d]	-1.6-4.5	12

[a] Drösler et al., 2013, Kasimir Klemedtsson et al., 2009, Van den Bos, 2003.

[b] Augustin et al., 1996, Best and Jacobs, 1997, Flessa and Beese, 1997, Flessa et al., 1998, Jacobs et al., 2003, Kroon et al., 2010, Langeveld et al., 1997, Meyer et al., 2001, Nykanen et al., 1995, Petersen et al., 2012, Schrier-Uijl et al., 2010a, Schrier-Uijl et al., 2010b, Teh et al., 2011, Van den Bos, 2003, Van den Pol-van Dasselaar, 1998, Wild et al., 2001.

Nutrient rich, temperate, shallow drainage: (Augustin et al. 2003 – not in official reference list, i.e. cannot be found) (Drösler et al., 2013, Jacobs et al., 2003, Van den Pol-van Dasselaar, 1998.

[d] Grønlund et al., 2006, Hyvönen et al., 2009, Maljanen et al., 2001a, Maljanen et al., 2003a, Maljanen et al., 2004, Nykanen et al., 1995, Regina et al., 2007.

Table 19 shows emission factors for the categories semi-natural pastures taken from Forest land (see table 8). These emission factors are recommended, but it should be noted that there seems to be inconsistencies regarding emission factors of CH_4 from organic soils if forests and grasslands are compared. The nutrient status seems to have different effect within the two land-uses, and the only reasonable conclusion from this is that other factors such as drainage level or other differences between individual sites are causing these discrepancies. It is unlikely that this is a true response as this trends go in different directions in table 8 and 19 (Forest land and Grassland). It is more plausible that nutrient status influence vegetation composition which then influences CH_4 emissions. Nutrient status could also influence evapotranspiration by supporting more vegetation in forests, which then leads to lower ground water table and lower emissions. This is speculative, but based on the processes regulating emissions of CH_4 it is sounder to say that this response of CH_4 emissions on nutrient status is an indirect response rather than a direct one.

Table 19. Emission factors, for drained organic temperate grasslands directly taken from table 7 (CH_4 on drained organic Forest land) in kg CH_4 ha^{-1} yr^{-1} categorized by climate and nutrient status in the WL GL, and the EF from table 18 for Boreal Grasslands. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.

***Tabell 19**. Emissionsfaktorer för dränerad organogen tempererad Gräsmark, direkt tagna från tabell 7 (CH_4, för dränerade organogen Skogsmark) i kg CH_4 ha^{-1}, kategoriserade efter klimat och näringsstatus som de redovisas i WL GL, och EF från tabell 18 för boreal gräsmark. Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	Nutrient Rich			Nutrient Poor			Nutrient Rich + Poor		
	EF	95 % conf.	n	EF	95 % conf.	n	EF	95 % conf.	n
Temperate							**2.5**	-0.6–5.7	13
Boreal							**1.4**	-1.6–4.5	12

References: see table 8 and 18

Peat Extraction

Read in conjunction with relevant sections within the 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

Sweden reports emissions of GHGs from managed wetlands. Wetlands are not considered managed in general, and are thus not included in the reporting. One exception is wetlands used for peat extraction. The emission factor for peat extraction has been updated within the WL GL.

The emissions from peat extraction are associated with the mineralization of organic material as the water table is artificially altered. It does not account for emissions associated with the extraction and combustion of peat.

Areas

The areas that produce peat used for energy are recorded by SGU (Swedish Geological Survey) whereas areas of peat extraction for horticultural use are unavailable at present. Only annual extracted volumes are recorded (by Statistics Sweden, SCB). These datasets will be compiled and extended as appropriate prior to the next submission. In the previous submissions the data have been provided by the Swedish peat industry association. The total area reported in submission 2013 was 8970 ha.

CO_2

The previous submissions from Sweden have reported emissions at the Tier 2 level, with a country specific estimate calculated from Sundh et al. (2000) and Kasimir-Klemedtsson et al (2000) with an implied emission factor of 1.64 ton CO_2-C ha^{-1} yr^{-1}.This is lower than the emission factor proposed by the WL GL (see table 20). The emission factors are valid for boreal and temperate climates.

Table 20. Emission factors in ton CO_2-C ha^{-1} yr^{-1} from Peat extraction as reported in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.
Tabell 20*. Emissionsfaktorer i ton CO_2-C ha-1 år-1 från Torvbrytningsmark som de redovisas i WL GL Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

CO_2	EF	95 % conf.	n
Peat Extraction	**2.8**[a]	1.1 – 4.2	21

[a] Ahlholm and Silvola 1990, Glatzel et al. 2003, Hargreaves et al. 2003, McNeal and Waddington 2003, Shurpali et al. 2008, Strack and Zuback 2013, Sundh et al. 2000, Tuittila and Komulainen 1995, Tuittila et al. 1999; 2004, Waddington et al. 2010

Changing the emission factor from 1.64 to 2.8 CO_2-C ha^{-1} yr^{-1} would increase emissions from 53790 ton CO_2 to 92100 ton CO_2. It is recommended to use the new emission factor as to not underestimate emissions. The emission factor from the WL GL is also based on a larger number of sites, making the result more robust.

N_2O

Sweden has not reported emissions of N_2O from peat extraction sites in previous submissions. The emission factor given in the WL GL has been developed from measurements at four sites in Finland (see table 21), making the emission factor fairly uncertain compared to other emission factors presented in the WL GL. However, no further studies were found to be published in this field. This is a low emission factor compared to those calculated for Forest land, Cropland and Grassland. The emission factor is valid for both boreal and temperate climate conditions.

Table 21. Emission factors in kg N_2O-N ha^{-1} yr^{-1} from Peat extraction as reported in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.
Tabell 21*. Emissionsfaktorer i kg N_2O-N ha^{-1} yr^{-1} från Torvbrytningsmark som de redovisas i WL GL Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

N_2O	EF	95 % conf.	n
Peat Extraction	**0.3**[a]	-0.03 – 0.64	4

[a] Hyvönen et al. 2009, Nykänen et al. 1996, Regina et al 1996

The emissions in CO_2 equivalents (GWP 298) amounts to 1260 ton CO_{2eq} if using the areal estimate in the Swedish NIR (Swedish Environmental Protection Agency, 2013) and the emission factor from the WL GL.

CH_4

Sweden has not reported emissions of CH_4 from peat extraction sites in previous submissions. The guidance given in the WL GL (table 22) is valid for both boreal and temperate climate conditions.

Table 22. Emission factors in kg CH_4 ha^{-1} yr^{-1} from Peat extraction as reported in the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%) and number of sites (n) are displayed.
Tabell 22. *Emissionsfaktorer i kg CH_4 ha^{-1} yr^{-1} från Torvbrytningsmark som de redovisas i WL GL Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

CH_4	EF	95 % conf.	n
Peat Extraction	**6.1**[a]	1.6 – 11	15

[a] Hyvönen et al. 2009, Nykänen et al. 1996, Strack and Zuback, 2013, Tuittila et al. 2000, Waddington and Day 2007

The emissions in CO_2 equivalents (GWP 25) amounts to 1300 ton CO_{2eq} if using the areal estimate in Swedish NIR (Swedish Environmental Protection Agency, 2013) and the emission factor from the WL GL. This estimate was calculated after removing the fraction of ditches from the total area (see section 7.) However, as emissions of CH_4 from ditches also are to be accounted for, the total impact of peat extraction sites increases with 6000 ton CO_{2eq} from the ditches alone. See section: CH_4 from drainage ditches

Settlements

Read in conjunction with relevant sections in the 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

The WL GL does not provide specific guidance on emissions from Settlements and it is advised to use existing emission factors from land use categories that best represent an individual Settlement area.

CH_4 from drainage ditches

Read in conjunction with section 2.2.2.1, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

Although emissions from the soil surface of drained organic soils are low in comparison to undrained conditions, emissions from the ditch network may be substantial. In fact these emissions may exceed the flux of CH_4 from the soil if these are averaged over the land surface (Schrier-Uijl et al., 2011).

The shallow drained Grasslands have been excluded in table 23 as Sweden does not have this category.

The emissions from ditches per hectare are calculated by multiplying the emission factor with the fraction of ditches given for that land-use area (see table 23).

Table 23. Emission factors in kg CH_4 ha^{-1} yr^{-1} from drainage ditches for different land-uses as given by the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%), number of sites (n), and fraction of ditches as given by the WL GL are displayed.

Tabell 23. *Emissionsfaktorer i kg CH_4 ha^{-1} yr^{-1} från dräneringsdiken för olika markanvändningskategorier som de redovisas i WL GL Emissionsfaktorerna baseras på flera studier. Konfidensintervall (95%), antal mätplatser (n) och dikesandelen av den totala arealen redovisas också i tabellen.*

Land use	EF	95 % conf.	n	Frac	EF ha^{-1}
Forest, Wetland	**217**[a]	41 – 393	11	**0.025**	5.4
Grassland, Cropland Deep drained	**1165**[b]	335 – 1995	5	**0.05**	58.3
Grassland, Shallow drained	**527**[c]	285 – 769	5	**0.05**	26.4
Peat Extraction	**524**[d]	102 – 981	6	**0.05**	26.2

[a] Cooper and Evans, 2013, Glagolev et al., 2008, Minkkinen and Laine, 2006, Roulet and Moore, 1995, von Arnold et al., 2005c) and Sirin et al. 2012 – reference not found

[b] Best and Jacobs, 1997, Chistotin et al. 2006, Schrier-Uijl et al. 2010, S Schrier-Uijl et al. 2011, Teh et al. 2011, Vermaat et al. 2011) and Sirin et al. 2012 – unknown reference.

[c] Best and Jacobs, 1997, Hendriks et al., 2007, Hendriks et al., 2010, Van den Pol- van Dasselaar et al., 1999, Vermaat et al., 2011, McNamara, 2013)

[d] Chistotin et al. 2006, Hyvönen et al. 2013, Nykänen et al. 1996, Sundh et al. 2000, Waddington and Day 2007) and Sirin et al. 2012 – reference not found

If the same arguments that were used in section; Grasslands, are applied, then it is reasonable to question if the emission factor for Grasslands is representative for Swedish semi-natural pastures. It would then be reasonable to suggest using the emission factor for Forest land (217 kg CH_4 ha^{-1} yr^{-1}).

DOC

Read in conjunction with section 2.2.1.2, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

Dissolved organic carbon (DOC) is transported from the soil by runoff. The leaching of DOC primarily depends on the annual runoff, which in turn depends on precipitation patterns. Since precipitation is highly variable within and between years, so is the yearly leaching of DOC.

The release of DOC from boreal organic soils was estimated to 80 kg C ha^{-1} yr^{-1} within the WL GL. This value is a good representative for Swedish conditions (Bishop, K. pers. com.). This background flux is then assumed to change when drainage is applied and the emission factor presented for drained conditions is 120 kg C ha^{-1} yr^{-1} in the WL GL. Results from rewetted peat extraction areas, drained organic Forest lands and forested former peat extraction areas in Sweden confirm that the value presented here is within the range for Swedish conditions (Lundin, L. 1988, Lundin, L. 1996, Lundin, L. and Bergquist, B. 1990, Lucci, G. 2007. and Lundin, L. pers. com.).

The DOC flux emission factors in the WL GL increases sharply when going from the boreal to the temperate climate zone. This does not conform to the estimate presented by K. Bishop (pers. com.). Bishop argues that the emission factor from boreal drained organic soils should be applied also within the temperate zone.

Table 24. Emission factor in ton DOC-C ha^{-1} yr^{-1} from drained organic soils as given by the WL GL. The emission factors are based on several studies and the EF, confidence interval (95%), are displayed.
Tabell 24*. Emissionsfaktor i ton DOC-C ha^{-1} yr^{-1} från dränerad mark som de redovisas i WL GL. Emissionsfaktorer och konfidensintervall (95 %) baseras på flera studier.*

Climate	EF	95 % conf.	n
Boreal	**0.12**[a]	0.07 – 0.19	NA

[a] Ågren et al. 2007, Glazel et al. 2003, Heikkinen 1990, Jager et al. 2009, Juutinen et al. 2013, Kane et al. 2010, Koprivnjak and Moore 1992, Kortelainen et al. 2006, Moore et al. 2003, Nilsson et al. 2008, Rantakari et al. 2010, Strack et al. 2008

To avoid double accounting of DOC, it is important to consider which method that is used to estimate carbon losses from soils. In stock change methods, such as subsidence rate based emissions, the losses of carbon include carbon lost through DOC release. However, when the losses of carbon have been measured through flux measurements on the soil surface, as for organic soils, DOC is not included and should therefore be added.

Waterborne emissions from drained organic soils, belonging to the categories Grassland, Forest land or Wetland used for peat extraction, should be calculated as those are estimated from soil-atmosphere gas exchange fluxes. However, depending on the choice of emission factors for Cropland (subsidence based or flux-based) the DOC may or may not have to be added.

Emission factors describing losses of carbon as dissolved inorganic carbon (DIC) or particulate organic carbon (POC) were not presented within the WL GL as the knowledge in these areas are still lacking. However, it is possible to include these emissions if data is available nationally.

Rewetting

Read in conjunction with chapter 3, 2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS

"Rewetting is the deliberate action of raising the water table on drained soils to re-establish water saturated conditions, e.g. by blocking drainage ditches or disabling pumping facilities." (WL GL section 3.1).

Wetland restoration and rehabilitation are also defined, but no guidance is given of how to assess their contribution to GHG fluxes.

The water table level is a major control on the biogeochemical processes that determines the fluxes of GHGs from peatlands, and as a consequence rewetting is assumed to alter flux rates (WL GL section 3.1). It is assumed that CO_2 emissions decrease, while CH_4 emissions increase. N_2O emissions are thought to approach 0 upon rewetting. DOC fluxes are also assumed to decrease once the soil is rewetted.

CO_2 fluxes may become negative after rewetting - indicating a net ecosystem uptake of carbon. The re-establishment of wetland vegetation is necessary for carbon uptake and since this succession process may span over years it means that the rewetted soil may remain a large CO_2 source during the first years after rewetting. The transition from a carbon source to a carbon sink may vary from years to several decades (WL GL section 3,1).

The assumption that rewetting turns an organic soil into a carbon sink is new in the reporting guidelines since 2006 IPCC GL, where no such uptake was included in the methodology for organic soils.

In contrast to the other emission factors in the WL GL, the emission factors from rewetted organic soils integrate all carbon fluxes from the soil and the above- and belowground vegetation components other than trees. This is because it is difficult to separate the carbon pools on these lands (WL GL section 3.1).

The nutrient status of a rewetted peatland is determined by its source of water, i.e. ombrotrophic (nutrient poor) and minerotrophic (nutrient rich) wetlands (WL GL section 3.1).

It should be noted that the method for estimating GHG fluxes from rewetted organic soils at the Tier 1 level is simplified as flux rate transitions over years or decades are not accounted for. This means that the rewetted surface immediately is considered to be in a new steady state, which it is not. It is advised to avoid this problem by improving the time dependence of the emissions related to the transition of the ecosystem at the Tier 2 level. This relates to both CO_2 and to CH_4 fluxes.

Sweden has not submitted data of GHG-fluxes from rewetted organic soils in previous submissions to the UNFCCC. For this reason, new data sources had to be found as seen in the next section, where data on wetland restoration were taken from the Swedish Meteorological and Hydrological Institute (SMHI).

Areas

The area of rewetted soils can be calculated from the Swedish Metereological and Hydrological Institute's (SMHI) database for wetlands[6] (*våtmarksdatabasen*). This database contains information about size, coordinates and year of construction of each individual wetland. As the wetlands relevant within this section are located on organic soils they are assumed to be rewetted rather than constructed as they previously have been wet.

The soil type (organic or mineral) and the former land use has not been recorded in this database, which means that this had to be solved by merging the coordinates with a georeferenced map of soil type (*jordartskartan*) from Swedish Geological Survey (1:50000, 1:100000, 1:200000). These datasets present the soil type at 50 cm depth. As the definition of organic soils also include shallower soils (40 cm), additional maps of shallow peat layers (same resolutions as above) was used in conjunction with the other data.

These data are spatially explicit data, and as such they differ from the data on land-use areas for all the other land-uses, which are taken from the statistical sampling approach used within the NFI.

The result of this analysis showed that 1300 ha of wetland has been rewetted on organic soils since 1990.

---

[6] http://vattenwebb.smhi.se/wetlands/

To account for the fact that the rewetted area may be large, and that the coordinate only is a point coordinate, a x,y tolerance of 25 meter was used when overlaying the two datasets in ArcMap 10.1. The areal estimate would improve if the soil type is recorded in the database when the wetland is constructed. All constructed wetlands except one (area: 2 ha) was located in the temperate climate zone.

It is also possible to create a time series of wetland rewetting since 1990 based on the information in this database, thus fulfilling the requirements for reporting of Wetland rewetting under the Kyoto protocol.

This dataset does not include all rewetted wetlands, as it only includes those created within certain funding programs (Brandt et al. 2009). However, it is currently the most complete dataset available. Additional data could perhaps be provided by peat mining companies that have rewetted extracted peatlands.

CO_2

The WL GL states that CO_2 fluxes from natural/undrained sites have been used in addition to CO_2 fluxes from rewetted soils to provide data for the emission factors shown in table 25. Based on this assumption it would be possible to use national studies of data from undrained peatlands and treat them in the same manner since this data is generally more available. However, the data presented in the WL GL seem to be representative for Swedish conditions (if comparing data from the WL GL to Nilsson et al. 2008), and as the emissions from rewetted organic soil is negligible compared to the total national emissions of GHGs from organic soils – no further literature study was conducted.

Table 25. Emission factors, for rewetted organic soils, in ton CO_2-C ha^{-1} yr^{-1} from the WL GL. The emission factors are categorized by climate and nutrient status and are based on several studies. The EF, confidence interval (95%) and number of sites (n) are displayed.
***Tabell 25**. Emissionsfaktorer för återvätad organogen mark i ton CO_2-C ha^{-1} yr^{-1} från WL GL. Emissionsfaktorerna baseras på flera studier och kategoriseras efter klimat och näringsstatus. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	Nutrient status	EF	95 % conf.	n
Boreal	Poor	**-0.34**[a]	-0.59 – -0.09	26
	Rich	**-0.55**[a]	-0.77 – -0.34	39
Temperate	Poor	**-0.23**[b]	-0.64 – +0.18	43
	Rich	**0.5**[b]	-0.71 – +1.71	15

[a] Alm et al., 1997, Aurela et al., 209, Bubier et al., 1999, Drewer et al., 2010, Harazono et al., 2003, Heikkinen et al., 2002, Kivimäki et al., 2008, Komulainen et al., 1999, Laine et al., 1996, Maanavilja et al., 2011, Nilsson et al., 2008, Nykänen et al., 2003, Sagerfors et al., 2008, Soegarard and Nordstroem, 1999, Soini et al., 2010, Suyker et al., 1997, Tuittila et al., 1999, Waddington and Price, 2000, Waddington and Roulet, 2000, Whiting and Chanton, 2001, Yli-Petäys et al., 2007.
[b] Adkinson et al., 2011, Augustin and Chojnicki, 2008, Augustin et al., 2011, Aurela et al., 2002, Billett et al., 2004, Bortoluzzi et al., 2006, Cagampan and Waddington, 2008, Christensen et al., 2012, Drewer et al., 2010, Drösler, 2005, Drösler et al., 2013, Golovatskaya and Dyukarev, 2009, Hendriks et al., 2007, Herbst et al., 2013, Jacobs et al., 2007, Koehler et al., 2011, Kurbatova et al., 2009, Lafleur et al., 2001, Lund et al., 2007, Nagata et al., 2005, Petrone et al., 2003, Riutta et al., 2007, Roehm and Roulet, 2003, Roulet et al., 2007, Schulze et al., 2002, Shurpali et al., 1995, Strack and Zuback, 2013, Urbanová et al., 2012, Waddington et al., 2010, Wickland, 2001, Wilson et al., 2007, Wilson et al., 2013.

The emission factors in the WL GL are disaggregated by climate region and nutrient status. If the nutrient status is unknown, poor conditions should be assumed for boreal climate, and rich conditions should be assumed for temperate climate.

The CO_2 emission factor includes the net carbon flux from soil and non-tree vegetation. By this method, it is not possible to directly compare the emission factors with those from drained organic soils. Also, if rewetting causes a change in land-use that involves Forest Land or Cropland with perennial woody biomass, these changes in carbon stocks must be accounted for by methods in the 2006 IPCC Guidelines.

CH_4

As with the CO_2 emissions from rewetted organic soils, the CH_4 emissions are most probably increasing during a transition period between rewetting and vegetation establishment and succession. This transient behavior could be assessed at higher Tiers.

CH_4 fluxes from both rewetted and natural/undrained sites have been used to calculate the emission factors in table 26 (WL GL, Annex 3A.3)

Table 26 Emission factors in kg CH_4 ha^{-1} $yr^{-1}$for rewetted organic soils, adapted from the WL GL. The emission factors are categorized by climate and nutrient status and are based on several studies. The EF, confidence interval (95%) and number of sites (n) are displayed.
Tabell 26 *Emissionsfaktorer för återvätad organogen mark i kg CH_4 ha^{-1} yr^{-1} från WL GL. Emissionsfaktorerna baseras på flera studier och kategoriseras efter klimat och näringsstatus. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	Nutrient status	EF	95 % conf.	n
Boreal	Poor	**55**[a]	0.6 – 328	39
	Rich	**183**[a]	0 – 657	35
Temperate	Poor	**123**[b]	4 – 593	42
	Rich	**288**[b]	0 – 1141	37

[a] Alm et al., 1997, Bubier et al., 1993, Clymo and Reddaway, 1971, Drewer et al., 2010, Gauci and Dise, 2002, Juottonen et al., 2012, Komulainen et al., 1998, Laine et al., 1996, Nykanen et al., 1995, Strack and Zuback, 2013, Tuittila et al., 2000, Urbanová et al., 2012, Verma et al., 1992, Waddington and Price, 2000, Whiting and Chanton, 2001, Yli-Petäys et al., 2007.
[b] Augustin and Merbach, 1998, Augustin, 2003, Augustin et al., 1996, Augustin et al., 2011, Beetz et al., 2013, Bortoluzzi et al., 2006, Cleary et al., 2005, Crill et al., 1993, Dise and Gorham, 1983, Drösler, 2005, Drösler et al., 2013, Flessa et al., 1997, Glatzel et al., 2011, Hendriks et al., 2007, Jungkunst and Fiedler, 2007, Koehler et al., 2011, Nagata et al., 2005, Nilsson et al., 2008, Roulet et al., 2007, Scottish Executive, 2007, Shannon and White, 1994, Sommer et al., 2003, Tauchnitz et al., 2008, Waddington and Price, 2000, Wickland, 2001, Wild et al., 2001, Wilson et al., 2009, Wilson et al., 2013.

The CH_4 emissions from Swedish undrained/natural peatlands have been extensively studied. National estimates disaggregated between different peatland types and climatic regions using data from the NFI was developed by Nilsson et al. (2001). Based on the assumption that methane emissions from undrained/natural mires are not significantly different from those measured from rewetted sites (WL GL, Annex 3A.3) it should be possible to use the information in Nilsson et al. (2001) to estimate CH_4 fluxes from rewetted organic soil. The total number of sites measured was 619.

Nilsson et al. (2001) classified peatlands according to vegetation types consistent with those in the NFI, which contrasts to the classification given to the rewetted wetlands that are reported by SMHI. The categories (Type 1 to 4) in the database (*våtmarksdatabasen*) are not comparable to the classifications in table 27. If further information on nutrient level status is provided in the database in the future, it should be possible to use the emission factors in table 27, otherwise it is recommended to use the emission factors from the WL GL (see table 26).

Table 27. Emission factors in kg CH_4 ha^{-1} yr^{-1} adapted from Nilsson et al. (2001) for Swedish mires. Adaptions have been made regarding long-term climate and winter emissions (Nilsson, M. pers.com.). The emission factors (EF), standard error (SE) are presented. The standard errors are those estimated before adaptions were made.

Tabell 27*. Emissionsfaktorer för svenska myrar i kg CH4 ha*$^{-1}$ *år*$^{-1}$ *anpassade efter Nilsson et al. (2001). Anpassningar har gjorts avseende långsiktiga klimat-och vinter utsläpp (Nilsson, M. pers.com.). Emissionsfaktor (EF) och standardfel (SE) presenteras. Standardfelen är beräknade innan anpassningarna gjordes.*

Vegetation type	EF	SE
Hummock sites	118	±13
Transitional fens	60	±5
Low sedge fens	197	±8
Tall sedge fens	396	±36

The estimates in table 27 are within the ranges presented within the WL GL.

The emission factors in table 27 have been modified compared to the original numbers given in Nilsson et al. (2001) to account for discrepancies between the climate during the measurement year (1994) and the long-term climate by multiplying the emissions with 2. Additional emissions of 20% of the measured emissions were also added to account for winter emissions according to guidance given in the article (Nilsson et al. 2001). This is different from the guidance given in the WL GL (Annex 3A.3) which uses15%.

As a general comment, it is unlikely that the different types of wetlands that are created on organic soils for different purposes (biodiversity, climate change mitigation, nutrient uptake) will have the same effect on the GHG fluxes as they most probably differ in characteristics such as water table level. At a local scale it might not be advisable to use the emission factors from the WL GL to assess greenhouse gas emissions if other estimates from similar wetland conditions exist.

DOC

The emissions of DOC from rewetted organic soils have been calculated based on rewetted sites in the temperate region, and then adapted to the boreal climate (WL GL). The flux of 0.08 ton CO_2-C ha^{-1} yr^{-1} agrees with the emissions presented as background emissions before drainage which has been used when assessing DOC from drained organic soils (see section; Peat extraction). As with those emissions, the considerably higher emissions from temperate zones (see table 28) are not considered to be representative for Swedish conditions (Bishop, K. pers. com.).

Table 28. Emission factors for DOC from rewetted organic soils in ton CO_2-C ha^{-1} yr^{-1} adapted from the WL GL. The emission factors are categorized by climate and are based on several studies. The EF, confidence interval (95%) and number of sites (n) are displayed.
Tabell 28. *Emissionsfaktorer för DOC från återvätad organogen mark, i ton CO_2-C ha^{-1} yr^{-1} från WL GL. Emissionsfaktorerna baseras på flera studier och kategoriseras efter klimat. Konfidensintervall (95%) och antal mätplatser (n) redovisas också i tabellen.*

Climate	EF	95 % conf.	n
Boreal	**0.08**[a]	0.06 – 0.11	10
Temperate	**0.26**[b]	0.17 – 0.36	15

[a] Jager et al., 2009, Juutinen et al., 2013, Koprivnjak and Moore, 1992, Kortelainen et al., 2006, Moore et al., 2003, Nilsson et al., 2008, Rantakari et al., 2010.

[b] Billett et al., 2010, Clair et al., 2002, Dawson et al., 2004, di Folco and Kirkpatrick, 2011, Dinsmore et al., 2011, Koehler et al., 2009, Koehler et al., 2011, Kolka et al., 1999, Moore et al., 2003, O'Brien et al., 2008, Roulet et al., 2007, Strack et al., 2008, Strack and Zuback, 2013, Turner et al., 2013, Urban et al., 1989, Waddington et al., 2008.

GHG reduction by Rewetting

Rewetting has been proposed as a land-use activity to reduce GHG emissions from drained organic soils. This activity may be costly, and land owners may or may not be interested in converting their land into wetlands. To find a stable ground for arguments, this section is provided to account for the possible benefits of rewetting in terms of GHG emissions as given in the WL GL. The emission factors used for these calculations are the recommended emission factors presented in table 1 and 2 and given in ton CO_2-C eq ha^{-1} yr^{-1} (see table 29).

Due to the differences in methods regarding emissions from rewetted soils compared to drained soils these numbers are in part incorrect. This difference leads to a slight overestimate of the carbon release from rewetted sites, so the benefits of the rewetting activity are likely higher than reported here. Other problems with the data, such as the assumption of an instant transition into a new steady state, are equally large or larger. Therefore these numbers are preferably used as markers – pointing out the most suitable areas to rewet in terms of GHG emission reductions. More detailed calculations must be made, including all carbon pools, to find the real benefit of rewetting within a given land-use.

Table 29. Summary of the possible emission reductions caused by rewetting of drained organic soils given for land-use classes. Negative values indicate no benefit of rewetting. The values are in ton CO_2 –C eq ha^{-1} yr^{-1} Croplands are considered nutrient rich. This has been computed with the recommended emission factors seen in table 1 and 2.

Tabell 29*. Sammanfattning av möjliga utsläppsminskningar genom återvätning av dränerade organogena jordar för olika markanvändningskategorier. Negativa värden indikerar att återvätningen inte var till någon klimatnytta. Värdena är i ton CO_2-C eq ha^{-1} $år^{-1}$ all åkermark (Cropland) anses näringsrik. Beräkningarna baseras på de emissionsfaktorerna i tabell 1 och 2.*

Land-use	Climate	Nutrient status	Benefit of Rewetting in CO_2 –C eq ha^{-1} yr^{-1}
Forest	Boreal	rich	1.60
		poor	-0.51
	Temperate	rich	1.71
		poor	1.32
Cropland	Boreal	rich	8.37
	Temperate	rich	6.86
Grassland	Boreal	rich	1.64
		poor	-0.51
	Temperate	rich	1.75
		poor	1.35
Wetland (Peat Extraction)	Boreal	rich	3.28
		poor	2.20
	Temperate	rich	1.77
		poor	1.37

Total impact on national GHG emissions

The total impact of the emissions treated within this report has been calculated as to give an indication of the contribution of these land use areas to the national GHG emissions if the recommended emission factors are used. The emission factors are those recommended in this report. The total GHG emissions are 10.63 Mt $CO_{2\ eq.}$

Table 30. Summary of land-use areas, implied emission factors (IEF) in ton CO_2-C eq ha^{-1} or ton CO_2 eq ha^{-1} and the total emissions in million ton CO_2 eq.

Tabell 30*. Sammanfattning av arealer för olika markanvändningskategorier, implicerade emissionsfaktorer (IEF) i ton CO_2-C ekv ha^{-1} resp. ton CO_2 ekv ha^{-1} och de totala utsläppen i miljoner ton CO_2 eq.*

Land-use	Climate	Nutrient status	Area (ha)	IEF (ton ha^{-1})		Total
				CO_2-C	CO_2	Mt CO_2 eq
Forest	Boreal	rich	313029	1.51	5.53	1.73
		poor	242146	0.48	1.77	0.43
	Temperate	rich	270233	3.13	11.48	3.10
		poor	52242	3.13	11.48	0.60
Cropland	Boreal Temperate		145000	8.28	30.35	4.40
Grassland	Boreal	rich	994	1.54	5.65	0.01
		poor		0.48	1.76	
	Temperate	rich	21828	3.17	11.62	0.25
		poor		3.17	11.62	
Wetland (Peat Extraction)			8970	3.18	11.67	0.10
Rewetting	Boreal	rich		-0.10	-0.35	
		poor	2	0.99	3.62	0.00
	Temperate	rich	1299	1.42	5.20	0.01
		poor		1.81	6.65	

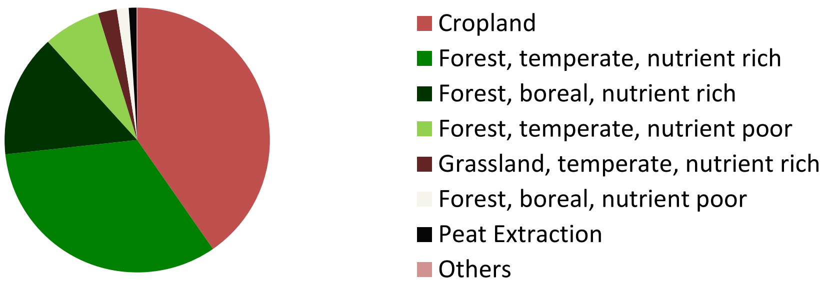

Figure 2. Pie-chart showing the contribution of each land-use category to the total emissions in $CO_{2\ eq.}$ The category others include the remaining land-use categories that are mentioned in table 29 but not in the list.

Figur 2*. Diagram som visar bidraget från varje markanvändningskategori till de totala utsläppen av växthusgaser. Kategorin "other" inkluderar de kategorier som nämns i tabell 29 men inte i listan.*

Fire

Fire is relatively uncommon in Swedish forests due to intensive fire controls, and a cool, moist climate. The wild-fires that do occur are recorded by Swedish Civil Contingencies Agency in a database where area estimates are made subjectively by personnel at the site. It is not recorded if the fire occurs on organic or mineral soil, nor if it occurs as ground fire or forest fire. Due to the uncertainties regarding total area of burned organic soil it has not been possible to calculate an area estimate.

The total area of wild-fire on both organic and mineral soil in Sweden has been 2100 ha on average over the period 1998 to 2012. The interannual variation can be very large as climate determines the risk of fire. It should be noted that controlled fires are not included in this estimate.

It could be possible to obtain the area on organic soil as a coordinate is taken at each fire. If these coordinates are combined with the georeferenced data of histosols from the Swedish Geological Survey it is possible to produce an estimate. However, this has not been done within this study.

Default emission factors are presented in the WL GL section 2.2.2.3.

Coastal Wetlands

Coastal Wetlands are treated within chapter 4 of the WL GL. The activities that have their own emission factors are 1) Forest management activities in mangroves, 2) Extraction, 3) Rewetting and revegetation of mangroves, tidal marches and seagrass meadows, 4) Drainage in mangroves and tidal marshes, 5) Aquaculture. None of these activities, except perhaps aquaculture, are commonly practiced in Sweden, and thus; they have not been prioritized within this report. If any of these activities are occurring on coastal wetlands these should be accounted for based on the methods in the WL GL.

Although these activities are not commonly occurring, an estimate of the areas of coastal wetlands was conducted to assess their importance (area-wise). Two different methods were used; the first was based on georeferenced data of different land-uses that have been produced by Lantmäteriet (Marktäckedata)[7]. In this map the land-use category *saltpåverkade kärr och marskland* 74/421 defines coastal wetlands and the total area was estimated to 5000 ha. The second estimate was made by using TUVA,[8] which is a database covering *Ängs- och betesmarksinventeringen* (meadow and pasture inventory). In this database, the categories 13/10, 13/30 and 16/30 can be used to describe coastal wetlands. As a large part of the Swedish coastline meets brackish water, areas north of Stockholm was not included as the water is not saline enough according to the definition of coastal wetlands in the WL GL. In this second estimate the area of coastal wetland increased compared to the prior estimate to an area of 7500 ha.

---

[7] http://www.lantmateriet.se/Kartor-och-geografisk-information/Kartor/Geografiska-teman/GSD-Marktackedata/

[8] https://etjanst.sjv.se/tuvaut/site/index.htm

Inland Wetland Mineral Soils

Chapter 5 in the WL GL gives guidance on how to estimate and report GHG emissions and removals from managed lands with Inland wetland mineral soils (Gleysols) for all land categories. Guidance is provided for 1) artificial drainage, 2) rewetting of artificially drained inland wetland mineral soils, 3) artificial inundation for the purpose of wetland creation.

N_2O are not reported for these soils within the WL GL as the data was deemed insufficient.

It is possible to estimate the area of drained forest Gleysols from the NFI database. It is also possible that the new survey of soils on Croplands (presently under construction at SLU) can provide data to form a similar estimate.

Wetland construction on agricultural soils is recorded in SMHI's wetland database (*våtmarksdatabas*) where the year of construction, coordinates, and size are recorded for each wetland. As this dataset had to be combined with a georeferenced soil classification map from SGU to obtain the area of constructed wetlands on organic soils, the remaining area is then assumed to be on mineral soils. The total area of these constructed wetlands on mineral soils within all land-use categories is 3400 ha according to this estimate.

This section has not been reviewed further as the focus of this project is drained organic soils.

Data sources

The relevant data sources that are needed for the reporting of GHG emissions from drained organic soils, peat extraction and peatland rewetting are summarized in table 31.

Table 3241. Summary of data sources for the different activity data.
Tabell 31. Summering av användbara datakällor för aktivitetsdata.

Land-use	Data source	Alternative	Note
Forest land	NFI		Statistical data
Cropland	SGU+ Blockdatabasen, NFI		Data sources are used together to form an estimate. Spatially explicit data from SGU must be adjusted to fit with NFI data.
Grassland	NFI	SGU+ Blockdatabasen	If the definition of Grassland changes, the alternative data source might be included
Wetland – Peat Extraction	Peat extraction industry	SGU	
Rewetting	SMHI+SGU		It is possible that other data sources exist, but none were confirmed in this study.
Fire	Swedish Contingency Agency		Highly uncertain data

References

Adkinson, A. C., Syed, K. H., & Flanagan, L. B. 2011. Contrasting responses of growing season ecosystem CO2 exchange to variation in temperature an dwater table depth in two peatlands in northern Alberta, Canada. Journal of Geophysical Research, 116(G1): G01004.

Ågren, A., Jansson, M. Ivarsson, H., Bishop, K., Seibert, J. 2007. Seasonal and runoff-related changes in the organic carbon conventrations in the River Öre, Northern Sweden. Aquatic Science

Ahlholm, U. and Silvola, J. 1990. Turvetuotannon ja turpeen käytön osuus maapallon ja Suomen hiilitaseessa, Ministry of Trade and Industry, Ser. D 183, 1-57 [in Finnish]

Alm, J., Talanov, A., Saarnio, S., Silvola, J., A., I., Aaltonen, H., Nykänen, H., & Martikainen, P. 1997. Reconstruction of the carbon balance for microsites in a boreal oligotrophic pine fen, Finland. Oecologica, 110: 423-431.

Augustin, J., Merbach, W., Käding, H., Schmidt, W., & Schalitz, G. 1996. Lachgas- und Methaneemission aus degradierten Niedermorrstandorten Nordostdeutchlands unter dem Einflus unterschiedlicher Bewirtschaftung. . In Alfred.Wegener.Stiftung (Ed.), Von den Ressourcen zum Recycling: 131-139. Berlin: Ernst & Sohn.

Augustin, J., & Merbach, W. 1998. Greenhouse gas emissions from fen mires in Northern Germany: quantification and regulation. In W. Merbach, & L. Wittenayer (Eds.), Beiträge aus der Hallenser Pflanzenernährungsforschung: 97-110. Grauer, Beuren.

Augustin, J., Merbach, W., Käding, H., Schmidt, W., & Schalitz, G. 1996. Lachgas- und Methaneemission aus degradierten Niedermorrstandorten Nordostdeutchlands unter dem Einflus unterschiedlicher Bewirtschaftung. . In Alfred.Wegener.Stiftung (Ed.), Von den Ressourcen zum Recycling: 131-139. Berlin: Ernst & Sohn.

Augustin, J., Merbach, W., & Rogasik, J. 1998. Factors influencing nitrous oxide and methane emissions from minerotrophic fens in northeast Germany. Biology and Fertility of Soils, 28(1): 1-4.

Augustin, J. 2003. Gaseous emissions from construced wetlands and (re)flooded meadows. . Publicationes Instituti Geographici Universitatis Tartuensis, 94: 3-8.

Augustin, J., & Chojnicki, B. 2008. Austausch von klimarelevanten Spurengasen, Klimawirkung und Kohlenstoffdynamik in den ersten Jahren nach der Wiedervernässung von degradiertem Niedermoorgrünland. In J. Gelbrecht, D. Zak, & J. Augustin (Eds.), Phosphor. und Kohlenstoff-Dynamik und Vegetationsentwicklung in wiedersvernässten Mooren des Peenetals in Mecklenburg-Vorpommern - Status, Steuergrössen und Handlungsmöglichkeiten: 50-67. Berlin: Berichte des IGB Heft 26.

Augustin, J., unpubl., cited in Couwenberg, J., Thiele, A., Tanneberger, F., Augustin, J., Bärisch, S., Dubovik, D., Liashchynskaya, N., Michaelis, D., Minke, M., Skuratovich, A., & Joosten, H. 2011. Assessing greenhouse gas emissions from peatlands using vegetation as a proxy. Hydrobiologica, 674: 67-89.

Aurela, M., Laurila, T., & Tuovinen, J. P. 2002. Anual CO2 balance of a subarctic fen in nothern Europe: Importance of wintertime efflux. Journal of Geophysical Research, 107(D21): 4607.

Aurela, M., Lohila, A., Tuovinen, J. P., Hatakka, J., Riutta, T., & Laurila. 2009. Carbon dioxide exchange on a northern boreal fen. Boreal Environment Research, 14: 699-710.

Beetz, S., Lieberbach, H., Glatzel, S., Jurasinski, G., Buczko, U., & Höper, H. 2013. Effects of land-use intennsity on the full greenhouse gas balance in an Atlantic peat bog. Biogeosciences, 10: 1067-1082.

Berglund, K. 1989. Ytsänkning på mosstorvjord. Sammanställning av materal från Lidhult, Jönjöpings län, Vol. 89. Uppsala: Swedish University of Agricultural Sciences.

Berglund, Ö., Berglund, K., Sohlenius, G. 2009. Organogen jordbruksmark i Sverige 1999 – 2008. Sveriges Lantbruksuniversitet, Institutionen för markvetenskap, Avdelningen för hydroteknik – rapport 12 2009. Uppsala

Berglund, Ö. 2011. Greenhouse gas emissions from cultivated peat soils in Sweden- Doctoral Thesis no 2011:2. Swedish Agricultural University, Uppsala.

Berglund, Ö., & Berglund, K. 2011. Influence of water table level and soil properties on emissions of greenhouse gases from cultivated peat soil. Soil Biology and Biochemistry, 43(5): 923-931.

Best, E. P. H., & Jacobs, F. H. H. 1997. The influence of raised water table levels on carbon dioxide and methane production in ditch-dissected peat grasslands in the Netherlands. Ecological Engineering, 8(2): 129-144.

Billett, M. F., Charman, D. J., Clark, J. M., Evans, C. D., Ostle, N. J., Worrall, F., Burden, A., Dinsmore, K. J., Jones, T., McNamara, N. P., Parry, L., Rowson, J. G., & Rose, R. 2010. Carbon blance of UK peatlands: current state of knowledge and future research challanges. Climate Research, 45: 13-29.

Billett, M. F., Palmer, M., Hope, D., Deacon, C., Storeton-West, R., Hargreaves, K. J., Flechard, C., & Fowler, D. 2004. Linking land-atmosphere-stream carbon fluxes in a lowland peatland system. Global Biogeochemical Cycles, 18(GB1024).

Bortoluzzi, E., Epron, D., Siegenthaler, A., Gilbert, D., & Buttler, A. 2006. Carbon balance of a European mountain bog at contrasting stages of regeneration. New Phytologist, 172(4): 708-718.

Brandt, M., Arheimer, B., Gustavsson, H., Pers, C., Rosberg, J. Sundström, M. Thorén, A-K.2009. Uppföljning av effekten av anlagda våtmarker i jordbrukslandskapet – Belastning av kväve och fosfor. Naturvårsverket Rapport 6309, Oktober 2009

Bubier, J., Frolking, S., Crill, P., & Linder, E. 1999. Net ecosystem productivity and its uncertainty in a diverse boreal peatland. Journal of Geophysical Research, 104(D22): 27683-27692.

Bubier, J., Moore, T. R., & Roulet, N. T. 1993. Methane emissions from wetlands in the midboreal region of Northern Ontario, Ganada. Ecology, 74(8): 2240-2245.

Cagampan, J., & Waddington, J. M. 2008. Net ecosystem CO2 exchange of a cutover peatland rehabilitated with a transplanted acrotelm. Ecoscience, 15(2): 258-267.

Chistotin, M.V., Sirin, A.A., Dulov, L.E. 2006. Seasonal dynamics of carbon dioxide and methane emission from a peatland I nMoscow Regoin drained for peat extraction and agricultural use. Agrokhimija. 6:54-62.

Christensen, T. R., Jackowicz-Korczynski, M., Aureala, M., Crill, P., Heliasz, M., Mastepanov, M., & Friborg, T. 2012. Monitoring the Multi-Year Carbon Balance of a Subarctic Palsa Mire with Micrometeorological Techniques. Ambio 41(3): 207-217.

Clair, T. A., Arp, P., Moore, T. R., Dalvac, M., & Meng, F.-R. 2002. Gaseous carbon dioxide and methane, as well as dissolved organic carbon losses from a small temperate wetland under a changing climate. Environ. Pollut., 116(143-148).

Cleary, J., Roulet, N. T., & Moore, T. R. 2005. Greenhouse Gas Emissions from Canadian Peat Extraction, 1990–2000: A Life-cycle Analysis. AMBIO: A Journal of the Human Environment, 34(6): 456-461.

Clymo, R. S., & Reddaway, E. J. F. 1971. Productivity of Sphagnum (Bog-moss) and peat accumulation. Hidrobiologia 12: 181-192.

Cooper, M., & Evans, C. 2013. CH4 emissios from ditches in a drained upland blanket bog, North Wales, UK, Emissions of greenhouse gases associated with peatland drainage waters: Report to Defra under poject SP1205: Greenhouse Gas Emissions Associated with Non Gaseous Losses of Carbon from Peatlands - fate of Particulate and Dissolved Carbon. Report to the Department of Environment: Food and Rural Affairs, UK.

Crill, P., unpubl. data, Cited in Bartlett, K. B., & Harris, R. C. 1993. Review and assessment of Methane Emissions from Wetlands. Chemosphere, 26(1-4): 261-320.

Czaplak, I., & Dembek, W. 2000. Polish peatlands a s a source of emission fo greenhoues gases. Zeszyty Edukacyjne wyd. IMUZ, 6: 61 - 71.

Dawson, J. J. C., Billett, M. F., Hope, D., Palmer, M., & Deacon, C. 2004. Sources and sinks of aquatic carbon in a peatland stream continuum. Biogeochemistry, 70: 71-92.

di Folco, M.-B., & Kirkpatrick, J. B. 2011. Topographic variation in burning-induced loss of carbon from organic soils in Tasmanian moorlands. Catena, 87: 216-255.

Dinsmore, K. J., Smart, R. P., Billett, M. F., Holden, J., Baird, A., & Chapman, P. J. 2011. Greenhouse gas losses from peatland pipes: a major pathway for loss to the atmosphere? Journal of Geophysical Research, 116(G0341).

Dise, N. B., & Gorham, E. 1983. Environmental Factors Controlling Methane Emissions from Peatlands in Northern Minnesota. Journal of Geophysical Research, 98(D6): 10583-10594.

Drewer, J., Lohila, A., Aurela, M., Laurila, T., Minkkinen, K., Penttilä, T., Dinsmore, K. J., McKenzie, R. M., Helfter, C., Flechard, C., Sutton, M., & Skiba, U. 2010. Comparison of greenhouse gas fluxes and nitrogen budgets from an ombrotrophic bog in Scotland and a minerotrophic sedge fen in Finland. European Journal of Soil Science.

Drösler, M. 2005. Trace gas exchange and climatic relevance of bog ecosystems, southern Germany. Techische Universität München.

Drösler, M., Adelmann, W., Augustin, J., Bergman, L., Beyer, C., Chojinicki, B., Förster, C., & al., e. 2013. Klimaschutz durch Moorschutz. Schlussbericht des BMBF-Vorhabens: Klimaschutz - Moornutzungsstrategien 2006-2010: TIB/UB Hannover.

Elsgaard, L., Görres, C.-M., Hoffmann, C. C., Blicher-Mathiesen, G., Schelde, K., & Petersen, S. O. 2012. Net ecosystem exchange of CO2 and carbon balance for eight temperate organic soils under agricultural management. Agriculture, Ecosystems & Environment, 162(0): 52-67.

Ernfors, M., Arnold, K., Stendahl, J., Olsson, M., & Klemedtsson, L. 2007. Nitrous oxide emissions from drained organic forest soils—an up-scaling based on C:N ratios. Biogeochemistry, 84(2): 219-231.

Flessa, H., Wild, U., Klemisch, M., & Pfadenhauer, J. 1997. C- und N Stoffflüsse auf Torfstichsimulationsflächen um Donaumoos. Zeitschrift für Kulturtechnik und Landentwicklung, 38: 11-17.

Flessa, H., & Beese, F. 1997. Einfluss unterschiedlicher Gülleapplikationstechnik auf die gasförmige Freisetzung von N2O; CH4 und CO2, Mitteilungen der Deutchen Bodenkundlichen Gesellschaft, Band 85, Heft 2: 883-887.

Flessa, H., Wild, U., Klemisch, M., & Pfadenhauer, J. 1998. Nitrous oxide and methane fluxes from organic soils under agriculture. European Journal of Soil Science, 49(2): 327-335.

Gauci, V., & Dise, N. 2002. Controls on supression of methane flux from a peat bog subjected to simulated acid rain sulfate deposition. Global Biogeochemical Cycles, 16(1): 1-12.

Glagolev, M. V., Chistotin, M. V., Shnyrev, N. A., & Sirin, A. A. 2008. The emissions of carbon dioxide and methane from drained peatlands changed by economic use and from natural mires during the summer-fall periods (on example of a region of Tomsk oblast.). Agrokhmija, 5: 46-58.

Glatzel, S., Kalbitz, K., Dalva, M., Moore, T. 2003. Dissolved organic matter properties and their relationship to carbon dioxide efflux from restored peat bogs. Geoderma 113: 397-411

Glatzel, S., Koebsch, F., Beetz, S., Hahn, J., Richter, P., & Jurasinski, G. 2011. Maßnahmen zur Minderung der Treibhausgasfreisetzung aus Mooren im Mittleren Mecklenburg. Telma, 4: 85-106.

Glenn, S., Heyes, A., & Moore, T. 1993. Carbon dioxide and methane fluxes from drained peat soils, southern Quebec. Global Biogeochemical Cycles, 7(2): 247-257.

Golovatskaya, E., & Dyukarev, E. 2009. Carbon budget of oligotrophic mire sites in the Southern Taiga of Western Siberia. Plant and SOil, 315(1): 19-34.

Grønlund, A., Hauge, A., Hovde, A., & Rasse, D. 2008. Carbon loss estimates from cultivated peat soils in Norway: a comparison of three methods. Nutrient Cycling in Agroecosystems, 81(2): 157-167.

Grønlund, A., Sveistrup, T. E., Søvik, A. K., Rasse, D. P., & Kløve, B. 2006. Degradation of cultivated peat soils in northern norway based on field scale CO2, N2O and CH4 emission measurements. Archives of Agronomy and Soil Science, 52(2): 149-159

Harazono, Y., Mani, M., Miyata, A., Zulueta, R., & Oechel, W. C. 2003. Inter-annual carbon dioxide uptake of a wet sedge tundra ecosystem in the Arctic. Tellus B(215-231).

Heikkinen, K. 1990. Transport of organic and inorganic matter in a river, brook and peat mining water in a drainage basin of the River Kiiminkijoki. Aqua Fennica, 20: 143-155

Heikkinen, J. E. P., Elsakov, V., & Martikainen, P. 2002. Carbon dioxide and methane dynamics and annual carbon balance in tundra wetland in NE Europe, Russia. Global Biogeochemical Cycles, 16(4): 1115.

Hendriks, D. M. D., van Huissteden, J., Dolman, A. J., & van der Molen, M. K. 2007. The full greenhouse gas balance of an abandoned peat meadow. Biogeosciences Discuss., 4(1): 277-316.

Hendriks, D. M. D., van Huissteden, J., & Dolman, A. J. 2010. Multi-technique assessment of spatial and temporal variability of methane fluxes in a peat meadow. Agricultural and Forest Meteorology, 150(6): 757-774.

Herbst, M., Friborg, T., Schelde, J., Jensen, R., Ringgaard, R., Vasquez, V., Thomsen, A. G., Soegaard, H., & 2013. Climate and site management as driving factors for the atmospheric greenhouse gas exchange of a restored wetland. Biogeosciences, 10: 39-52.

Hyvönen, N. P., Huttunen, J. T., Shurpali, N. J., Tavi, N. M., Repo, M. E., & Martikainen, P. J. 2009. Fluxes of nitrous oxide and methane on an abandoned peat extraction site: Effect of reed canary grass cultivation. Bioresource Technology, 100(20): 4723-4730.

Hyvönen, N.P. Huttunen, J.T. Shurpali, N.J., Lind, E.S. Marushchak, M.E., Heitto, J., Martikainen, P.J. 2013. The role of drainage ditches in greenhouse gas emissions and surface leaching losses from a cutaway peatland cultivated with a perennial bioenergy crop. Boreal Enf. Res. 18: 109-126

Höper, H. 2002. Carbon and nitrogen mineralization rates in German agriculturally used fenlands. In W. Merbach, & E.-M. Pfeiffer (Eds.), Wetlands in Central Europe. Soil organisms, soil ecological processes, and trace gas eimssions: 244. Berlin: Springer.

IPCC 2014, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland

Jaakkola, A. 1985. Lannoite ja kasviainestypen hyväksikäyttö ja häviö Biologisen typensidonnan ja ravinnetypen hyvaksikäyton projekti. Helsinki: Julkaisu 13.

Jacobs, C. M. J., Moors, E. J., & van der Bolt, F. J. E. 2003. Invloed van vaterbeheer op gekoppelde broeikasgasemissies in het veenweidegebied by ROC Xegveld, Alterra-rapport 840: 93 pp. Alterra, Wageningen.

Jacobs, C. M. J., Jacobs, A. F. G., Bosveld, F. C., Hendriks, D. M. D., Hensen, A., Kroon, P. S., Moors, E. J., Nol, I., Schrier-Uijl, A. P., & Veenendaal, E. M. 2007. Variability of annual CO2 exchange from Dutch grasslands. Biogeosciences, 4(803-816).

Jager, D. F., Wilmking, & Kukkonen, J. K. 2009. The influence of summer seasonal extremes on dissolved organic carbon export from a boreal peatland catchment: Evidence from one dry and one wet growing season. Sci.Total Environ., 407: 1373-1382.

Jungkunst, H. F., & Fiedler, S. 2007. Latitudinal differentiated water table control of carbon dioxide, methane and nitrous oxide fluxes from hydromorphic soils: feedbacks to climate change. Global Change Biology, 11: 1788-1797.

Juottonen, H., Hynninen, A., Nieminen, M., Tuomivirta, T., Tuittila, E.-S., Nousiainen, H., Yrjäla, K., Tervahauta, A., & Fritze, H. 2012. Methane-cycling microbial communities and methane emission in natural and restored peatland buffer areas. Applied and Environmental Microbiology, 78: 6386-6389.

Juutinen, S., Väliranta, M., Kuutti, V., Laine, A. M., Virtanen, T., Seppä, H., Weckström, J., & Tuittila, E.-S. 2013. Short-ter and long-term carbon dynamics in a northern peatland-stream-lake continuoum: A catchment approach. Journal of Geophysical Research, 118: 171-183.

Kane, E.S., Turetsky, M.R., Harden, J.W., McGuire, A.D., Waddington, J.M. 2010. Seasonal ice and hydrologic controls on dissolved organic carbon and nitrogen concentrations in a boreal-rich fen. J. Geophys. Res. 115

Kasimir-Klemedtsson, Å., 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.

Kasimir Klemedtsson, Å., Weslien, P., & Klemedtsson, L. 2009. Methane and nitrous oxide fluxes from a farmed Swedish Histosol. European Journal of Soil Science, 60(3): 321-331.

Kivimäki, S. K., Yli-Petäys, M., & Tuittila, E.-S. 2008. Carbon sink function of a sidge and Sphagnum patches in a restored cut-away peatland: increased functional diversity leads to higher production. Journal of Applied Ecology, 45: 921-292.

Klemedtsson, L., Ernfors, M., Björk, R. G., Weslien, P., Rütting, T., Crill, P., & Sikström, U. 2010. Reduction of greenhouse gas emissions by wood ash application to a Picea abies (L.) Karst. forest on a drained organic soil. European Journal of Soil Science, 61(5): 734-744.

Klemedtsson, L., Von Arnold, K., Weslien, P., & Gundersen, P. 2005. Soil CN ratio as a scalar parameter to predict nitrous oxide emissions. Global Change Biology, 11(7): 1142-1147.

Kløve, B., Sveistrup, T. E., & Hauge, A. 2010. Leaching of nutrients and emission of greenhouse gases from peatland cultivation at Bodin, Northern Norway. Geoderma, 154(3–4): 219-232.

Koehler, A.-K., Murphy, J., Kiely, G., & Sottocornola, M. 2009. Seasonal variation of DOC concentration and annual loss of DOC from an Atlantic blanket bog in South Western Ireland. Biogeochemistry, 95: 231-242.

Koehler, A.-K., Sottocornola, M., & Kiely, G. 2011. How strong is the current carbon sequestration of an Atlantic blanket bog? Global Change Biology, 17(1): 309-319.

Kolka, R. K., Grigal, D. F., Verry, E. S., & Nater, E. A. 1999. Mercury and organic carbon relationships in streams draining forested upland peatland watersheds. J. Environmental Quality, 28(766-775).

Komulainen, V.-M., Nykänen, H., Martikainen, P. J., & Laine, J. 1998. Short-term effect of restoration on vegetation change and methane emissions from peatlands drained for forestry in southern Finland. Canadian Journal of Forest Research, 28(3): 402-411.

Komulainen, V.-M., Tuittila, E.-S., Vasander, H., & Laine, J. 1999. Restoration of drained peatlands in southern Finland: initial effects on vegetation change and CO2 balance. Journal of Applied Ecology, 36(5): 634-648.

Koprivnjak, J.-F., & Moore, T. R. 1992. Sources, sinks and fluxes of dissolved organic carbon in subarctic fen catchments. Arctic and Alpine Research, 24: 204-210.

Kortelainen, P., Mattsson, T., Finer, L., Ahtiainen, M., Saukkonen, S., & Sallantaus, T. 2006. Controls on the export of C, N, P, and Fe from undisturbed boreal catchments, Finland. Aquat. Sci., 68(453-468).

Kreshtapova, V. N., & Maslov, B. S. 2004. Contents of carbon compounds in reclaimed peat soils as a function of the propertieso of peat organic matter. , Proc of 12th Peat Cong., Vol. 2: 988-992. Tampere.

Kroon, P. S., Schrier-Uijl, A. P., Hensen, A., Veenendaal, E. M., & Jonker, H. J. J. 2010. Annual balances of CH4 and N2O from a managed fen meadow using eddy covariance flux measurements. European Journal of Soil Science, 61(5): 773-784.

Kuntze, H. 1992. Peat losses by liming and fertilization of peatlands used as Grassland, Proc of 9th Peat Congress, Vol. 2.

Kurbatova, J., Li, C., Tataronov, F., Varlagin, A., Shalukhina, N., & Olchev, A. 2009. modeling of the carbon dioxide fluxes in European Russia peat bogs. Environmental Research Letters, 4(045022).

Lafleur, P. M., Roulet, N. T., & Admiral, S. W. 2001. Annual cycle of CO2 exchange at a bog peatland. Journal of Geophysical Research, 106(D3): 3071-3081.

Laine, J., Minkkinen, K., Sinisalo, J., Savolainen, I., & Martikainen, P. J. 1996. Greenhouse Impact of a mire after drainage for Forestry. In C. C. Trettin, M. F. Jurgensen, D. F. Grigal, M. R. Gale, & J. K. Jeglum (Eds.), Northern Forested Wetlands, Ecology and Management: 437-447. USA: CRC Lewis Publishers.

Langeveld, C. A., Segers, R., Dirks, B. O. M., van den Pol-van Dasselaar, A., Velthof, G. L., & Hensen, A. 1997. Emissions of CO2, CH4 and N2O from pasture on drained peat soils in the Netherlands. European Journal of Agronomy, 7(1–3): 35-42.

Laurila, T., Lohila, A., Aurela, M., Tuovinen, J. P., Thum, T., Aro, L., Laine, J., Penttilä, T., Minkkinen, K., Riutta, T., Rinne, J., Pihlatie, M., & Vesala, T. 2007. Ecosystem-level carbon sink measurements on forested peatlands. In S. Sarkkola (Ed.), Greenhouse Impacts of the Use of Peat and Peatlands in Finland: 38-40: Ministry of Agriculture and Forestry 11a 2007

Leifeld, J., Müller, M., & Fuhrer, J. 2011. Peatland subsidence and carbon loss from drained temperate fens. Soil Use and Management, 27(2): 170-176.

Lloyd, J., & Taylor, J. A. 1994. On the Temperature Dependence of Soil Respiration. Functional Ecology, 8(3): 315-323.

Lohila, A., Aurela, M., Tuovinen, J.-P., & Laurila, T. 2004. Annual CO2 exchange of a peat field growing spring barley or perennial forage grass. Journal of Geophysical Research: Atmospheres, 109(D18): D18116.

Lohila, A., Laurila, T., Aro, L., Aurela, M., Tuovinen, J. P., Laine, J., Kolari, P., & Minkkinen, K. 2007. Carbon dioxide exchange above a 30-year-old Scots pine plantation established on organic-soil cropland. Helsinski, FINLANDE: Finnish Environment Institute.

Lohila, A., Minkkinen, K., Aurela, M., Tuovinen, J. P., Penttilä, T., Ojanen, P., & Laurila, T. 2011. Greenhouse gas flux measurements in a forestry-drained peatland indicate a large carbon sink. Biogeosciences, 8(11): 3203-3218.

Lorenz, W. D., Sauerbrey, R., Eschner, D., Lehrkamp, H., & Zeitz, J. 1992. Zustand der landwirtschaftlich genutzen Niedermoore in der ehemaligen DDR. Wasser und Boden, 44: 58-61.

Lucci, G. 2007. Element balances and retention for wetlands in the forest environment – case study Bohyttan fen. MSc thesis. Department of Forest Soils, SLU. Report 17. Uppsala. 38pp.

Lund, M., Lindroth, A., Christensen, T. R., & Ström, L. 2007. Annual CO2 balance of a temperate bog. Tellus, 59(5): 804-811.

Lundin, L. 1988. Impacts of drainage for forestry on runoff and water chemistry. Proceedings of the international symposium.on the hydrology of wetlands in temperate and cold regions. Joensuu, Finland 6-8 June 1988. Academy of Finland. Vol. 1. 197-205.

Lundin, L. 1996. Effects of peat-winning on the water environment at a sedge fen ecosystem. Proceedings from the 10th International Peat Congress, 27 May - 2 June, Bremen, Germany. Vol. 2, 426-432.

Lundin, L., & Bergquist, B. 1990. Effects on water chemistry after drainage of a bog for forestry. Hydrobiologia 196:167-181.

Maanavilja, L., Riutta, T., Aurela, M., Pulkkinen, M., Laurila, T., & Tuittila, E.-S. 2011. Spatial variation in CO2 exchange at a northern aapa mire. Biogeochemistry, 104: 325-345.

Maljanen, M., Hytönen, J., & Martikainen, P. 2001a. Fluxes of N2O, CH4 and CO2 on afforested boreal agricultural soils. Plant and Soil, 231(1): 113-121.

Maljanen, M., Hytönen, J., & Martikainen, P. J. 2010a. Cold-season nitrous oxide dynamics in a drained boreal peatland differ depending on land-use practice. Canadian Journal of Forest Research, 40(3): 565-572.

Maljanen, M., Hytönen, J., Mäkiranta, P., Alm, J., Minkkinen, K., Laine, J., & Martikainen, P. J. 2007. Greenhouse gas emissions from cultivated and abandoned organic croplands in Finland. Helsinski, FINLAND: Finnish Environment Institute.

Maljanen, M., Jokinen, H., Saari, A., Strömmer, R., & Martikainen, P. J. 2006a. Methane and nitrous oxide fluxes, and carbon dioxide production in boreal forest soil fertilized with wood ash and nitrogen. Soil Use and Management, 22(2): 151-157.

Maljanen, M., Komulainen, V. M., Hytönen, J., Martikainen, P. J., & Laine, J. 2004. Carbon dioxide, nitrous oxide and methane dynamics in boreal organic agricultural soils with different soil characteristics. Soil Biology and Biochemistry, 36(11): 1801-1808.

Maljanen, M., Liikanen, A., Silvola, J., & Martikainen, P. J. 2003a. Methane fluxes on agricultural and forested boreal organic soils. Soil Use and Management, 19(1): 73-79.

Maljanen, M., Liikanen, A., Silvola, J., & Martikainen, P. J. 2003b. Nitrous oxide emissions from boreal organic soil under different land-use. Soil Biology and Biochemistry, 35(5): 689-700.

Maljanen, M., Martikainen, P. J., Walden, J., & Silvola, J. 2001b. CO2 exchange in an organic field growing barley or grass in eastern Finland. Global Change Biology, 7(6): 679-692.

Maljanen, M., Nykänen, H., Moilanen, M., & Martikainen, P. J. 2006b. Greenhouse gas fluxes of coniferous forest floors as affected by wood ash addition. Forest Ecology and Management, 237(1–3): 143-149.

Maljanen, M., Shurpali, N., Hytönen, J., Mäkiranta, P., Aro, L., Potila, H., Laine, J., Li, C., & Martikainen, P. 2012. Afforestation does not necessarily reduce nitrous oxide emissions from managed boreal peat soils. Biogeochemistry, 108(1-3): 199-218.

Maljanen, M., Sigurdsson, B. D., Guðmundsson, J., Óskarsson, H., Huttunen, J. T., & Martikainen, P. J. 2010b. Greenhouse gas balances of managed peatlands in the Nordic countries – present knowledge and gaps. Biogeosciences, 7(9): 2711-2738.

Maljanen, M., Virkajärvi, P., Hytönen, J., Öquist, M., Sparrman, T., & Martikainen, P. J. 2009. Nitrous oxide production in boreal soils with variable organic matter content at low temperature – snow manipulation experiment. Biogeosciences Discuss., 6(3): 5305-5337.

Martikainen, P., Nykänen, H., Alm, J., & Silvola, J. 1995a. Change in fluxes of carbon dioxide, methane and nitrous oxide due to forest drainage of mire sites of different trophy. Plant and Soil, 168-169(1): 571-577.

Martikainen, P. J., Nykanen, H., Crill, P., & Silvola, J. 1993. Effect of a lowered water table on nitrous oxide fluxes from northern peatlands. Nature, 366(6450): 51-53.

Martikainen, P. J., Nykänen, H., Crill, P., & Silvola, J. 1992. The effect of changing water table on methane fluxes at two Finnish mire sites. Sou, 43: 237-240.

Martikainen, P. J., Nykänen, H., Regina, K., Lehtonen, M., & Silvola, J. 1995b. Methane fluxes in a drained and forested peatland treated with different nitrogen compounds in: Northern Petalands in Blobal Climatic Change. Paper presented at the Proceedings of the International Workshop Held in Hyytiälä, Helsinki, Finland.

McNamara, N. P. 2013. CH4 emissions from ditches in a drained lowland peat Grassland, Somerset, UK, Emnissions of greenhouse gases asociated with peatland drainage waters: Report to Defra under porject SP1205: Greenhouse Gas Emisisons Associated with NOn Gaseous Losses of Carbon from Peatlands - fate of Particulate and Dissolved Carbon. Report to the Department of Environment: Food and Rural Affairs, UK.

McNeal, P. and Waddington, J.M. 2003. Moisture controls on Sphagnum growth and CO2 exchange on a cutover bog. Journal of Applied Ecology, 40: 354-367

Meyer, K., Höper, H., & Blankenburg, J. 2001. Spurengashaushalt und Klimabilanz von Niedermooren unter dem Einflus des Vernässungmanagements. In R. Kratz, & J. Pfadenhauer (Eds.), Ökosystemmanagement für Niedermoore. Strategien und Verfahren zur Renaturierung: 104-111. Stuttgart: Ulmer.

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.

Minkkinen, K., & Laine, J. 2006. Vegetation heterogeneity and ditches create spatial variability in methane fluxes from peatlands drained for forestry. Plant and Soil, 285(1-2): 289-304.

Minkkinen, K., Laine, J., Shurpali, N. J., Mäkiranta, P., Alm, J., & T., P. 2007a. Heterotrophic soil respiration in forestry-drained peatlands. Helsinski, FINLANDE: Finnish Environment Institute.

Minkkinen, K., Penttilä, T., & Laine, J. 2007b. Tree stand volume as a scalar for methane fluxes in forestry-drained peatlands in Finlans. Boreal Environment Research, 12(2): 127-132.

Minkkinen, K., Vasander, H., Jauhiainen, S., Karsisto, M., & Laine, J. 1999. Post-drainage changes in vegetation composition anc carbon balance in Lakkasuo mire, Central Finland. Plant and Soil, 207: 107-120.

Moore, T. R., & Knowles, R. 1990. Methane emissions from fen, bog and swamp peatlands in Quebec. Biogeochemistry, 11(1): 45-61.

Moore, T. R., Matos, L., & Roulet, N. T. 2003. Dynamics and chemistry if dissolved organic carbon in Precambrian Sheild catchments and an impounded wetland. Can. J. Fish. Aquat. Sci., 60: 612-623.

Morrison, R., Cumming, A., Taft, H., Page, S., Kaduk, J., Harding, R., Jones, D., & Balzer, H. 2013. Carbon dioxide budget of a drained and intensively cultivated lowland fen in the East Anglian Fens. , Emissions of greenhouse gases from UK managed lowland peatlands: Repot to Defra under project SP1210: Lowland petland systems in England and Wales - evaluating greenhouse gas fluxes and carbon balances.

Mäkiranta, P., Hytönen, J., Aro, L., Maljanen, M., Pihlatie, M., Potila, H., Shurpali, N., Laine, J., Lohila, A., Martikainen, P. J., & Minkkinen, K. 2007. Soil greenhouse gas emissions from emissions from afforested organic soil croplands and peat extraction peatlands. Boreal Environment Research, 12: 159-175.

Nagata, O., Takakai, F., & Hatano, R. 2005. Effect of sasa invation on global warming potential in sphagnum dominated poor fen in Bibai, Japan. Phyton, 45(4): 299-307.

Nieveen, J. P., Campbell, D. I., Schipper, L. A., & Blair, I. J. 2005. Carbon exchange of grazed pasture on a drained peat soil. Global Change Biology, 11(4): 607-618.

Nilsson, M., Mikkelä, C., Sundh, I., Granberg, G., Svensson, B.H., Ranneby, B. 2001. Methane emission from Swedish mires: National and regional budgets and dependence on mire vegetation. Journal of Geophysical Reasearc 106: 20,847-20,860

Nilsson, M., Sagerfors, J., Buffam, I., Luadon, H., Eriksoon, T., Grelle, A., Klemedtsson, L., Weslien, P., & Lindroth, A. 2008. Contemporary carbon accumulation in a boreal oligotrophic minerogenic mire - a significatn sink after accounting for all C-fluxes. Global Change Biology, 14: 2317-2332.

Nykänen, H., Alm, J., Lang, K., Silvola, J., & Martikainen, P. J. 1995. Emissions of CH4, N2O and CO2 from a Virgin Fen and a Fen Drained for Grassland in Finland. Journal of Biogeography, 22(2/3): 351-357.

Nykänen , H., Silvola, J., Alm, J., and Martikainen, P.J. 1996. Fluxes of greenhouse gases CH4, CO2 and N2O on some peat minig areas in Finland, in: Northern Peatlands in Global Climatic Change, edited by: Laiho, R., Laine, J. and Vasander, H., Proceedings of the International Workshop held in Hyytiälä. Finland. Publication of the Academy of Finland, Helsinki 1/96, 141-147

Nykänen, H., Alm, J., Silvola, J., Tolonen, K., & Martikainen, P. J. 1998. Methane fluxes on boreal peatlands of different fertility and the effect of long-term experimental lowering of the water table on flux rates. Global Biogeochemical Cycles, 12(1): 53-69.

Nykänen, H., Heikkinen, J. E. P., Pirinen, L., Tiilikainen, K., & Martikainen, P. 2003. Annual CO2 exchange and CH4 fluxes on a subarctic palsa mire during climatically different years. Global Biogeochemical Cycles, 17(1): 1018.

O'Brien, H. E., Labadz, J. C., & Butcher, D. P. 2008. The role of blanket peat moorland management in the generation and amelioration of discolouration of surface water supplies. Nottingham Trent University.

Ojanen, P., Minkkinen, K., Alm, J., & Penttilä, T. 2010. Soil–atmosphere CO2, CH4 and N2O fluxes in boreal forestry-drained peatlands. Forest Ecology and Management, 260(3): 411-421.

Ojanen, P., Minkkinen, K., & Penttilä, T. 2013. The current greenhouse gas impact of forestry-drained boreal peatlands. Forest Ecology and Management, 289(0): 201-208.

Okruszko, H. 1989. Wirkung der Bodennutzung auf die Niedermoorentwicklung.Ergebnisse eines längjähringen Feldversuches. Z f Kulturtechnik und Landentwicklung, 30: 167-176.

Pearson, M., Saarinen, M., Minkkinen, K., Silvan, N., & Laine, J. 2012. Short-term impacts of soil preparation on greenhouse gas fluxes: A case study in nutrient-poor, clearcut peatland forest. Forest Ecology and Management, 283(0): 10-26.

Petersen, S. O., Hoffmann, C. C., Schäfer, C. M., Blicher-Mathiesen, G., Elsgaard, L., Kristensen, K., Larsen, S. E., Torp, S. B., & Greve, M. H. 2012. Annual emissions of CH4 and N2O, and ecosystem respiration, from eight organic soils in Western Denmark managed by agriculture. Biogeosciences, 9(1): 403-422.

Petrone, R. M., Waddington, J. M., & Price, J. S. 2003. Ecosystem-scale flux of CO2 from a restored vacuum harvested peatland. Wetlands Ecology and Management, 11: 419-432.

Pihlatie, M., Rinne, J., Lohila, A., Laurila, T., Aro, L., & Vesala, T. 2004. Nitrous oxide emissions from an afforested peat field using eddy covariance and enclosure techniques. In P. e. al. (Ed.), Proceedings of 12th International Peat Congress, Vol. 2: 1010-1014. Tampere, Finland.

Rantakari, M., Mattsson, T., Kortelainen, P., Poorainen, S., Finer, L., & Ahtiainen, M. 2010. Organic and inorganic carbon concentrations anf fluxes from managed and unmanaged boreal first-order catchments. Sci.Total Environ., 408: 1649-1658.

Regina, K., Nykänen, H., Maljanen, M., Silvola, J., & Martikainen, P. J. 1998. Emissions of N2O and NO and net nitrogen mineralization in a boreal forested peatland treated with different nitrogen compounds. Canadian Journal of Forest Research, 28(1): 132-140.

Regina, K., Nykänen, H., Silvola, J., & Martikainen, P. 1996. Fluxes of nitrous oxide from boreal peatlands as affected by peatland type, water table level and nitrification capacity. Biogeochemistry, 35(3): 401-418.

Regina, K., Pihlatie, M., Esala, M., & Alakukku, L. 2007. Methane fluxes on boreal arable soils. Agriculture, Ecosystems & Environment, 119(3–4): 346-352.

Regina, K., Syväsalo, E., Hannukkala, A., & Esala, M. 2004. Fluxes of N2O from farmed peat soils in Finland. European Journal of Soil Science, 55(3): 591-599.

Riutta, T., Laine, J., Aurela, M., Rinne, J., Vesala, T., Laurila, T., Haapanala, S., Pihlatie, M., & Tuittila, E.-S. 2007. Spatial variation in plant community functions regulates carbon gas dynamics in a boreal fen ecosystem. Tellus, 59B(838-852).

Roehm, C. L., & Roulet, N. T. 2003. Seasonal contribution of CO2 fluxes in the annual C budget of a northern bog. . Global Biogeochemical Cycles, 17(1): 1029.

Roulet, N. T., & Moore, T. R. 1995. The effect of forestry drainage practices on the emission of methane from northern peatlands. Canadian Journal of Forest Research, 25(3): 491-499.

Roulet, N. T., Lafleur, P. M., Richard, P. J. H., Moore, T. R., Humphreys, E. R., & Bubier, J. 2007. Contemporary carbon balance and late Holocene carbon accumulation in a northern peatland Global Change Biology, 13: 397-411.

Saari, P., Saarnio, S., Kukkonen, J. K., Akkanen, J., Heinonen, J., Saari, V., & Alm, J. 2009. DOC and N2O dynamics in upland and peatland forest soils after clear-cutting and soil preparation. Biogeochemistry, 94(3): 217-231.

Sagerfors, J., Lindroth, A., Grelle, A., Klemedtsson, L., Weslien, P., & Nilsson, M. 2008. Annual CO2 exchange between a nutrient-poor, minerotrophic, boreal mire and the atmosphere. Journal of Geophysical Research, 113(G1).

Schothorst, C. J. 1977. Subsidence of low moor peat soils in the Western Netherlands, Proc of 5th Int Peat Congress, Vol. 1: 206-217. Poznan.

Schrier-Uijl, A., Kroon, P., Leffelaar, P., Huissteden, J. C., Berendse, F., & Veenendaal, E. 2010a. Methane emissions in two drained peat agro-ecosystems with high and low agricultural intensity. Plant and Soil, 329(1-2): 509-520.

Schrier-Uijl, A. P., Kroon, P. S., Hensen, A., Leffelaar, P. A., Berendse, F., & Veenendaal, E. M. 2010b. Comparison of chamber and eddy covariance-based CO2 and CH4 emission estimates in a heterogeneous grass ecosystem on peat. Agricultural and Forest Meteorology, 150(6): 825-831.

Schrier-Uijl, A. P., Veraart, A. J., Leffelaar, P. A., Berendse, F., & Veenendaal, E. M. 2011. Release of CO2 and CH4 from lakes and drainage ditches in temperate wetlands. Biogeochemistry, 102(1-3): 265-279.

Schulze, E. D., Prokuschkin, A., Arneth, A., Knorre, N., & Vaganov, E. A. 2002. Net ecosystem productivity and peat accumulation an a Siberian Aapa mire. Tellus, 54B(531-536).

Scottish Executive. 2007. Ecosse - Estimating Cargon in Prganic Soil, Sequestration and emissions. In S. Executive (Ed.): http://www.scotland.gov.uk/Publications/2007/2003/16170508. Edinburgh.

Shannon, R. D., & White, J. R. 1994. A three-year study of controls on methane emissions from two Michigan peatlands. Biogeochemistry, 27: 40-46.

Shurpali, N. J., Verma, S. B., Kim, J., & Arkebauer, T. J. 1995. Carbon dioxide exchange in a peatland ecosystem. Journal of Geophysical Research, 100(D7): 14319-14326.

Shurpali, N. J., Hyvönen, N., Huttunen, J.T., Biasi, C., Nykänen, J. Pekkarinen, N. and Martikainen, P.J. 2008. Bare soil and reed canary grass ecosystem respiration in peat extraction sites in Eastern Finland, Tellus 60B, 200-209

Shurpali, N. J., HyvÖNen, N. P., Huttunen, J. T., Clement, R. J., Reichstein, M., NykÄNen, H., Biasi, C., & Martikainen, P. J. 2009. Cultivation of a perennial grass for bioenergy on a boreal organic soil – carbon sink or source? GCB Bioenergy, 1(1): 35-50.

Sikström, U., Björk, R. G., Ring, E., Ernfors, M., Jacobson, S., Nilsson, M., & Klemedtsson, L. 2009. Addition of ash on drained forested peatlands in southern Sweden - Effects on forest production, fluxes of greenhouse gases and water chemistry. Stockholm.

Sikström, U., Ernfors, M., Jacobson, S., Klemedtsson, L., Nilsson, M., & Ring, E. 2006. Addition of ash on drained forested peatlands in southern Sweden - Effects on forest production, fluxes of greenhouse gases and water chemistry. Stockholm.

Simola, H., Pitkänen, A., & Turunen, J. 2012. Carbon loss in drained forestry peatlands in Finland, Estimated by re-sampling peatlands surveyed in the 1980s. European Journal of Soil Science, 63: 798-807.

Soegarard, H., & Nordstroem, C. 1999. Carbon dioxide exchange in a high-arctic fen estimated by eddy covariance measurements and modelling. Global Change Biology, 5(5): 547-562.

Soini, P., Riutta, T., Yli-Petäys, M., & Vasander, H. 2010. Comparison of vegetation and CO2 dynamics between a restored cut-away peatland and a pristine fen: evaluation of the restoration success. Restoring Ecology, 18(6): 894-903.

Sommer, M., Fiedler, S., Glatzel, S., & Kleber, M. 2003. First estimates of regional (Allgäu, Germany) and global CH4 fluxes from wet colluvial margins of closed depressions in glacial drift areas. Agriculture Ecosystems and Environment, 103: 251-257.

Strack, M., Waddington, J. M., Bourbonniere, R. A., Buckton, L., Shaw, K., Whittington, P., & Price, J. S. 2008. Effect of water table drawdown on peatland dissolved organic carbon exports and dynamics. Hydrol. Process., 22: 3373-3385.

Strack, M., & Zuback, Y. C. A. 2013. Annual carbon balance of a peatland 10 yr following restoration. Biogeosciences, 10: 2885-2896.

Ståhlberg, D., Karltun, E., Jacobson, A., & Lennartsson, T. 2010. inlagring av kol i betesmark (in Swedish), Rapport 2010:25: 28: Jordbruksverket.

Sundh, I., Nilsson, M., Mikkelä, V., Granberg, G. and Svensson, B.H. 2000. Fluxes of methane and carbon dioxide on peat-mining ares in Sweden, Ambio, 29: 499-503

Suyker, A. E., Verma, S. B., & Arkebauer, T. J. 1997. Season.long measurement of carbon dioxide exchange in a boreal fen. Journal of Geophysical Research, 102(D24): 29021-29028.

Swedish Environmental Protection Agency. 2013. National Inventory Report 2013 Sweden.

Taft, H., Cross, P., & Jones, D. 2013. Annual emission cycle of greenhouse gases from peat soils managd for horticultural production Emissions of greenhouse gases from UL managed lowland petlands: Report to Defra under project SP1210: Lowland petland systems in England and Wales - evaluating greenhouse gas fluxces and carbon balances.

Tauchnitz, N., Brumme, R., Bernsdorf, S., & Meissner, R. 2008. Nitrous oxide and methane fluxes of a pristine slope mire in the German National Park Harz Mountains. Plant and Soil, 303: 131-138.

Teh, Y., Silver, W., Sonnentag, O., Detto, M., Kelly, M., & Baldocchi, D. 2011. Large Greenhouse Gas Emissions from a Temperate Peatland Pasture. Ecosystems, 14(2): 311-325.

Tuittila, E.-S., and Komulainen, V. M. 1995. Vegetation and CO_2 balance in an abandoned harvested peatland in Aitoneva, southern Finland, Suo, 46, 69-80

Tuittila, E.-S., Komulainen, V. M., Vasander, H., & Laine, J. 1999. Restored cut-away peatland as a sink for atmospheric CO2. Oecologica, 120: 563-574.

Tuittila, E.-S., Komulainen, V. M., Vasander, H., Nykänen, H., Martikainen, P., & Laine, J. 2000. Methane dynamics of a restored cut-away peatland. Global Change Biology, 6(569-581).

Tuittila, E.-S., Vasander, H. and Laine, J. 2004. Sensitivity of C Sequestration in Reintroduced Sphagnum to Water-Level Variation in a Cutaway Peatland. Restoration Ecology, 12, 483-493

Turner, E. K., Worrall, F., & Burt, T. P. 2013. The effect of drain blocking on the dissloved organic carbon (DOC) budget of an upland catchment in the UK. Journal of Hydrology, 479: 169-179.

Urban, N. R., Bayley, S. E., & Eisenreich, S. J. 1989. Export of dissolved organic carbon and acidity from peatlands. Water Resour. Res., 25: 1619-1628.

Urbanová, Z., Picek, T., Hájek, T., Bufková, I., & Tuittila, E.-S. 2012. Impact of drainage and restoration on vegetation and carbon gas dynamics in Central European peatlands. Plant Ecology and Diversity, In press.

van Beek, C. L., Pleijter, M., Jacobs, C. M. J., Velthof, G. L., Groenigen, J. W., & Kuikman, P. J. 2010. Emissions of N2O from fertilized and grazed grassland on organic soil in relation to groundwater level. Nutrient Cycling in Agroecosystems, 86(3): 331-340.

Van den Bos, R. M. 2003. Restoration of former wetlands in the Netherlands; effect on the balance between CO2 sink and CH4 sources. Netherlands Journal of Geosciences, 82: 325-332.

Van den Pol- van Dasselaar, A., Beusichem, M., & Oenema, O. 1999. Methane emissions from wet grasslands on peat soil in a nature preserve. Biogeochemistry, 44(2): 205-220.

Van den Pol-van Dasselaar, A. 1998. Methane emissions from Grassland. Unpublished PhD Thesis, Wageningen Agricultural University, Wageningen.

Veenendaal, E. M., Kolle, O., Leffelaar, P. A., Schrier-Uijl, A. P., Van Huissteden, J., Van Walsem, J., Moller, F., & Berendse, F. 2007. CO2 exchange and carbon balanve in two grassland sites on eutrophic drained peat soils. Biogeosciences, 4: 1027-1040.

Velthof, G. L., Brader, A. B., & Oenema, O. 1996. Seasonal variations in nitrous oxide losses from managed grasslands in The Netherlands. Plant and Soil, 181(2): 263-274.

Vermaat, J., Hellmann, F., Dias, A. C., Hoorens, B., Logtestijn, R. P., & Aerts, R. 2011. Greenhouse Gas Fluxes from Dutch Peatland Water Bodies: Importance of the Surrounding Landscape. Wetlands, 31(3): 493-498.

Verma, S. B., Ullman, F. G., Billesbach, D., Clement, R. J., Kim, J., & Verry, E. S. 1992. Eddy correlation measurements of methane flux in a northern peatland ecosystem. Boundary Layer Meteorology, 58: 289-304.

von Arnold, K., Hånell, B., Stendahl, J., & Klemedtsson, L. 2005a. Greenhouse gas fluxes from drained organic forestland in Sweden. Scandinavian Journal of Forest Research, 20(5): 400-411.

von Arnold, K., Nilsson, M., Hånell, B., Weslien, P., & Klemedtsson, L. 2005b. Fluxes of CO2, CH4 and N2O from drained organic soils in deciduous forests. Soil Biology and Biochemistry, 37(6): 1059-1071.

von Arnold, K., Weslien, P., Nilsson, M., Svensson, B. H., & Klemedtsson, L. 2005c. Fluxes of CO2, CH4 and N2O from drained coniferous forests on organic soils. Forest Ecology and Management, 210(1–3): 239-254.

Waddington, J. M., & Price, J. S. 2000. Effect of peatland drainage, harvesting and restoration on atmosphereic water anc carbon exchange. Physical Geography, 21(5): 433-451.

Waddington, J. M., & Roulet, N. T. 2000. Carbon balance of a boreal patterned peatland. Global Change Biology, 6(1): 87-97.

Waddington, J.M. & Day, S.M. 2007. Methane emissions from a peatland following restoration. Journal of Geophysical Research. 112

Waddington, J. M., Strack, M., & Greenwood, M. J. 2010. Toward restoring the net carbon sink function of degraded peatlands: Short-term response in CO2 exchange to ecosyuste-scale restoration. Journal of Geophysical Research, 115(G01008).

Waddington, J. M., Tóth, J., & Bourbonniere, R. A. 2008. Dissolved organic carbon export from a cutover and restored peatland. Hydro. Process., 22(2215-2224).

Weinzierl, W. 1997. Niedermoore in Baden-Würtemberg - Bilanzierung der CO2-Emission am Beispiel des Donaurieds. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft, 85: 1059-1062.

Weslien, P., Kasimir Klemedtsson, Å., Börjesson, G., & Klemedtsson, L. 2009. Strong pH influence on N2O and CH4 fluxes from forested organic soils. European Journal of Soil Science, 60(3): 311-320.

Whiting, G. J., & Chanton, J. P. 2001. Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration. Tellus B, 53(5): 521-528.

Wickland, K. 2001. Carbon gas exchange at a southern Rocky Mountain wetland, 1996-1998. Global Biogeochemical Cycles, 15(2): 321-335.

Wild, U., Kamp, T., Lenz, A., Heinz, S., & Pfadenhauer, J. 2001. Cultivation of Typha spp. in constructed wetlands for peatland restoration. Ecological Engineering, 17(1): 49-54.

Wilson, D., Alm, J., Laine, J., Byrne, K. A., Farrell, E. P., & Tuittila, E.-S. 2009. Rewetting of cutaway peatlands: Are we re-creating hotspots for methane emissions? Restoring Ecology, 17(6): 796-806.

Wilson, D., Farrell, E. P., Muller, C., Hepp, S., & Renou-Wilson, F. 2013. Rewetted industrial cutaway peatlands in western Ireland: primpe location for climate change mitigation? Mires and Peat, 11: 1-22.

Wilson, D., Tuittila, E.-S., Alm, J., Laine, J., Farrell, E. P., & Byrne, K. A. 2007. Carbon dioxide dynamics of a restored maritime peatland. Ecoscience, 14(1): 71-80.

Yamulki, S., Anderson, R., Peace, A., & Morison, J. I. L. 2013. Soil CO2 CH4 and N2O fluxes from an afforested lowland raised peatbog in Scotland: implications for drainage and restoration. Biogeosciences, 10(2): 1051-1065.

Yli-Petäys, M., Laine, J., Vasander, H., & Tuittila, E.-S. 2007. Carbon gas exchange of a re-vegetated cut-away peatland five decades after abandonment. Boreal Environment Research, 12: 177-190.

I denna serie publiceras forsknings- och försöksresultat från institutionen för mark och miljö vid Sveriges lantbruksuniversitet.

In this series research results from the department of Soil and Environment at the Swedish University of Agricultural Sciences are reported.

Sveriges lantbruksuniversitet
Institutionen för mark och miljö

Swedish University of Agricultural Sciences
Department of Soil and Environment

Box 7014
SE-750 07 Uppsala
http://www.slu.se/mark