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Soil carbon effluxes in ecosystems of Forsmark and Laxemar

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Abstract

Soil carbon effluxes were estimated in a number of ecosystems in Laxemar and Forsmark investigations areas. It was done in a young Scots pine (*Pinus sylvestris*) stand, a wet deciduous stand, a poor fen and an agricultural field in the Laxemar investigation area in south-eastern Sweden (57°5'N, 16°7'E) and in a pasture, two Norway spruce (*Picea abies*) stands, a deciduous forest, a mire, a wet deciduous forest and a clear-cut in the Forsmark investigation area (60°4'N, 18°2'E). It was measured with the closed chamber technique in 2005 and 2006. Soil temperature at 10 cm depth, air temperature and photosynthetically active radiation (PAR) were also measured. Exponential regressions with soil respiration against air and soil temperature were used to estimate annual soil respiration. A hyperbolic curve with Gross Primary Production (GPP) against PAR was used for modelling GPP for the growing season in the poor fen and the agricultural area of Laxemar. The exponential regressions with soil respiration against air and soil temperature explained on average 33.6% and 44.0% of the variation, respectively. GPP of the ground vegetation were reducing soil carbon effluxes, in all stands but one of the spruce stands, the deciduous forest, the mire and the wet deciduous forest of Forsmark. The significant (all but spruce 2 in Forsmark) curves with GPP against PAR explained on average 22.7% of the variation in GPP. The cubic regressions with GPP against air temperature were only significant for the poor fen and the agricultural field in Laxemar and it explained on average 34.8% of the variation in GPP for these ecosystems. The exponential regressions with air and soil temperature against soil respiration could be used to temporally extrapolate the occasional field measurements. The hyperbolic curve with GPP against PAR could also be used for temporal extrapolation of GPP for the ecosystems without a tree layer, i.e. the poor fen and the agricultural field in Laxemar. Annual soil respirations for the ecosystems were estimated to between 0.34 and 1.30 kg $Cm^{-2}y^{-1}$ using air and soil temperature, respectively. Annual GPP for the poor fen and the agricultural field was estimated to 0.70 and 0.71 kg $Cm^{-2}y^{-1}$, respectively. This gives a net ecosystem exchange for the poor fen of between –0.29 and 0.32 kg $Cm^{-2}y^{-1}$ and for the agricultural field between –0.38 and 0.00 kg $Cm^{-2}y^{-1}$.

Sammanfattning

Kolflöden i markskiktet har uppskattats för ekosystem i Laxemars undersökningsområde i nordöstra Småland (57°5'N, 16°7'E) och i Forsmarks undersökningsområde i nordöstra Uppland (60°4'N, 18°2'E). De ekosystem som undersöktes var ett tallbestånd, ett ungt tallbestånd, en våtmark med lövbestånd, ett fattigt kärr och en jordbruksmark i Laxemar. I Forsmark gjordes undersökningen i en betesmark med lövträd, två granbestånd, ett lövbestånd, en myr, en våtmark med lövskog och ett hygge. Kolflödena uppskattades med hjälp av en infrarödgasanalysator som kopplats till en plexiglaskammare vid 5 tillfällen mellan mars och oktober 2006 i Laxemar och mellan 3 och 9 tillfällen mellan maj 2005 och oktober 2006 i Forsmark. Under tiden som mätningarna pågick mättes även luft- och jordtemperatur och den del av solljuset som fotosynteserande växter tar upp (PAR). Markskiktets kolflöden delades upp i markrespirationen och i brutto primär produktionen (GPP). GPPs inverkan på markskiktets kolflöden undersöktes. De abiotiska faktorernas påverkan på både markrespirationen och GPP analyserades därefter. Exponentiella regressioner mellan markrespirationen och luft- och jordtemperatur användes tillsammans med ett temperaturdataset för att extrapolera ut markrespirationen 2005–2006. De modellerade värdena utvärderades sedan gentemot de fältmätta värdena. För det ekosystem där GPP påverkade markskiktets kolflöden och där det inte fanns ett täckande krontak användes en ljusresponskurva med GPP mot PAR för att extrapolera ut GPP över växtsäsongen 2006. Även denna modell utvärderades gentemot fältundersökningar.

Luft och jordtemperatur hade en direkt påverkan på markrespirationen för alla ekosystem och under alla säsonger i Laxemar. I Forsmark hade det en påverkan för alla ekosystem och alla säsonger bortsett från lufttemperatur i betesmarken under säsong 1 (för de olika säsongerna i Forsmark se Tabell 3-1) och för myren. Marktemperaturen i Forsmark påverkade markrespirationen i alla ekosystem utom betesmarken under säsong 1, ett av granbestånden (Spruce 2) under säsong 1 och myren. Den troligaste anledningen till att det inte påverkade i dessa undersökningar var att för få data var uppmätta. I genomsnitt förklarade de exponentiella regressionerna markrespirationen bra, lufttemperaturen förklarade i genomsnitt 45,8 % av variationen i markrespiration medan jordtemperaturen förklarade 61,6 % i Laxemar. I Forsmark var motsvarande siffror 35,8 % och 37,0 %.

Utvärderingena av den modellerade markrespirationen visade på att de exponentiella regressionerna gav rimliga värden på markrespirationen. Med lufttemperaturen modellerades den årliga markrespirationen fram till mellan 0,34 kg Cm^{-2} och år för lövbeståndet till 0,84 kg Cm^{-2} och år för hygget i Forsmark. I Laxemar modellerades årlig markespirationen till mellan 0,34 kg Cm^{-2} och år för fattigkärret till 1,19 kg Cm^{-2} och år för unga tallbeståndet. Med jordtemperaturen modellerades markrespirationen i Forsmark fram till mellan 0,45 kg Cm^{-2} och år för våtmarken med lövbestånd till 1,09 kg Cm^{-2} och år för ett betesmarken. I Laxemar var jordtemperaturmodellerad markrespiration mellan 0,73 kg Cm^{-2} och år för våtmarken med lövbestånd till 1,30 kg Cm^{-2} och år för det unga tallbeståndet.

Den fotosynteserande markvegetationen tog upp tillräckligt mycket kol för att detta skulle vara mätbart i alla bestånd utom ett av granbestånden (spruce 1), lövbeståndet, myren och våtmarken med lövbestånd i Forsmark. Studier visar att markvegetationens fotosyntes har en påverkan på markens kolflöden emellanåt medan vid andra tillfällen är den försumbar. Fotosyntesen skiljer sig beroende på markvegetations kvantitet och struktur samt abiotiska faktorer och har härmed mer eller mindre påverkan. I Laxemar hade både temperatur och PAR en signifikant påverkan på GPP för alla ekosystem utom i det unga talbeståndet och i våtmarken med lövbestånd. I det unga tallbeståndet påverkade ingen av de båda abiotiska faktorerena GPP medans i våtmarken med lövbeståndet påverkade PAR. Ljusresponskurvan med GPP mot PAR förklarade i genomsnitt 32,7 % av variationen i GPP medan tredjegradsekvationen med GPP mot lufttemperaturen förklarade i genomsnitt 33,9 % i Laxemar. I Forsmark påverkades GPP varken av lufttemperatur eller PAR i spruce 2 medans i betesmarken hade PAR en påverkan. De signifikanta kurvorna

förklarade i genomsnitt 22,7 % av variationen i GPP för PAR medans temperaturen förklarade i genomsnitt 34,8 %.

Ljusresponskurvan med GPP mot PAR användes till att modellera GPP för fattigkärret och jordbruksmarken i Laxemar och utvärderingen av de modellerade GPP värdena gentemot fältundersökningarna visade att de modellerade värdena var rimliga. Årlig GPP modellerades till 0,70 kg Cm^{-2} och år för fattigkärret och till 0,71 kg Cm^{-2} och år för jordbruksmarken. För dessa ekosystem innebär detta att man kan beräkna nettoflödet av kol från markskiktet (NEE), och fattigkärret har årlig markNEE på mellan –0,29 kg Cm^{-2} och 0,32 kg Cm^{-2} och år. För jordbruksmarken var NEE mellan –0,38 och 0,00 kg Cm^{-2} och år. Ett negativt värde innebär en förlust av kol medans ett positivt värde innebär ett upptag.

Contents

1 Introduction

The Swedish Nuclear and Fuel Waste Management Co (SKB) has the responsibility to investigate and present detailed proposals of how the spent nuclear fuel in Sweden should be taken care of. Two sites in Sweden are investigated for a potentially deep repository of the nuclear waste, the Laxemar and the Forsmark investigation areas. In the work of siting a deep repository, extensive site investigations will precede the coming proposal. An important part of the site characterisation is the development of site descriptive models that gives an integrated description of the current state of the regions and the processes that might affect this state in the future /Lindborg 2005, 2006/. One process that is important in these site descriptive models is carbon balances.

The work of siting a deep repository also includes a safety assessment, where different types of scenarios are analysed. If a future leakage occurs, the radioactive isotopes could end up in the ecosystems above the repository. The fate of the radionuclides and their possible radiological impacts are then highly determined by ecosystem carbon balances since radioactive isotopes often follow the same pathway as stable elements vital for the vegetation /Greger 2004/. It could also be that the ecosystems are affected by the handling of the waste and the activity around the repository. To notice this possible change, it is of main importance to have knowledge about carbon balances beforehand, both for the understanding of an unaffected ecosystem and to have something to compare the damaged ecosystem with.

A vegetation map derived from remotely sensed data for Forsmark and Laxemar were used in order to identify the range of different vegetation types, /Boresjö Bronge and Wester, 2003/. From this list of vegetation types a selection were made in order to represent the most abundant and important vegetation types, in regard to potential sinks for organic matter and those that are of potential interest as human food sources. In Laxemar, the vegetation types chosen were, Norway spruce (*Picea abies*) forest, young and old Scots pine (*Pinus sylvestris*) forest, deciduous forests, pastures, agricultural field, wet forest and poor fen. In Forsmark, the sites chosen were pasture, spruce forest, deciduous forest, mire, wet forest and clear-cut.

Carbon stored in the soil can be released through soil respiration and it represents between 60 and 80% of total forest ecosystem respiration /Kelliher et al. 1999, Granier et al. 2000, Janssens et al. 2001a/ and is therefore an important part of the total carbon exchange between ecosystems and the atmosphere. Soil respiration constitutes a large part of the total ecosystem respiration, but it can be diminished by photosynthetic activity of the ground vegetation. The carbon taken up by the vegetation is gross primary production (GPP). Some studies show that the influence of ground vegetation photosynthesis can be extensive and have a large influence on soil carbon effluxes /Goulden and Crill 1997, Law et al. 1999a, Morén and Lindroth 2000, Janssens et al. 2001b, Widén 2002/ while others indicate that the uptake is negligible due to regulation of environmental factors /Baldocchi et al. 1997, Kelliher et al. 1999/.

Soil respiration is the sum of respiration from ground vegetation, roots, rhizosphere, mycorrhiza and microbes. There are many different factors that control soil respiration where temperature and sometimes moisture are the dominant factors /Lloyd and Taylor 1994, Kirschbaum 1995, Davidson et al. 2000, Morén and Lindroth 2000, Swanson and Flanagan 2001 etc/. The temperature sensitivity varies for different temperature ranges /Kirschbaum 1995/ and for the different soil respiration components (roots, microbes etc) /Boone et al. 1998, Janssens et al. 2003/. Temperature and respiration from the different components fluctuate seasonally and the temperature sensitivity differs accordingly /Rayment and Jarvis 2000, Widén 2002/. GPP is also affected by abiotic factors, where the part of the spectrum from solar radiation that is used in photosynthesis (PAR), temperature and soil moisture are the most important factors /Lambers et al. 1998/.

There have been several studies attempting to estimate soil carbon effluxes with more or less advanced models /Baldocchi et al. 1997, Fang and Moncrieff 1999, Law et al. 1999b, Rayment and Jarvis 2000, Adams et al. 2004, Novick et al. 2004/. A simple model that has been successful is to use the response of soil carbon effluxes to temperature, moisture and PAR to temporally extrapolate occasional soil carbon efflux measurements /e.g. Morén and Lindroth 2000, Widén 2002, Janssens et al. 2003, Olsrud and Christensen 2004/. This empirical approach is the most frequently used method to simulate soil carbon effluxes, because of its simplicity.

1.1 Aims

This study is a continuation of the report "Seasonal variation and controlling factors of soil carbon effluxes in six vegetation types in southeast of Sweden" /Tagesson 2006a/. In that report soil carbon effluxes and their relationships to abiotic factors for six different ecosystems in Laxemar were studied. To get a complete picture of the soil carbon effluxes of Laxemar, it was necessary to analyze additional ecosystems in the investigation area. During 2006, additional field measurements of soil carbon effluxes and their related abiotic factors in a young pine stand, an agricultural field, a wet deciduous forest and a poor fen were done /Lundkvist 2006/. In Forsmark, the same type of measurements in a pasture, two spruce stands, a deciduous forest, a mire, a wet forest and a clear-cut have also been done /Heneryd 2007/. The aim of this study is to use the relationships of abiotic factors to soil carbon effluxes to estimate annual soil respiration, GPP and when possible net ecosystem exchange (NEE).

2 Carbon balances in terrestrial ecosystems

All living tissues are composed of carbon and all life on Earth is depending on the carbon dynamic processes. Photosynthesis and respiration are together with mortality and different disturbance regimes (fire, storms, drought etc) the most important processes of the carbon cycling /Schlesinger 1997/. The main constituents of the carbon cycle are illustrated in Figure 2-1.

2.1 Gross primary production, GPP

The total uptake of carbon through photosynthesis is the gross primary production, GPP, of the vegetation. Photosynthesis is the biogeochemical process that transfers carbon from the atmosphere and its oxidized form, carbon dioxide, into the biosphere and its organic form, carbohydrates.

$6CO_2 + 6H_2O + \text{sunlight} = C_6H_{12}O_6 + 6O_2$

It is the process capturing sunlight, which provides life with energy and results in plant growth. The photosynthesis provides the atmosphere with the oxygen necessary for all animal life.

Temperature, precipitation and photosynthetically active radiation (PAR) are abiotic factors influencing primary production /Lambers et al. 1998/. High temperature gives a longer growing season increasing annual production of the ecosystems /Hasenauer et al. 1999/. A raise in temperature can have a negative effect due to a rise in evapotranspiration, which is lowering photosynthesis if water is a limiting factor /Sitch et al. 2003/. Biomass contains 80–95% water and insufficient water in the soil can be a limiting factor for biomass production /Lambers et al. 1998/. PAR and primary production has a positive relationship at low irradiance due to PAR being the limiting factor in the transport of electrons in photosynthesis /Lambers et al. 1998/. At higher PAR it is the uptake of carbon dioxide that is the limiting factor and PAR does not have any effect on GPP /Lambers et al. 1998/.

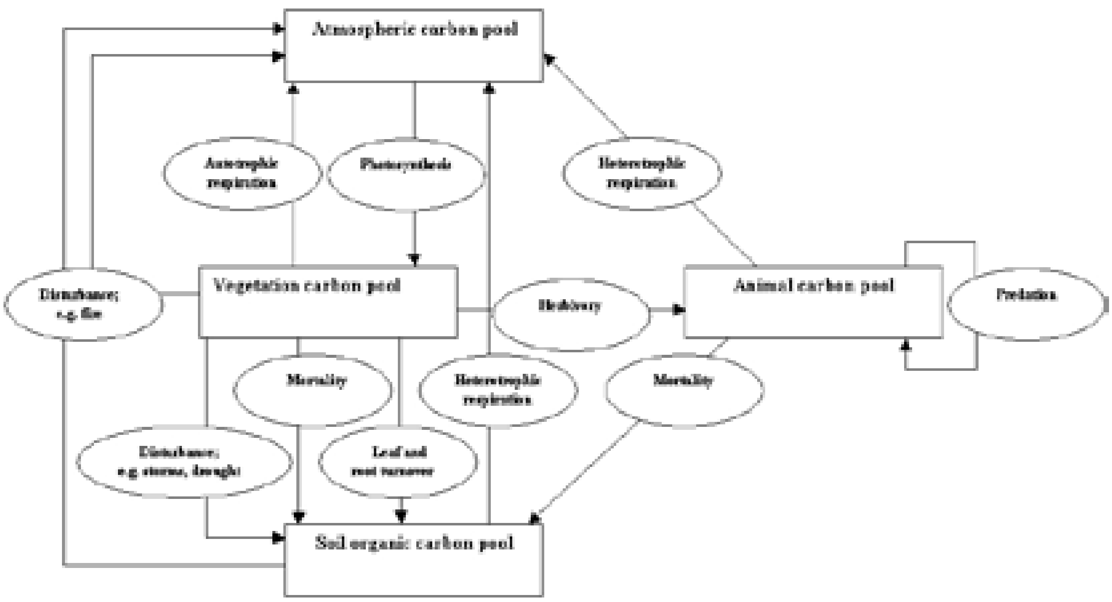


Figure 2-1. *Flowchart describing the carbon cycle in terrestrial ecosystems. Squares are carbon pools; arrows and circles are processes moving carbon between the pools.*

2.2 Respiration

Energy stored by photosynthesis is used for maintenance, growth or reproduction by living organisms. The process responsible for the breakdown of the carbohydrates is respiration.

$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O$ + energy

The plants use about half of GPP for their own maintenance /Schlesinger 1997/ and this carbon is released back to the atmosphere through autotrophic respiration, while the rest is accumulated by the plants. Parts of GPP accumulated by vegetation is consumed by herbivores and becomes a part of the animal carbon pool, this carbon is either released to the atmosphere through heterotrophic respiration or transported to the soil through mortality. The rest of the carbon taken up by plants will either be released to the atmosphere through disturbance, such as fire, or transported to the soil through mortality of the vegetation. The main part of the carbon transported to the soil is decomposed and released to the atmosphere through heterotrophic soil respiration.

Soil respiration varies as a function of soil temperature, soil moisture and chemical composition of material to be decomposed /Schlesinger 1997/. Soil respiration and soil temperature has an exponential relationship in the soil temperature range found in the field; higher soil temperature gives more soil respiration /Widén 2002/. Soil respiration and soil moisture has different relationships at different moisture ranges /Davidson et al. 2000, Janssens et al. 2003/. Soil respiration can be inhibited due to dryness and in dry soils there is a positive linear relationship. In waterlogged soils decomposition is reduced due to anaerobic conditions and there is a negative linear relationship between soil moisture and soil respiration. In between these conditions is a plateau where soil respiration is not affected by soil moisture /Heal et al. 1981/. Nitrogen and lignin content in litter will speed up respectively slow down the breakdown processes /Yao et al. 2003/. In soil organic matter there are different acids that are more or less easy to decompose /Schlesinger 1997/.

2.3 Net ecosystem exchange

Net ecosystem exchange, NEE, is here defined as all carbon fluxes added together:

$$NEE = GPP - (R_p + R_d + R_h) + F_{dist}$$

where R_p is autotrophic respiration, R_d is heterotrophic soil respiration and R_h is herbivore respiration and F_{dist} is carbon fluxes caused by disturbances.

NEE mainly constitutes of GPP and respiration and is hereby influenced by the same abiotic and biotic factors as they are. Carbon fluxes caused by disturbances can also have a major influence, e.g. fire.

3 Materials and method

3.1 Site description

The investigations took place at the Laxemar investigation area, situated 25 km north of Oskarshamn in southern Sweden (57 °5'N, 16°7'E), and at the Forsmark investigation area situated 70 km north-northeast of Uppsala in the center of Sweden (60°4'N, 18°2'E). In Laxemar, mean annual temperature in 2005 was 7.3°C with the warmest average monthly temperature of 18.6°C in July and the coldest average monthly temperature of –1.4°C in March. In Forsmark, mean annual temperature 2005 was 6.9°C with the warmest average monthly temperature of 17.7°C in July and the coldest average monthly temperature of –3.2°C in March. Annual precipitation for the same period was 435 mm for Laxemar and 437 mm for Forsmark. The growing season 2005 started the 3rd of April and ended the 14th of November in Laxemar and in Forsmark it started the 3rd of April and ended the 13th of November (threshold 5°C). Dry Scots pine forests dominate the Laxemar investigation area, but in the areas with deeper soil layers Norway spruce forests are also common. The deciduous forests, mainly Pedunculate oak (*Quercus robur)*, are important constituents along the coast, and this makes the mixed forests the second most abundant forest type. In the Forsmark investigation area, the dominant forests are Scots pine and Norway spruce. Birch (*Betula pendula*), alder (*Alnus glutinosa*) and rowan (*Sorbus acuparia*) dominate the deciduous forests in Forsmark /Lindborg 2005, 2006/.

The soil carbon efflux measurements were done in four different vegetation types in Laxemar and seven vegetation types in Forsmark (Figure 3-1, Table 4-1 for SKB id codes). In Laxemar, it was done in a young pine stand, a wet forest, a poor fen and an agricultural field. The young (c 20–25 y) Scots pine stand had a field layer dominated by dwarf shrub and bracken. The wet forest had a tree and shrub layer dominated by Alder (*Alnus glutinosa*) and the field layer was dominated by grasses, mainly broad-leaved, and Soft rush (*Juncus effusus*). The poor fen had a shrub layer dominated by Bog-myrtle (*Myrica gale*) and also a few birches (*Betula pubescens and B. pendula*) in the tree layer. *Sphagnum* spp., *Potentilla palustris*, and thin leaved grasses dominated the ground layer. The agricultural field was temporary abandoned but was sometimes used for hay production. Grass and herbs dominate the field layer. In Forsmark, it was a pasture, 2 Norway spruce forests, a deciduous forest, a clear-cut and a forested wetland. The pasture was dominated by *Elymus repens* and has until recentely been used as arable land. Spruce 1 is Norway spruce dominated forest with elements of deciduous trees, such as Aspen (*Populus tremula*) and Birch (*Betula pendula*), and the field layer is rich in herbs. Spruce 2 is a younger (60 y) evenaged forest on a thiner soil layer dominated by dwarf shrubs in the field layer. The deciduous forest is fairly open with a herb-rich field layer that is grassed regularly. The clear cut is dominated by Birch and Scots pine that was planted after the clear-cut. The age of the Scots pine was estimted to 15–20 y by counting the branch rounds (plantation is performed within three years from the clear-cut). The forested wetland was a Norway spruce swamp with Alder and Birch.

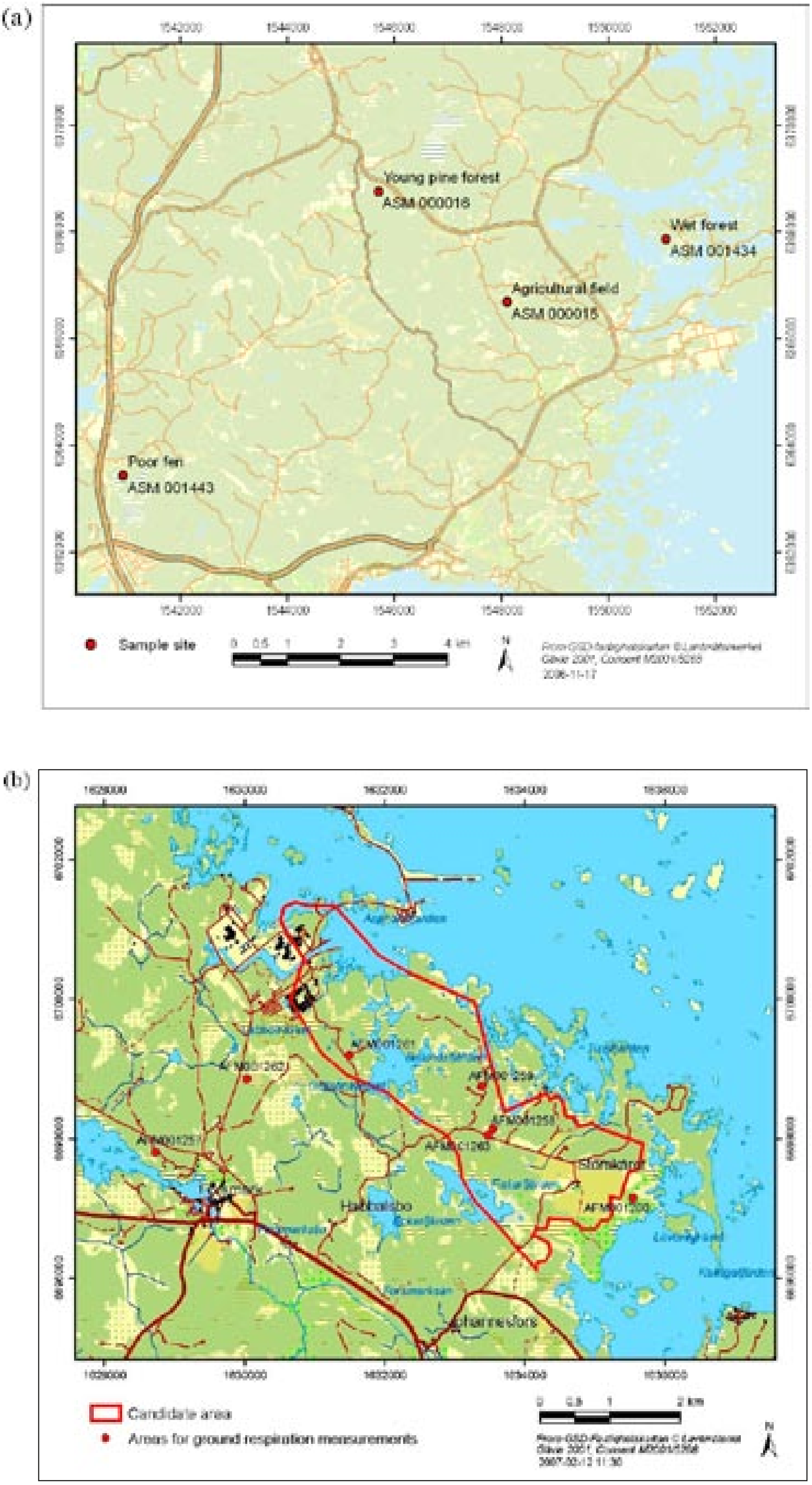


Figure 3-1. Map over (a) the Laxemar investigation area and (b) the Forsmark investigation area. The red dots marks the sites investigated.

3.2 Soil carbon efflux measurements

In Laxemar, the soil carbon efflux measurements were made on 5 occasions between March and October 2006 and in Forsmark, it was done between 3 and 9 occasions between May 2005 and October 2006, depending on ecosystem. The measurements were done at exactly the same spots all times for all ecosystems. In Forsmark there were nine spots within each ecosystem type and in Laxemar there were eight spots.

Soil carbon effluxes were measured using the closed chamber technique. An infrared gas analyzer (EGM-4) together with a canopy assimilation chamber (CPY-2) from PP-systems was used (PP-systems, Hitchin, Hertfordshire, UK). It was measured by placing the canopy assimilation chamber on the ground and continuously measures the change in concentration of carbon dioxide in the chamber either for two minutes or when the difference in concentration of carbon dioxide had changed by 50 ppm. Soil respiration was measured directly afterwards by taking a new measurement but this time the chamber was darkened with a lightproof hood. The chamber was flushed for fifteen seconds in between the measurements to clean the chamber of carbon dioxide. During the soil carbon efflux measurements, photosynthetically active radiation (PAR), air and soil temperature were also measured. In Forsmark, the EGM-4 had problems with overestimations of soil carbon effluxes and data were therefore adjusted according to /Tagesson 2006b/.

Finally, GPP was estimated by subtracting soil respiration from the soil carbon efflux measurements. The sign of GPP was changed from being negative to being positive, as GPP is an uptake of carbon by the ground vegetation. For closer description of field measuremens, see /Lundkvist 2006, Heneryd 2007, Tagesson and Lindroth 2007/.

3.3 Statistical methods

Soil respiration

SPSS 12.0.1 for Windows was used for the statistical analysis. The result of the regressions were set to be significant if the *p*-value was lower than 0.05, a trend if they were between 0.05 and 0.1 and non-significant above 0.1.

In Oskarshamn soil respiration data was separated into two different periods, the first half of the year, until 31st of June 2006 and the second half of the year, after 31st of June 2006. In Forsmark, field measurements were done at different periods and at different number of occasions at the different locations. Soil respiration data were therefore divided into different periods depending on when and how often the field measurements were done. See Table 3-1. In clear-cut, two highly unlikely values were taken away from the analysis (soil respiration: –7.75 and –3.10).

Exponential regressions were done for the different seasons with soil respiration (R) against air temperature and against soil temperature at 10 cm depth, $R = R_0 e^{kT}$, where R_0 is soil respiration at the reference temperature of 0°C and T is temperature (°C). The soil respiration values that were zero or negative were excluded to enable the use of exponential regressions. In the exponential equation k is related to Q_{10}, the relative increase in soil respiration when soil temperature is increased by 10°C. Q_{10} were calculated by using the formula $Q_{10} = e^{10k}$ /Strömgren 2001/.

Table 3-1. Seasons into which the soil respiration data for the ecosystems in Forsmark were separated.

Ecosystem	Start	End
Pasture	2005-06-01	2005-11-10
	2005-11-11	2006-05-31
	2006-06-01	2006-05-31
Spruce 1	2005-05-01	2005-08-14
	2005-08-15	2005-12-31
	2006-01-01	2006-07-15
	2005-05-01	2006-07-15
Spruce 2	2005-05-01	2005-08-14
	2005-08-15	2005-12-31
	2006-01-01	2006-07-15
	2005-05-01	2006-07-15
Wet forest	2005-12-31	2006-12-30
Mire	2005-05-01	2006-12-31
Deciduous	2005-06-01	2005-11-10
	2005-11-11	2006-05-31
	2005-06-01	2006-05-31
Clear cut	2005-12-31	2006-12-30

Soil respiration modelling

At Högmasten in Forsmark and at Äspö climate station in Laxemar, air temperature is measured every half hour /Lärke et al. 2005, Larsson-McCann et al. 2002, Johansson et al. 2005/. To obtain air temperatures for the different ecosystems, linear regressions with air temperature measured in the field against air temperature measured at the climate stations were done. For most of the ecosystems, too few measurements were done to give a correct regression and in these cases the air temperature measurements taken up at the climate stations were used directly. It was only spruce 1 and spruce 2, in Forsmark were enough measurements had been done. In these ecosystems, the linear regressions were used to estimate an air temperature data set for these specific localities.

The exponential regression equations with soil respiration against air temperature were used on these datasets to model soil respiration for the different periods. In Laxemar the different regressions for the different periods were used. In Forsmark, the exponential regressions with all data were used for pasture, wet forest, clear-cut, spruce 1 and deciduous. No significant relationships were found for mire since too few field measurements had been done. For spruce 2, the exponential regressions where the soil respiration data were separated into different periods were used. In spruce 1 and deciduous there were significant relationships for the different periods as well but when the exponential regression was used for the first period, incredibly large values were retrieved. The probable reason for this is that field measurements were taken up in a small temperature span and when the exponential regression was used on the high summer temperature values, to large values were modelled. Annual soil respirations for the different ecosystems were calculated by taking an average value for all half hour modelled values in g $Cm^{-2}h^{-1}$ and multiply it with amount of hours for a year. Residuals were calculated with modelled soil respiration subtracted from soil respiration measured in the field at the closest half-hour from the time of when the field measurements were done.

No soil temperature data set for 2005 and 2006 existed in either Forsmark or Laxemar and soil temperature was therefore modelled. Linear regressions between air temperatures measured at the climate stations and soil temperature measured in the field was done. The air temperature measured at the climate station was taken up at the closest half-hour from the time of the field measurement.

The exponential regression equations with soil respiration against soil temperature were used on the modelled soil temperature set to model annual soil respiration. In Laxemar data were separated into its different periods while in Forsmark, all values were used for clear-cut, wet forest, deciduous, pasture, spruce 2 while the data were separated into its different periods for spruce 1. No significant relationships were found in Mire for soil respiration against soil temperature and no model could be done. Residuals were calculated from modelled soil respiration subtracted from soil respiration measured in the field at the closest half-hour from when the field measurements were done.

Ground Gross Primary Production, GPP

GPP measured during the growing seasons (14th of April 2006–3rd of November 2006 in Laxemar and 1st of April 2005–25th of October 2005 and 16th of April 2006–30th of October 2006 in Forsmark) were included in One-Sample Kolmogorov-Smirnov tests to check whether GPP values fitted a normal distribution. In Forsmark, pasture, wet forest, mire and deciduous was normally distributed while the other ecosystems were not. In Laxemar, all ecosystems were normally distributed. A one-sample *t*-test for the ecosystems with normally distributed data and Mann Whitney *U*-tests for the other ecosystems against zero were done. In Forsmark, it was only in Pasture and Spruce 2, where GPP had an effect on the soil carbon effluxes while GPP affected soil carbon effluxes in all ecosystems in Laxemar. In these ecosystems, the effect of abiotic factors on GPP was therefore analyzed for.

For analyzing the effect of PAR on GPP, a hyperbolic Michaelis-Menten curve was fitted to the GPP data set /Suyker et al. 2005/.

$$GPP = (GPP_{max}PAR)/(K_m+PAR)$$

Where GPP_{max} is saturated GPP and K_m is the PAR level at which GPP is half maximum GPP.

A commonly used equation to analyze the relationship between GPP and temperature is the Arrhenius function of temperature /Wang et al. 1996, Lankreijer 1998/. In this study, a cubic regression was fitted to the GPP data set because it has the same sigmoidal shape as the Arrhenius function, but it is mathematically easier to work with.

$$GPP = GPP_0 + b_1T_a + b_2T_a^2 + b_3T_a^3$$

where GPP_0 is the GPP at 0°C, T_a is the air temperature (°C) and $b_{1,2,3,}$ are coefficients of the regression.

GPP modelling

All ecosystems in Forsmark have a canopy and GPP modelling against solar radiation could hereby not be done. No significant relationships to air temperature could be found and therefore no models could be done for this investigation area. In Laxemar, significant relationships were found for GPP against air temperature but the regressions cannot be used for modelling since they are misleading due to negative results in the lower temperatures. In Laxemar, the poor fen and the agricultural field do not have a canopy and modelling against solar radiation could hereby be done for these ecosystems.

At Äspö climate station, global radiation is measured every half hour /Lärke et al. 2005/. It is given in W m^{-2}, but was changed to micromoles m^{-2} s^{-1} by multiplication by 4.6 /Hickler personal communication/. PAR was then calculated by taking 0.45 of the global radiation /Monteith and

Unsworth 1990/. To extrapolate GPP throughout the growing season 14th of April 2006–3rd of November 2006, the GPP-PAR regression was used on the PAR values from Äspö. Residuals were calculated with modelled GPP subtracted from GPP measured in the field at the closest half-hour from when the field measurements were done.

Model evaluations

To evaluate the models and to be able to calculate the error of the obtained results, the standard deviation was needed. For the regression models without propagation errors in them, i.e. modelled air temperature and PAR-modelled GPP, standard deviation was calculated in SPSS. For the other models, which included several modelled variables, i.e. modelled soil temperature, air temperature modelled soil respiration and soil temperature modelled soil respiration the formula for error of propagation /Leo 1994/ was used:

$$\sigma^2(f) = (\partial f/\partial x)^2\sigma^2(x) + (\partial f/\partial y)^2\sigma^2(y) + (\partial f/\partial z)^2\sigma^2(z) + (\partial f/\partial a)^2\sigma^2(a) +$$
$$+ 2\,\mathrm{cov}(x,y)(\partial f/\partial x)(\partial f/\partial y)$$

where $\sigma^2(f)$ is variance in modelled result, $\sigma^2(x)$ is variance of factor in function, i.e. $T_{average\ soil}$, R_0 and GPP_0, $\sigma^2(y)$ is variance of coefficient in function, A_0 and k, $\sigma^2(z)$ is variance of variable in function, $T_{air,}$ and T_{soil}, $\sigma^2(a)$ is variance from calibration of soil respiration and cov (x,y) is covariance between the factors and coefficients in the functions.

To calculate standard deviation of the models the square root of the variances was taken. Finally, to evaluate the results of the model, a *t*-test were done where residuals were compared against *t* times the standard deviation of the models to see if field results were significantly outside the 95% confidence interval of the model. *t* is from the Students *t*-statistics and it was found in a table of critical values for *t*-distribution.

4 Result

4.1 Effect of air temperature and soil temperature on soil respiration

In Laxemar there were clear significant relationships for all ecosystems and all seasons. In Forsmark, air temperature had a significant effect on soil respiration for all ecosystems and during all seasons but for pasture in season 1, spruce 2 in season 1 and mire and clear-cut for all values. For spruce 2 and clear-cut, there were trend relationships though. In Laxemar, on average 45.8% of the variation in soil respiration was explained by air temperature and at best 75.0% of the variation was explained (wet forest, season 1). In Forsmark, for those ecosystems with significant or trend relationships, on average 35.8% of the variation in soil respiration was explained by air temperature and at best 54.1% (pasture, all values) was explained. For regression statistics see Appendix Table A-1.

The exponential regressions between soil temperature at 10 cm depth and soil respiration was significant for all ecosystems and during all seasons in Laxemar. In Forsmark it was significant for all seasons but pasture in season 1, spruce 2 in season 1, deciduous in season 1 and season 2 and all values for mire. In deciduous, there were trend relationships though. In Laxemar, soil temperature at 10 cm depth explains on average 61.6% of the variation in soil respiration and in the best case, it explains as much as 85.0% of the variation (agricultural field, season 1). In Forsmark, soil temperature at 10 cm depth explains on average 37.0% of the variation in soil respiration and in the best case, it explains 75.1% of the variation (spruce 1, season 1). For regression statistics see Appendix Table A-2.

Q_{10} gives the effect of soil temperature on soil respiration within the temperature range in which the measurements were made. On average Q_{10} was 4.1 in Forsmark and 4.6 in Laxemar. In Forsmark, the largest value (31.6) was found in the spruce 1 in season 1 and the smallest value (1.18) was found in the first period of pasture. In Laxemar, the largest value was found for the second half or 2006 in poor fen (12.3) while the smallest value (2.5) was found for the second half of 2006 in the agricultural field. For all Q_{10} values, see Appendix Table A-3.

4.2 Seasonal and annual soil respiration

In Forsmark, total annual soil respiration for the air temperature model was between 0.34 kg $Cm^{-2}y^{-1}$ for deciduous to 0.84 kg $Cm^{-2}y^{-1}$ for clear-cut while in Laxemar it was between 0.38 kg $Cm^{-2}y^{-1}$ for poor fen to 1.19 kg $Cm^{-2}y^{-1}$ for pine. For the soil temperature model the range was between 0.45 kg $Cm^{-2}y^{-1}$ in wet forest and 1.09 kg $Cm^{-2}y^{-1}$ for pasture in Forsmark and between 0.73 kg $Cm^{-2}y^{-1}$ in wet forest and 1.30 kg $Cm^{-2}y^{-1}$ for the young pine stand in Laxemar, (Table 4-1). There was large seasonal variation in modelled soil respiration. Both air temperature and soil temperature based models peaked in July. For monthly average values in soil respiration for the different ecosystems, see Figure 4-1 and Figure 4-2 and Appendix Table A-4 to A-7.

Table 4-1. Annual soil respiration and standard deviation in kg Cm^{-2}y^{-1} for the air temperature and soil temperature based models in Forsmark.

Ecosystem	SKB ID-Code	Air temperature modelled soil respiration	std. dev.	Soil temperature modelled soil respiration	std. dev.
Poor Fen	ASM 001443	0.44	0.14	0.99	1.84
Agricultural field	ASM 000015	0.70	0.21	1.08	0.56
Pine	ASM 000016	1.19	0.31	1.30	1.76
Wet forest	ASM 001434	0.67	0.36	0.73	0.62
Pasture	AFM001257/ AFM001081	0.44	0.34	1.09	0.75
Spruce 1	AFM001258/ AFM001068	0.71	0.43	0.79	1.24
Spruce 2	AFM001259/ AFM001247	0.60	1.16	0.58	0.25
Deciduous	AFM001260/ AFM001071	0.34	0.35	0.47	0.37
Wet forest	AFM001263/ AFM001076	0.42	0.39	0.45	0.38
Clear cut	AFM001261	0.84	0.72	0.71	0.54

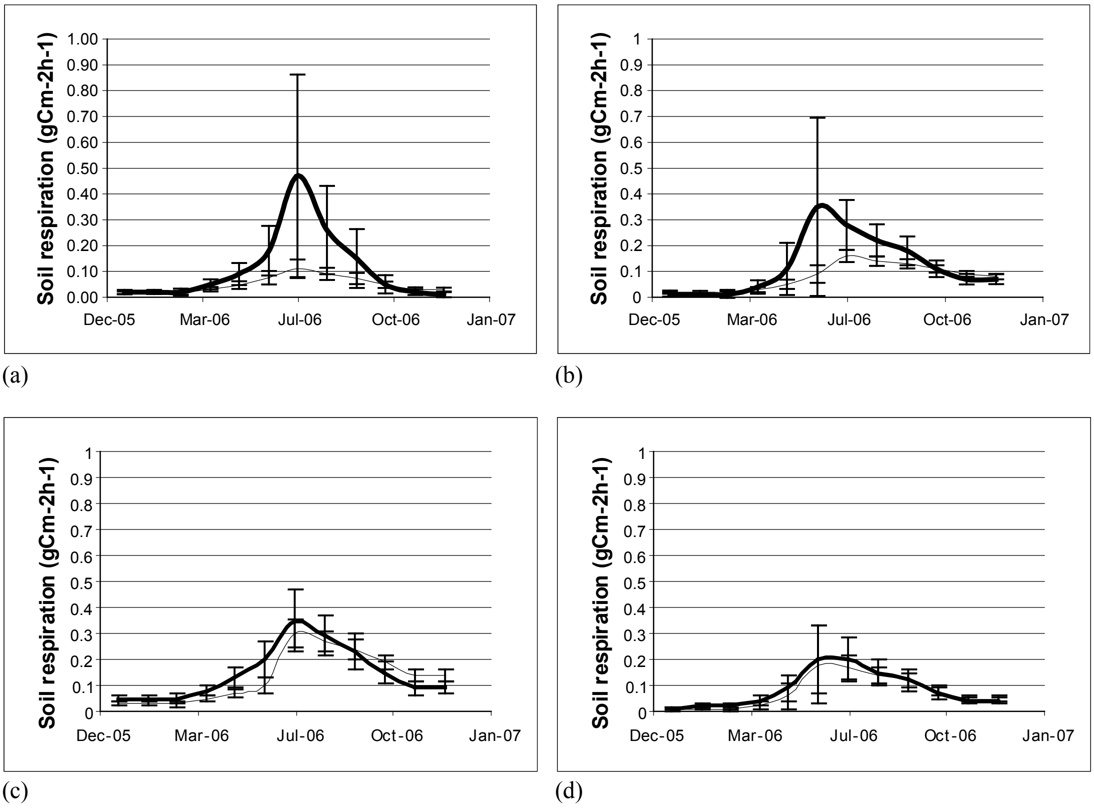
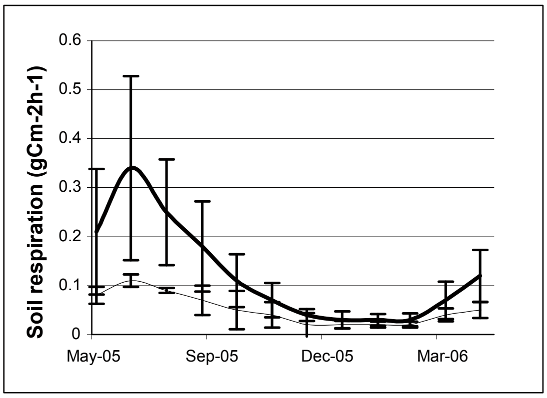
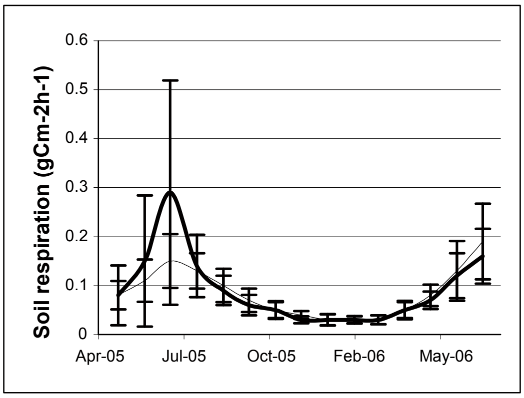


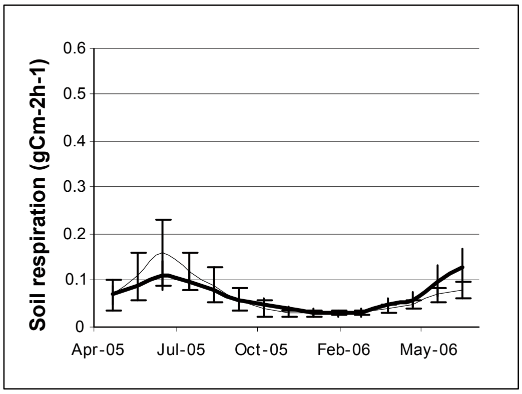
Figure 4-1. *Seasonal variation in soil respiration for (a) the poor fen, (b) the agricultural field, (c) the young pine forest and (d) the wet forest in Laxemar. The thick line is the soil temperature modelled soil respiration and the thin line is the air temperature modelled soil respiration.*



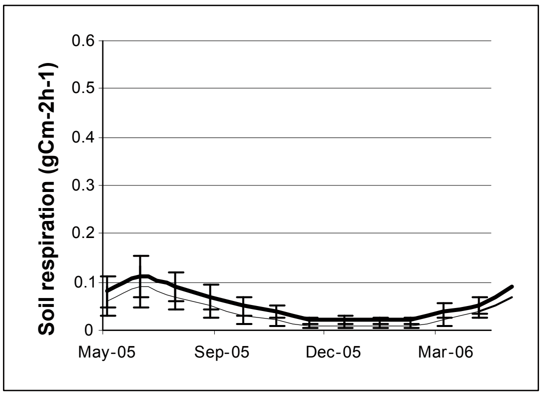
(a)



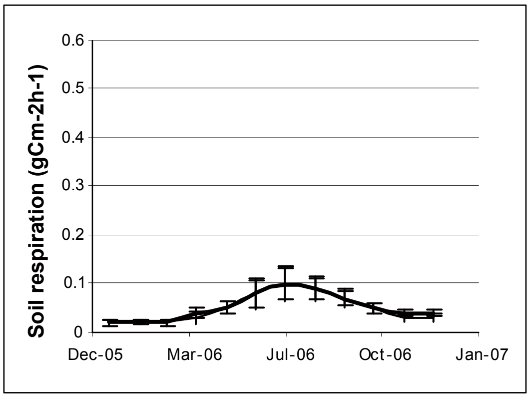
(b)



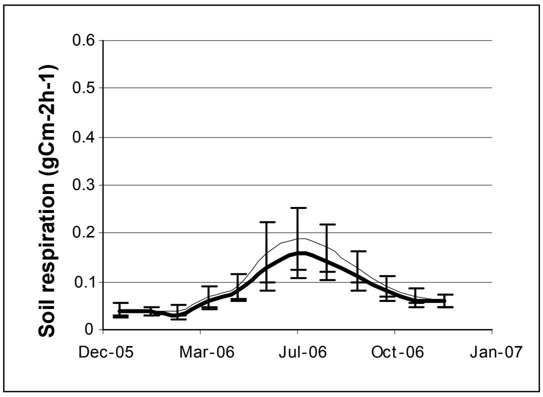
(c)



(d)



(e)



(f)

Figure 4-2. *Seasonal variation in soil respiration for (a) the pasture, (b) spruce 1, (c) spruce 2, (d) the deciduous forest stand, (e) the wet forest and (f) the clear-cut in Forsmark. The thick line is the soil temperature modelled soil respiration and the thin line is the air temperature modelled soil respiration. Observe that the dates of the x-axis differ at the different graphs and the y-axis has a different scale in comparison to Laxemar.*

4.3 Effect of PAR and air temperature on ground GPP

In Forsmark, GPP did not affect soil carbon effluxes in any of the ecosystems but pasture and spruce 2. There was not enough carbon dioxide taken up by the ground vegetation to affect soil carbon effluxes. Neither air temperature nor PAR affected GPP in spruce 2, whereas in pasture PAR had an effect. In Laxemar, GPP significantly affected soil carbon effluxes in all ecosystems. GPP were affected by both PAR and air temperature in all ecosystems but young pine and wet forest, in young pine neither of the abiotic factors affected GPP whereas in wet forest PAR did. Regression statistics is shown in Appendix Table A-8.

4.4 Seasonal and annual GPP and NEE

The PAR modelled GPP indicated that the ground vegetation annually took up 0.70 ± 0.17 kg $Cm^{-2}y^{-1}$ in the poor fen and 0.71 ± 0.27 kg $Cm^{-2}y^{-1}$ in the agricultural field. How these were distributed over the growing season can be seen in Appendix Table A-9. For these ecosystems, NEE could be calculated since both GPP and soil respiration was estimated and annual NEE for the poor fen was between –0.29 and 0.32 kg $Cm^{-2}y^{-1}$ and for the agricultural field it was between –0.38 and 0.00 kg $Cm^{-2}y^{-1}$. A negative sign is a loss of carbon due to large respiration.

4.5 Evaluation of regression models

The comparison between soil respiration measured in the field and air temperature modelled soil respiration indicated that they were reasonably close to each other. Most of the residuals were inside the 95% confidence interval. In total the residuals indicated that the model slightly underestimated soil respiration for most of the ecosystems. For residual data, see Appendix Table A-10 and A-11.

The comparison between soil respiration measured in the field and soil temperature modelled soil respiration indicated that this model also was close to the field measurements. One of the residuals on Forsmark was outside the 95% confidence interval of the soil temperature modelled soil respiration. In total, this model also slightly underestimated soil respiration. For residual data, see Appendix Table A-12 and A-13.

The comparison between PAR modelled GPP and GPP measured in the field indicated that the models fitted well compared to field measured results. None of the residuals were outside the 95% confidence interval of the modelled GPP. For residuals data see Appendix Table A-14.

5 Discussion

5.1 Effect of temperature on soil respiration

Studies made in temperate and boreal regions have indicated that the main factor to influence soil respiration is temperature /Davidson et al. 1998, Morén and Lindroth 2000, Swansson and Flanagan 2001 etc/, which also can be seen in the ecosystems studied in Laxemar and Forsmark. All ecosystems and seasons but Pasture, season 1 and mire had significant or trend relationships to air and soil temperature. Mire did not have any significant relationship because too few measurements were done. There was no significant relationship between temperature and soil respiration for pasture and the reason could be that there was too small temperature ranges or too few data.

The parameter *k* is not a constant coefficient; it decreases with an increase in temperature, which results in a decrease in the effect of temperature on soil respiration /Kirschbaum 1995/. Q_{10}, the relative increase in soil respiration when temperature is raised 10°C, therefore differs between seasons. Average Q_{10} in Laxemar, 4.6, was quite similar to many other ecosystem studied, where a 10°C increase in soil temperature at soil depths between 2–15 cm gives 2.0–6.0 times the soil respiration /Goulden and Crill 1997, Boone et al. 1998, Davidson et al. 1998, Hollinger et al. 1998, Morén and Lindroth 2000, Pilegaard et al. 2001, Swansson and Flanagan 2001/. It is hard to compare Q_{10} between different studies, Q_{10} are derived from measurements taken up in different temperature ranges, and /Kirschbaum 1995/ showed that Q_{10} is temperature-dependent and decreasing with a temperature increase. Secondly, it is important that Q_{10} is derived out of soil temperature taken up at the same depth in the different studies. Q_{10} in Laxemar would differ greatly if they had been derived out of the air temperature set instead. This indicates that Q_{10} can only be used in the same temperature range and against soil temperature taken up at the same depth, as the field measurements that were used to derive Q_{10} were.

5.2 Evaluation of soil respiration regression models

The main problem with the modelled soil respiration is that too few measurements were done. The same soil respiration measurements that were used in the model were used to evaluate it; some data should have been separated and used in the evaluation. Another problem is that soil respiration varies over the seasons due to differences in the amount of living biomass, amount of roots, water availability, litter quality and active soil layer /Rayment and Jarvis 2000, Strömgren 2001/. If there had been more data, the seasons could have been separated narrower and a separation could have been done for the ecosystems where all data were used in the regression analysis.

5.3 Seasonal and annual soil respiration

The seasonal differences in soil respiration seen in Appendix, Table A-4 to A-7 can be explained by seasonal changes in depth of active soil layer, amount and production of vegetation and roots and changes in microbial activity. The volume of active soil is highly seasonal dependent and it differs due to seasonal changes in temperature, water table and frost /Rayment and Jarvis 2000/. When it comes to root respiration, which is between 50–60% of soil respiration /Högberg et al. 2001, Granier et al. 2000/, it is strongly correlated to soil temperature /Boone et al. 1998/ and photosynthesis of the aboveground biomass /Högberg et al. 2001/. Another cause to the seasonal variation in root respiration is growth respiration due to fine root production, as discussed by /Widén 2002/. When it comes to the heterotrophic respiration, microbial populations do not differ between the seasons but activity and metabolism highly follows temperature and is therefore largest in summer /Blume et al. 2002/.

The annual soil respiration (0.58–0.79 kg $Cm^{-2}y^{-1}$) for the coniferous ecosystems of Forsmark (spruce 1 and spruce 2) and (1.19–1.30 kg $Cm^{-2}y^{-1}$) for Laxemar (young pine) is large compared to the estimated mean for boreal forests of 0.33 kg $Cm^{-2}y^{-1}$ /Raisch and Schlesinger 1992/. But, there are a large number of studies showing soil respiration well above this estimated mean. /Morén and Lindroth 2000/ and /Lindroth et al. 1998/ found annual soil respiration in Norrunda, Sweden to be 1.23–1.50 kg $Cm^{-2}y^{-1}$, /Rayment and Jarvis 2000/ estimated annual soil respiration at 0.90 kg $Cm^{-2}y^{-1}$ for a black spruce stand in northern Saskatchewan and /Law et al. 1999b/ found a value of 0.68 kg $Cm^{-2}y^{-1}$ for a pine forest in Oregon. The annual soil respiration for the deciduous forest in Forsmark (0.34–0.47 kg Cm^{-2}) is lower than the estimated mean for temperate forests of 0.65 kg Cm^{-2} /Raisch and Schlesinger 1992/. Soil respiration in the clear-cut was in the upper range of soil respiration estimates for the Forsmark investigation areas (Table 4-1). The clear-cut was cut approximately 20 y ago. /Kolari et al. 2004/ estimated total ecosystem respiration for differently aged stands and they reported that soil carbon effluxes were largest for 12-y-old stands.

An explanation to why the coniferous forests have larger soil respiration than the estimated mean could be that Laxemar and Forsmark is situated further south than the ecosystems used in the mean estimate by /Raisch and Schlesinger 1992/, the investigation areas is on the southern edge of boreal forests. /Lindroth et al. 1998/ explained their high soil respiration estimate with climate variables; the temperature was high and soil moisture were low during periods of large soil respiration. Another explanation could be that the forests of Laxemar and Forsmark are managed. If the forests were ditched recently, the lowered water table would start off an increased decomposition due to the high organic soil carbon content. Another explanation could be climate since temperature has been large the years when the field estimates were done.

Soil respiration for the pasture (0.44–1.09 kg $Cm^{-2}y^{-1}$) and the agricultural field (0.70–1.08 kg $Cm^{-2}y^{-1}$) was comparable to other studies. /Novick et al. 2004/ reported for a grass covered field in North Carolina, 1.30 kg $Cm^{-2}y^{-1}$, while other studies found lower values. /Suyker and Verma 2001/ and /Suyker et al. 2003/ estimated annual soil respiration to 0.52–0.54 kg $Cm^{-2}y^{-1}$ for a tall grass prairie in Oklahoma, /Maljanen et al. 2001/ reported 0.76 kg $Cm^{-2}y^{-1}$ for an organic field in eastern Finland and in a moist mixed grassland near Lethbridge in Alberta /Flanagan et al. 2002/ did estimate it to be 0.27–0.30 kg $Cm^{-2}y^{-1}$.

In wet forests soil respiration is lowered as a result of inhibition due to development of anaerobic conditions /Heal et al. 1981/. Estimates are quite large (0.42–0.45 kg $Cm^{-2}y^{-1}$ in Forsmark and 0.68–0.73 kg $Cm^{-2}y^{-1}$ in Laxemar) in comparison to estimates for a swampy mixed hardwood stand in the Harvard forest in Massachusetts of 0.14 kg $Cm^{-2}y^{-1}$ /Davidson et al. 1998/. Estimates are more similar to others though. Soil respiration was estimated to 0.396 kg Cm^2 from May to October 1996 for a boreal black spruce forest in Saskatchewan /Swansson and Flanagan 2001/. /Kolari et al. 2004/ estimated total ecosystem respiration both during growing season and during the whole year, and at their sites growing season is 0.716 of annual respiration. This gives a 0.553 kg Cm^2y^{-1} for the site in Saskatchewan, which is about the same as the wet forest of both Laxemar and Forsmark with an average of 0.568 kg Cm^2y^{-1}. /Davidson et al. 1998/ explained their low values not only as caused by wetness but also due to low input of C to the soil. In the Hardvard stand in Massachusetts, trees are sparse and hereby NPP are low as well, whereas at the Laxemar and Forsmark site, trees are dense /Tagesson 2006c/ and it might be that NPP therefore is large and there are a large C input to the soils.

The poor fen were in a similar range as other studies done at mires and fens in the same region. In the Nordic countries, values estimated varies between 0.456 and 0.214 kg $Cm^{-2}y^{-1}$, where the large values estimated was for Fäjemyren, close to Hässleholm in the Southern parts of Sweden and the low values were estimated for Kaamanen in the Northern subarctic regions of Finland /Lindroth et al. 2007/.

5.4 Shortages of the closed chamber technique

The measurement of soil carbon effluxes with chambers is the most commonly used technique for estimating soil carbon effluxes. It has been used widely for several decades and the main potential sources of error are hereby well known /Davidson et al. 2002/. The trouble with the closed chamber technique is that the chamber always affects the soil that it does its measurements on. First, since the concentration of carbon dioxide in the chamber is altered and this affects the concentration gradient from the soil /Davidson et al. 2002/. When the concentration in the chamber increases it results in a decrease of the diffusion gradient, which results in an underestimation of the soil carbon dioxide effluxes. This problem can be corrected for by using a quadratic relationship in the curve fitting and by using short measurement periods, which were done in this study.

The large problem with the estimates of soil carbon dioxide effluxes is caused by under or overpressure in the chamber /Widén and Lindroth 2003/. Over and under pressure in the chamber can occur due to circulating gases and warming or cooling of chamber air. In an over pressurized chamber soil carbon dioxide effluxes is slowed down while in an under pressurized chamber carbon dioxide is sucked out of the soil /Davidson et al. 2002/. These problems can be avoided with properly designed chambers.

/Pumpanen et al. 2004/ did a study where several different chambers frequently used in the estimations of soil carbon dioxide effluxes were compared to a known CO_2 flux. Their study showed that chambers under and overestimated soil carbon effluxes with between –21 to +33%, depending on type of chamber and method used for mixing the air in the chamber. In average the estimates of the chambers were within 4% of the reference flow /Pumpanen et al. 2004/. Tests were done with SRC-1 chambers from PP-systems and it ranged between underestimates of the soil carbon dioxide effluxes with between –14% to overestimates with +33%. The differences depended on which sand and which soil moisture that the measurements were done on and if collars were used or not.

Most of the times the SRC-1 overestimated the soil carbon effluxes and this were explained by turbulences from the fan. The use of collars also resulted in a larger increase than when no collars were used. In measurements with collars, the chamber gets tightly sealed to the ground and the better results without the collar could be explained by leakage of CO_2 from under the edges of the chamber, which would compensate for the disturbance of the fan. In the CPY-2 measurements done in Laxemar, collars were not used. Without a collar the estimates of the SRC-1 chamber were between 0.94 and 1.19, with an average of 1.05 of the reference flux. The SRC-1 chamber is different from the CPY-2 chamber though; it is made out of aluminum and it is nontransparent. It is hereby hard to tell if 1.05 is a correction factor, which also could be used for the CPY-2 chamber.

5.5 Effect of GPP on soil carbon effluxes

In a previous study, over spring, /Tagesson 2006d/ found GPP significantly different from zero for a spruce, a meadow and two deciduous ecosystems, the pine ecosystem did not have any significant GPP though. In another study by /Tagesson and Lindroth 2007/ including values for the entire growing season, GPP did not have any effect on soil carbon effluxes for any of those ecosystems but meadow. In this study, photosynthesis was found for the ground vegetation for all ecosystems of Laxemar and for pasture and spruce 2 in Forsmark. These two ecosystems have more lush ground vegetation compared to the others in Forsmark. Ground photosynthesis, naturally depends on the structure of the ground vegetation, which then depends on type of forest. It is also dependent on other factors such as soil moisture, temperature and radiation /Baldocchi et al. 1997, Kelliher et al. 1999/. Some studies have indicated that the forest floor vegetation can be a significant part of the soil carbon effluxes and that they take up a large portion of carbon dioxide /Widén 2002, Morén and Lindroth 2000/. In other studies it have been seen that the uptake of carbon dioxide by the forest floor vegetation is negligible /Baldocchi et al. 1997, Kelliher et al. 1999/.

5.6 Effect of PAR and temperature on ground GPP

GPP was generally saturated at between 0.094 and 0.23 g $Cm^{-2}h^{-1}$, which is in the same range as several other studies. /Valentini et al. 1995/ found for a California grassland that light saturation occurred approximately between 0.13 and 0.30 g $Cm^{-2}h^{-1}$, for plants with sun characteristic leaves, /Rothstein and Zak 2001/ found a leveling off between 0.17 and 0.66 g $Cm^{-2}h^{-1}$ and for a grassland and barley fields in Finland, /Maljanen et al. 2001/ found that maximum uptake was between 0.11 and 0.27 g $Cm^{-2}h^{-1}$. There were one large outlier, pasture in Forsmark (8.6927e + 18 g $Cm^{-2}h^{-1}$), with more linear relationship between PAR and GPP, which increased the level at which GPP was saturated. The measurements never reached saturation level in pasture and the relationship were therefore linear instead of saturated.

Former studies have shown that photosynthesis increases exponentially at lower temperatures, to an optimum where after it starts to decrease /Cannell and Thornley 1998, Wang et al. 1996, Lankreijer 1998/. Many studies have used the Arrhenius function of temperature to show this relationship, whereas /Cannell and Thornley 1998/ used a cubic regression since it has the same shape but it is more mathematically transparent. In this study, the cubic regression was chosen since it is easier for the calculation of the standard deviations. The negative part with the cubic regression is though that the underlying processes cannot be interpreted.

5.7 GPP and NEE in the poor fen and agricultural areas

GPP by the ground vegetation in the poor fen (0.70 kg $Cm^{-2}y^{-1}$) is large compared to other Fen studies in the Nordic countries with values between 0.25–0.48 kg $Cm^{-2}y^{-1}$ /Lindroth et al. 2007/. These ecosystems had smaller uptake, which might be because most of them are situated further north than Laxemar. One of their study sites, Fäjemyren (0.48 kg $Cm^{-2}y^{-1}$), is at a similar latitude as Laxemar but there are also other factors affecting GPP, such as nutrition, microclimate, biomass, species etc. GPP by ground vegetation in the agricultural field (dominated by grass and herbs) (0.71 kg $Cm^{-2}y^{-1}$) is similar compared to other grassland studies with values between 0.27–1.21 kg $Cm^{-2}y^{-1}$ /Flanagan et al. 2002, Suyker and Verma, 2001, Suyker et al. 2003, Novick et al. 2004/.

The NEE of between –0.29 and 0.32 kg $Cm^{-2}y^{-1}$ shows that there is approximately no net carbon uptake or loss from the poor fen. This is similar to other studies; in Fäjemyren there is a net uptake of 0.02 kg $Cm^{-2}y^{-1}$ /Lund et al. 2007/. In kaamanen, Siikaneva and Degerö NEE is between 0.03 and 0.00 kg $Cm^{-2}y^{-1}$ /Lindroth et al. 2007/. NEE in the agricultural areas indicate that there is net loss of carbon (on average –0.19 kg $Cm^{-2}y^{-1}$) to the atmosphere. Other studies have retrieved a large range of NEE estimates (–0.950 to 0.274 kg $Cm^{-2}y^{-1}$) /Suyker et al. 2003, Flanagan et al. 2002, Novick et al. 2004, Maljanen et al. 2001, Byrne et al. 2005, Soegaard et al. 2005, Hollinger et al. 2005/.

5.8 Conclusions

Abiotic factors can be used to model soil carbon effluxes and to extrapolate occasional field measurements temporally. Annual soil respirations in these ecosystems were estimated to between 0.34–1.30 kg $Cm^{-2}y^{-1}$. GPP of the ground vegetation were reducing soil carbon effluxes, in all stands but one of the spruce stands, the deciduous forest, the mire and the wet deciduous forest of Forsmark. Annual GPP for the poor fen and the agricultural field was estimated to be 0.70 and 0.71 kg $Cm^{-2}y^{-1}$, respectively. This gives a net ecosystem exchange for the poor fen of between –0.29 and 0.32 kg $Cm^{-2}y^{-1}$ and for the agricultural field it was between –0.38 and 0.00 kg $Cm^{-2}y^{-1}$.

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Appendix

Table A-1. Regression parameters and statistics for measured soil respiration against air temperature. Equations follow the form $R = R_0e^{kT}$ where R is soil respiration in g $Cm^{-2}h^{-1}$, T is air temperature in °C and d.f. is degrees of freedom. R_0 is initial soil respiration at 0°C.

Ecosystem	SKB ID-code	Season	d.f.	R_0	*k*	*F*-value	*p*-value	R^2
Poor fen	ASM 001443	01-01-2006–30-06-2006	22	0.0202	0.0780	27.63	0.000	0.557
	ASM 001443	01-07-2006–31-12-2006	22	0.0185	0.0844	44.58	0.000	0.670
	ASM 001443	01-01-2006–31-12-2006	46	0.0192	0.0817	76.30	0.000	0.624
Agricultural field	ASM 000015	01-01-2006–30-06-2006	19	0.0212	0.0851	14.26	0.001	0.429
	ASM 000015	01-07-2006–31-12-2006	22	0.0680	0.0397	12.29	0.002	0.358
	ASM 000015	01-01-2006–31-12-2006	43	0.0385	0.0611	24.98	0.000	0.367
Young pine	ASM 000016	01-01-2006–30-06-2006	22	0.0329	0.0674	13.14	0.001	0.374
	ASM 000016	01-07-2006–31-12-2006	22	0.1103	0.0478	9.97	0.005	0.312
	ASM 000016	01-01-2006–31-12-2006	46	0.0908	0.0321	4.87	0.032	0.096
Wet forest	ASM 001434	01-01-2006–30-06-2006	22	0.0084	0.1727	66.03	0.000	0.750
	ASM 001434	01-07-2006–31-12-2006	22	0.0360	0.0722	13.79	0.001	0.385
	ASM 001434	01-01-2006–31-12-2006	46	0.0178	0.1145	61.54	0.000	0.572
Pasture	AFM001257	01-06-2005–14-09-2005	23	0.1757	0.0164	0.43	0.520	0.018
	AFM001257	15-09-2005–31-05-2006	18	0.0226	0.0680	18.39	0.000	0.505
	AFM001257	01-06-2005–31-05-2006	43	0.0248	0.0779	50.63	0.000	0.541
Spruce 1	AFM001258	01-05-2005–14-08-2005	21	0.0004	0.3453	8.28	0.009	0.283
	AFM001258	15-08-2005–31-12-2005	18	0.0331	0.0799	17.89	0.001	0.499
	AFM001258	01-01-2006–15-07-2006	21	0.0315	0.0666	12.46	0.002	0.372
	AFM001258	01-05-2005–15-07-2006	64	0.0310	0.0798	26.43	0.000	0.292
Spruce 2	AFM001259	01-05-2005–14-08-2005	18	0.0243	0.0938	4.02	0.060	0.183
	AFM001259	15-08-2005–31-12-2005	21	0.0232	0.0934	21.11	0.000	0.501
	AFM001259	01-01-2006–15-07-2006	18	0.0316	0.0429	7.44	0.014	0.293
	AFM001259	01-05-2005–15-07-2006	61	0.0287	0.0737	37.37	0.000	0.380
Mire	AFM001262	01-05-2005–31-10-2006	16	0.0371	0.0202	0.51	0.487	0.031
Deciduous	AFM001260	01-06-2005–10-11-2005	24	0.0020	0.2117	10.32	0.004	0.301
	AFM001260	11-11-2005–15-06-2006	13	0.0168	0.0561	6.66	0.023	0.339
	AFM001260	01-06-2005–15-06-2006	39	0.0145	0.0980	29.86	0.000	0.434
Wet forest	AFM001263	31-12-2005–30-12-2006	30	0.0233	0.0708	10.22	0.003	0.254
Clear cut	AFM001261	31-12-2005–30-12-2006	18	0.0438	0.0565	4.19	0.056	0.189

Table A-2. Regression parameters and statistics for measured soil respiration against soil temperature for the ecosystems. Equations follow the form $R = R_0 e^{kT}$ where R is soil respiration in g $Cm^{-2}h^{-1}$, T is air temperature in °C and d.f. is degrees of freedom. R_0 is initial soil respiration at 0°C.

Ecosystem	SKB ID-code	Season	d.f.	R_0	*k*	*F*-value	*p*-value	R^2
Poor fen	ASM 001443	01-01-2006–30-06-2006	22	0.0247	0.1341	30.85	0.000	0.584
	ASM 001443	01-07-2006–31-12-2006	22	0.0040	0.2507	57.11	0.000	0.722
	ASM 001443	01-01-2006–31-12-2006	46	0.0190	0.1488	66.66	0.000	0.592
Agricultural field	ASM 000015	01-01-2006–30-06-2006	19	0.0159	0.1935	107.75	0.000	0.850
	ASM 000015	01-07-2006–31-12-2006	22	0.0467	0.0919	23.32	0.000	0.515
	ASM 000015	01-01-2006–31-12-2006	43	0.0252	0.1420	95.05	0.000	0.689
Young pine	ASM 000016	01-01-2006–30-06-2006	22	0.0406	0.1205	76.87	0.000	0.777
	ASM 000016	01-07-2006–31-12-2006	22	0.0378	0.1377	9.78	0.005	0.308
	ASM 000016	01-01-2006–31-12-2006	46	0.0395	0.1300	98.93	0.000	0.683
Wet forest	ASM 001434	01-01-2006–30-06-2006	22	0.0282	0.1385	55.73	0.000	0.717
	ASM 001434	01-07-2006–31-12-2006	22	0.0275	0.1104	12.46	0.002	0.362
	ASM 001434	01-01-2006–31-12-2006	46	0.0312	0.1114	66.04	0.000	0.589
Pasture	AFM001257	01-06-2005–14-09-2005	24	0.2747	0.0016	0.00	0.975	0.000
	AFM001257	15-09-2005–31-05-2006	18	0.0255	0.1709	6.32	0.022	0.260
	AFM001257	01-06-2005–31-05-2006	44	0.0315	0.1541	35.64	0.000	0.448
Spruce 1	AFM001258	01-05-2005–14-08-2005	21	0.0058	0.2994	63.29	0.000	0.751
	AFM001258	15-08-2005–31-12-2005	18	0.0198	0.1512	24.65	0.000	0.578
	AFM001258	01-01-2006–15-07-2006	21	0.0261	0.1297	10.64	0.004	0.336
	AFM001258	01-05-2005–15-07-2006	64	0.0176	0.1785	64.97	0.000	0.504
Spruce 2	AFM001259	01-05-2005–14-08-2005	18	0.0692	0.0726	1.12	0.304	0.059
	AFM001259	15-08-2005–31-12-2005	22	0.0089	0.2215	27.63	0.000	0.557
	AFM001259	01-01-2006–15-07-2006	20	0.0317	0.0727	5.61	0.028	0.219
	AFM001259	01-05-2005–15-07-2006	64	0.0242	0.1338	29.46	0.000	0.315
Mire	AFM001262	01-05-2005–31-10-2006	18	0.0246	0.1063	2.92	0.104	0.140
Deciduous	AFM001260	01-06-2005–10-11-2005	24	0.0197	0.1294	3.93	0.059	0.141
	AFM001260	11-11-2005–15-06-2006	19	0.0235	0.0674	3.36	0.082	0.150
	AFM001260	01-06-2005–15-06-2006	45	0.0202	0.1209	34.43	0.000	0.433
Wet forest	AFM001263	31-12-2005–30-12-2006	35	0.0277	0.0913	7.71	0.009	0.181
Clear cut	AFM001261	31-12-2005–30-12-2006	26	0.0231	0.1246	11.59	0.002	0.308

Table A-3. Seasonal Q_{10}, the relative increase in soil respiration when soil temperature is increased by 10°C in Forsmark. $Q_{10} = e^{10k}$, *k* is from the exponential regression equations and d.f. is degrees of freedom.

Ecosystem	SKB ID-code	Season	d.f.	Q_{10}	Soil temperature range (°C)
Poor fen	ASM 001443	01-01-2006–30-06-2006	22	3.82	4.0–17.3
	ASM 001443	01-07-2006–31-12-2006	22	12.27	10.0–16.3
	ASM 001443	01-01-2006–31-12-2006	46	4.43	4.0–16.3
Agricultural field	ASM 000015	01-01-2006–30-06-2006	20	6.92	0.4–16.0
	ASM 000015	01-07-2006–31-12-2006	22	2.51	6.4–19.5
	ASM 000015	01-01-2006–31-12-2006	44	4.14	0.4–19.5
Young pine	ASM 000016	01-01-2006–30-06-2006	22	3.34	1.4–13.8
	ASM 000016	01-07-2006–31-12-2006	22	3.96	9.0–14.5
	ASM 000016	01-01-2006–31-12-2006	46	3.67	1.4–14.5
Wet forest	ASM 001434	01-01-2006–30-06-2006	22	3.99	2.5–16.3
	ASM 001434	01-07-2006–31-12-2006	22	3.02	10.0–17.3
	ASM 001434	01-01-2006–31-12-2006	46	3.05	2.5–17.3
Pasture	AFM001257	01-06-2005–14-09-2005	24	1.18	8.3–17.4
	AFM001257	15-09-2005–31-05-2006	18	1.97	0.7–8.7
	AFM001257	01-06-2005–31-05-2006	44	2.18	0.70–17.4
Spruce 1	AFM001258	01-05-2005–14-08-2005	21	31.6	1.8–14.5
	AFM001258	15-08-2005–31-12-2005	18	2.22	3.7–15.4
	AFM001258	01-01-2006–15-07-2006	21	1.95	1.6–14.3
	AFM001258	01-05-2005–15-07-2006	64	2.22	1.6–15.4
Spruce 2	AFM001259	01-05-2005–14-08-2005	18	2.55	0.0–14.2
	AFM001259	15-08-2005–31-12-2005	22	2.54	3.0–14.2
	AFM001259	01-01-2006–15-07-2006	20	1.54	0.5–15.7
	AFM001259	01-05-2005–15-07-2006	64	2.09	0.0–15.7
Mire	AFM001262	01-05-2005–31-10-2006	18	1.22	0.0–13.0
Deciduous	AFM001260	01-06-2005–10-11-2005	24	8.31	10.8–16.8
	AFM001260	11-11-2005–15-06-2006	19	1.75	0.7–10.7
	AFM001260	01-06-2005–15-06-2006	45	2.66	0.7–16.8
Wet forest	AFM001263	31-12-2005–30-12-2006	35	2.03	0.8–15.7
Clear cut	AFM001261	31-12-2005–30-12-2006	26	1.76	0.0–19.5

Table A-4. Average monthly soil respiration in g $Cm^{-2}h^{-1}$ 2006 according the air temperature model for the ecosystems in Laxemar.

Date	Poor Fen soil respiration	std. dev.	Agricultural field soil respiration	std. dev.	Young pine soil respiration	std. dev.	Wet forest soil respiration	std. dev.
Jan-06	0.02	0.005	0.02	0.006	0.03	0.008	0.01	0.005
Feb-06	0.02	0.005	0.02	0.005	0.03	0.007	0.01	0.004
Mar-06	0.02	0.008	0.02	0.009	0.03	0.011	0.01	0.008
Apr-06	0.03	0.008	0.03	0.010	0.05	0.011	0.02	0.015
May-06	0.05	0.014	0.05	0.018	0.07	0.018	0.06	0.050
Jun-06	0.08	0.026	0.09	0.034	0.10	0.030	0.18	0.152
Jul-06	0.11	0.036	0.16	0.024	0.30	0.056	0.17	0.046
Aug-06	0.09	0.024	0.14	0.018	0.27	0.040	0.14	0.031
Sep-06	0.07	0.022	0.13	0.018	0.24	0.040	0.12	0.029
Oct-06	0.05	0.013	0.11	0.014	0.19	0.029	0.08	0.019
Nov-06	0.03	0.008	0.09	0.011	0.14	0.023	0.05	0.013
Dec-06	0.03	0.008	0.08	0.010	0.14	0.021	0.05	0.012
Total	0.04	0.034	0.08	0.050	0.14	0.098	0.08	0.078

Table A-5. Average monthly soil respiration in g $Cm^{-2}h^{-1}$ 2006 according the soil temperature model for the ecosystems in Laxemar.

Date	Poor Fen soil respiration	std. dev.	Agricultural field soil respiration	std. dev.	Young pine soil respiration	std. dev.	Wet forest soil respiration	std. dev.
Jan-06	0.02	0.009	0.01	0.008	0.05	0.015	0.01	0.008
Feb-06	0.02	0.008	0.01	0.006	0.05	0.013	0.02	0.007
Mar-06	0.02	0.014	0.01	0.013	0.05	0.021	0.02	0.013
Apr-06	0.05	0.019	0.04	0.026	0.08	0.022	0.04	0.019
May-06	0.09	0.043	0.11	0.101	0.13	0.039	0.09	0.051
Jun-06	0.18	0.096	0.35	0.345	0.20	0.070	0.20	0.129
Jul-06	0.47	0.392	0.28	0.097	0.35	0.120	0.20	0.085
Aug-06	0.26	0.171	0.22	0.063	0.29	0.078	0.15	0.052
Sep-06	0.15	0.114	0.18	0.056	0.23	0.071	0.12	0.045
Oct-06	0.05	0.035	0.11	0.032	0.15	0.041	0.07	0.023
Nov-06	0.02	0.011	0.07	0.020	0.09	0.026	0.04	0.013
Dec-06	0.01	0.010	0.07	0.019	0.09	0.024	0.04	0.012
Total	0.11	0.189	0.12	0.156	0.15	0.112	0.08	0.085

Table A-6. Average monthly soil respiration in g $Cm^{-2}day^{-1}$, May 2005–Dec 2006 according the air temperature model for the ecosystems in Forsmark.

Date	Pasture		Spruce 1		Spruce 2		Deciduous		Wet forest		Clear cut	
	soil respiration	std. dev.	soil respiration	std. dev.	soil respiration	std. dev.	soil respiration	std. dev.	soil respiration	std. dev.	soil respiration	std. dev.
May-05			0.08	0.029	0.07	0.033						
Jun-05	0.08	0.017	0.11	0.043	0.11	0.052	0.06	0.032				
Jul-05	0.11	0.013	0.15	0.055	0.16	0.071	0.09	0.044				
Aug-05	0.09	0.005	0.13	0.036	0.12	0.042	0.07	0.027				
Sep-05	0.07	0.030	0.10	0.034	0.09	0.038	0.05	0.024				
Oct-05	0.05	0.039	0.07	0.024	0.06	0.024	0.03	0.015				
Nov-05	0.04	0.026	0.05	0.018	0.04	0.018	0.02	0.010				
Dec-05	0.02	0.024	0.04	0.008	0.03	0.007	0.01	0.004				
Jan-06	0.02	0.008	0.03	0.012	0.03	0.006	0.01	0.006	0.02	0.007	0.04	0.014
Feb-06	0.02	0.006	0.03	0.008	0.03	0.004	0.01	0.004	0.02	0.005	0.04	0.008
Mar-06	0.02	0.006	0.03	0.009	0.03	0.005	0.01	0.004	0.02	0.006	0.04	0.011
Apr-06	0.04	0.013	0.05	0.019	0.04	0.008	0.02	0.011	0.03	0.011	0.07	0.021
May-06	0.05	0.016	0.08	0.022	0.05	0.008	0.04	0.014	0.05	0.012	0.09	0.024
Jun-06			0.13	0.061	0.07	0.016	0.07	0.048	0.08	0.032	0.16	0.062
Jul-06			0.19	0.077	0.08	0.018			0.10	0.035	0.19	0.064
Aug-06									0.09	0.025	0.17	0.048
Sep-06									0.07	0.018	0.13	0.033
Oct-06									0.05	0.011	0.09	0.022
Nov-06									0.03	0.007	0.07	0.014
Dec-06									0.03	0.007	0.06	0.014
Total	0.05	0.034	0.08	0.056	0.07	0.050	0.04	0.034	0.05	0.032	0.10	0.061

Table A-7. Average monthly soil respiration in g $Cm^{-2}day^{-1}$, May2005–Dec2006 according the soil temperature model for the ecosystems in Forsmark.

Date	Pasture Soil respiration	std. dev.	Spruce 1 Soil respiration	std. dev.	Spruce 2 soil respiration	std. dev.	Deciduous soil respiration	std. dev.	Wet forest soil respiration	std. dev.	Clear cut soil respiration	std. dev.
May-05			0.08	0.061	0.07	0.019						
Jun-05	0.21	0.128	0.15	0.134	0.09	0.025	0.08	0.033				
Jul-05	0.34	0.188	0.29	0.229	0.11	0.030	0.11	0.043				
Aug-05	0.25	0.108	0.14	0.064	0.10	0.021	0.09	0.028				
Sep-05	0.18	0.092	0.09	0.030	0.08	0.021	0.07	0.026				
Oct-05	0.11	0.054	0.06	0.021	0.06	0.016	0.05	0.018				
Nov-05	0.07	0.035	0.05	0.016	0.05	0.013	0.04	0.013				
Dec-05	0.04	0.012	0.03	0.007	0.04	0.006	0.02	0.006				
Jan-06	0.03	0.017	0.03	0.011	0.03	0.009	0.02	0.008	0.02	0.007	0.04	0.012
Feb-06	0.03	0.012	0.03	0.007	0.03	0.006	0.02	0.006	0.02	0.005	0.04	0.008
Mar-06	0.03	0.013	0.03	0.009	0.03	0.008	0.02	0.007	0.02	0.006	0.03	0.009
Apr-06	0.07	0.038	0.05	0.016	0.05	0.013	0.04	0.014	0.04	0.010	0.06	0.017
May-06	0.12	0.053	0.07	0.018	0.06	0.014	0.05	0.017	0.05	0.012	0.08	0.020
Jun-06			0.12	0.046	0.10	0.034	0.09	0.047	0.08	0.028	0.13	0.050
Jul-06			0.16	0.056	0.13	0.040			0.10	0.030	0.16	0.054
Aug-06									0.09	0.022	0.14	0.039
Sep-06									0.07	0.016	0.11	0.028
Oct-06									0.05	0.011	0.08	0.018
Nov-06									0.04	0.007	0.06	0.012
Dec-06									0.04	0.007	0.06	0.012
Total	0.12	0.127	0.09	0.103	0.07	0.035	0.05	0.038	0.05	0.029	0.08	0.051

Table A-8. Regression statistics for relationships between GPP and PAR and air temperature. Equations follow the form $GPP = GPP_0 + b_1T_a + b_2T_a^2 + b_3T_a^3$ for the air temperature regression and $GPP = (GPP_{max}\ PAR) / (K_m + PAR)$ for the PAR regression. GPP_0 is GPP at 0 PAR, GPP_{max} is saturated GPP and K_m is the PAR level where GPP is half the saturated GPP. GPP is in gC $m^{-2}h^{-1}$ and d.f. is degrees of freedom. PAR is in µmol photons $m^{-2}s^{-1}$.

Ecosystem	SKB ID-code	Regression	d.f	$GPP_{0,\ max}$	b_1, K_m	b_2	b_3	*F*-value	*p*-value	R^2
Agricultural field	ASM 000015	Air temperature	37	–0.2472	0.0322	–0.0010	1.2E–05	5.99	0.002	0.333
	ASM 000015	PAR	39	0.2147	269.7967	–	–	13.52	<0.001	0.262
Young pine	ASM 000016	Air temperature	37	0.2053	–0.0525	0.0038	–8.E–05	1.31	0.285	0.099
	ASM 000016	PAR	31	0.0942	112.6014	–	–	2.21	0.05>p>0.02	0.069
Wet forest	ASM 001434	Air temperature	38	–0.3510	0.0459	–0.0013	–	0.89	0.418	0.046
	ASM 001434	PAR	38	0.2311	358.6371	–	–	10.889	>0.001	0.227
Poor fen	ASM 001443	Air temperature	37	–0.1525	0.0159	–0.0002	1.1E–06	6.80	0.001	0.362
	ASM 001443	PAR	39	0.2100	271.4432	–	–	21.59	>0.001	0.362
Pasture	AFM001257	Air temperature	42	–0.6618	0.370	–	1.0E–05	1.80	0.178	0.081
	AFM001257	PAR	44	8.6927e+18	6.3294e+22	–	–	11.60	>0.001	0.213
Spruce 2	AFM001259	Air temperature	57	1.1488	–0.1940	0.0100	–0.0002	1.49	0.227	0.074
	AFM001259	PAR	56	0.1221	14.5407	–	–	1.22	>0.50	0.020

Table A-9. Average monthly GPP in g $Cm^{-2}day^{-1}$ during the growing season 14th of April 2006 –3rd of November 2006. The April and November values are only the days included in the growing season.

Ecosystem Date	Poor fen GPP mean ± s.d.	Agricultural field GPP mean ± s.d.
April	3.15 ± 0.75	3.23 ± 0.74
May	3.93 ± 0.62	4.03 ± 0.61
June	4.41 ± 0.59	4.51 ± 0.58
July	4.45 ± 0.42	4.56 ± 0.41
August	3.50 ± 0.67	3.59 ± 0.66
September	2.95 ± 0.36	3.02 ± 0.35
October	1.61 ± 0.58	1.65 ± 0.57
November	1.50 ± 0.51	1.54 ± 0.49

Table A-10. Average residuals of air temperature based model for Laxemar in g $Cm^{-2}h^{-1}$, model values were subtracted from measured value. All residuals but the ones with [1] were inside the 95% confidence interval of the air temperature modelled soil respiration. [1] means that the model was underestimating soil respiration.

Date	Poor fen	Agricultural Field	Young Pine	Wet Forest
30th–31st of march 2006	0.00	–0.01	0.01	–0.01
10th of may 2006	0.13[1]	0.10	0.03	–0.02
21st of June 2006	0.11	0.21	0.13	–0.04
23rd of August 2006	0.22[1]	0.20	0.03	0.09
26th of September 2006	0.09	0.02	0.05	–0.04
26th of October 2006	0.01	0.00	0.01	0.01
Total	0.11	0.08	0.04	0.00

Table A-11. Average residuals of air temperature based model for Forsmark in g $Cm^{-2}h^{-1}$, model values were subtracted from measured value. All residuals but the one with [1] were inside the 95% confidence interval of the air temperature modelled soil respiration. [1] means that the model was underestimating soil respiration. Missing data means that no comparison could be done because no field measurements were done.

Date	Pasture	Spruce 1	Spruce 2	Deciduous	Wet forest	Clear cut
2nd of May 2005		–0.07	–0.09	–	–	–
13th of June 2005– 16th of June 2005	0.31[1]	0.02	–0.02	0.12	–	–
2nd of August 2005	0.21	0.27	0.10	0.07	–	–
24th of August 2005	0.12	–0.12	–0.01	–	–	–
30th of September 2005– 5th of October 2005	–0.01	0.05	0.05	0.00	–	–
9th of December 2005– 15th of December 2005	–0.04	–0.04	–0.01	–0.02	–	–
8th of February 2006– 22nd of February 2006	–0.02	–0.02	0.01	0.00	–	–
2nd of march 2006– 23rd of March 2006	–	–	–	–	–0.03	–0.04
16th of may 2006– 1st of June 2006	0.15	0.08	–0.01	0.03	–0.03	–
4th of July 2006– 5th of July 2006	–	–0.03	–0.10	–	0.10	0.13
12th of September 2006	–	–	–	–	0.01	0.42[1]
25th of October 2006	–	–	–	–	0.02	0.01
Total	0.10	0.02	–0.01	0.03	0.02	0.13

Table A-12. Average residuals of soil temperature based model for Laxemar in g $Cm^{-2}h^{-1}$, model values were subtracted from measured value. All residuals were inside the 95% confidence interval of the soil temperature modelled soil respiration.

Date	Poor fen	Agricultural Field	Young Pine	Wet Forest
30th–31st of march 2006	–0.01	–0.01	–0.03	–0.04
10th of may 2006	0.08	0.05	–0.04	–0.05
21st of June 2006	0.02	–0.05	0.03	–0.06
23rd of August 2006	0.08	0.09	0.01	0.07
26th of September 2006	–0.18	–0.04	0.09	–0.07
26th of October 2006	0.01	0.00	0.07	0.03
Total	0.00	0.01	0.02	–0.02

Table A-13. Average residuals of soil temperature based model for Forsmark in g $Cm^{-2}h^{-1}$, model values were subtracted from measured value. All residuals but the one with [1] were inside the 95% confidence interval of the air temperature modelled soil respiration. [1] means that the model was underestimating soil respiration. Missing data means that no comparison could be done since no field measurements were done.

Date	Pasture	Spruce 1	Spruce 2	Deciduous	Wet forest	Clear cut
2nd of May 2005	–	–0.08	–0.08		–	–
13th of June 2005– 16th of June 2005	0.17	0.00	0.05	0.09	–	–
2nd of August 2005	–0.01	0.22	0.14	0.05	–	–
24th of August 2005	–0.05	–0.44	0.08	–	–	–
30th of September 2005– 5th of October 2005	–0.08	0.07	0.07	–0.03	–	–
9th of December 2005– 15th of December 2005	–0.06	–0.01	–0.02	–0.03	–	–
8th of February 2006– 22nd of February 2006	–0.03	0.00	0.00	–0.01	–	–
2nd of march 2006– 23rd of March 2006	–	–	–	–	–0.03	–0.02
16th of may 2006 – 1st of June 2006	0.10	0.09	–0.01	0.01	–0.03	
4th of July 2006– 5th of July 2006	–	–0.20	–0.01	–	0.09	0.14
12th of September 2006	–	–	–	–	0.00	0.43[1]
25th of October 2006	–	–	–	–	0.02	0.02
Total	0.01	–0.03	0.03	0.02	0.01	0.14

Table A-14. Average residuals, PAR based models against field measured GPP for the agricultural field and the poor fen. Residuals are given in g $Cm^{-2}h^{-1}$. All residuals were inside the 95% confidence interval of the modelled GPP.

Date	Agricultural field	Poor Fen
9th of May	0.02	0.00
20th of June	–0.03	–0.01
22nd of August	0.10	0.03
26th of September	–0.07	–0.06
26th of October	–0.05	–0.01
Total	–0.01	–0.01