R-06-41

Aspects of the carbon cycle in terrestrial ecosystems of Northeastern Småland

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February 2006

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Keywords: Carbon fluxes, Soil respiration, Primary production, Climate change, Ecosystem modeling, LPJ-GUESS, Simpevarp.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author and do not necessarily coincide with those of the client.

Foreword

This master thesis of 20 points was the finishing degree project in my studies in Environmental Science at Lund University and it was done at the department of Physical Geography and Ecosystem analysis. The Swedish Nuclear Fuel and Waste Management Co. (SKB) commissioned the project and all field measurements has been taken place at one of their sites investigated for a future deep repository of nuclear waste, the Simpevarp Investigation area. The master thesis passed with distinction and is now published in the site investigation report series by SKB to be further spread to the public.

First I like to thank:
SKB for the funding and all support. I am also grateful to the landowners in the Simpevarp investigation area for letting me do my field measurements on their properties.

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Abstract

Boreal and temperate ecosystems of the northern hemisphere are important for the future development of global climate. In this study, the carbon cycle has been studied in a pine forest, a meadow, a spruce forest and two deciduous forests in the Simpevarp investigation area in southern Sweden (57°5’N, 34°55’E). Ground respiration and ground Gross Primary Production (GPP) has been measured three times during spring 2004 with the closed chamber technique. Soil temperature, soil moisture and Photosynthetically Active Radiation (PAR) were also measured. An exponential regression with ground respiration against soil temperature was used to extrapolate respiration over spring 2004. A logarithmic regression with ground GPP against PAR was used to extrapolate GPP in meadow over spring 2004. Ground respiration is affected by soil temperature in all ecosystems but pine, but still it only explains a small part of the variation in respiration and this indicates that other abiotic factors also have an influence. Soil moisture affects respiration in spruce and one of the deciduous ecosystems. A comparison between measured and extrapolated ground respiration indicated that soil temperature could be used to extrapolate ground respiration. PAR is the main factor influencing GPP in all ecosystems but pine, still it could not be used to extrapolate GPP in meadow since too few measurements were done and they were from different periods of spring. Soil moisture did not have any significant effect on GPP. A Dynamic Global Vegetation Model, a DGVM called LPJ-GUESS, was downscaled to the Simpevarp investigation area. The downscaled DGVM was evaluated against measured respiration and soil organic acids for all five ecosystems. In meadow, it was evaluated against Net Primary Production, NPP. For the forest ecosystems, it was evaluated against tree layer carbon pools. The evaluation indicated that the DGVM is reasonably well downscaled to the Simpevarp investigation area and it was used for future predictions of soil respiration, tree layer carbon pool and fast decomposing soil organic carbon pool, 2001–2100. NPP was also predicted for meadow. Two different climate scenarios were used. The fast decomposing soil organic carbon pools and soil respiration increased for all ecosystems, the tree layer carbon pools increased for the forest ecosystems and NPP increased in meadow in both scenarios, 2001–2100.

Sammanfattning

De boreala och tempererade ekosystemen på den norra hemisfären har en stor betydelse för hur klimatet kommer att utvecklas i framtiden. I denna undersökning har kolets kretslopp undersökts i en tallskog, en betesmark, en granskog och två lövskogar i Simpvarps undersökningsområde (57°5’N, 34°55’E). Markrespiration och markskiktets bruttoprimärproduktion (GPP) har mätts i fält vid tre olika tillfällen under våren 2004. Det har skett med hjälp av en infrarödgasanalysator som kopplats till en plexiglaskammare. Jordtemperatur, jordfuktighet och den del av solljuset som fotosynteserande växter tar upp (PAR) har även mätts. Jordtemperaturen användes till att beräkna markrespiration under våren 2004 och PAR användes till att beräkna markskiktets GPP i betesmarken under våren 2004. Jordtemperaturen påverkar markrespiration i alla ekosystem utom tallskogen, men den förklarar bara en liten del av variationen i markrespirationen. Jordens fuktighet påverkar markrespirationen i granskogen och i en av lövskogarna. Jordtemperaturen kan användas till att beräkna markrespiration under vårens gång. PAR är den främsta faktorn som påverkar GPP i alla ekosystem utom tallskogen. PAR kan dock inte användas till att beräkna GPP under vårens gång eftersom för få mätningar gjordes vid vart mättillfälle. Det går inte att använda data från olika mättillfällen vid beräkningarna eftersom det är skillnad på yttre faktorer som t ex vegetation och temperatur. Jordens fuktighet har ingen signifikant påverkan på GPP. En Dynamisk Global Vegetations Modell, en DGVM som kallas LPJ-GUESS användes även till att göra simuileringar för de olika ekosystemtyperna. Klimatdata för Simpevarp fördes in i DGVMn och sedan kontrollerades den gentemot fältmättningar från de fem ekosystemen. Den kontrollerades mot markrespiration, mängd kol i trädskikt och mängd snabbnedbrytbara organiska syror i marken i alla fem ekosystem samt nettoprimärproduktion (NPP) i betesmarken. Inom en rimlig gräns gav DGVMn samma resultat som fältundersökningarna gjorde. DGVMn användes till framtidssimuleringar 2001–2100 av de kolflöden och de kolpooler som den var utvärderad gentemot. Två olika framtidsklimatscenarier användes. I båda scenarierna ökade NPP i betesmarken, mängden kol i trädskiktet, mängden snabbnedbrytbart kol i marken och jordrespirationen.

Contents

1 Introduction

The average temperature on earth has increased 0.8°C since 1860. The increase is probably due to human emissions of greenhouse gases, among them carbon dioxide. /IPCC 2001/ predicts an increase in average global temperature by 1.4–5.8°C in the coming century, 2001–2100. Precipitation patterns will also be altered /IPCC 2001/.

Boreal and temperate forests of the northern hemisphere are important for the future development of global climate. They are today considered the most important terrestrial carbon sinks and contain a large soil organic carbon pool /Denning et al. 1995/. The largest increase in air temperature is expected at high latitudes /IPCC 2001/. The combination with a large soil organic carbon pool and an increase in air temperature can result in a change in the boreal and temperate forests from being carbon sinks to become sources /Kirschbaum 1995/.

In the study of the carbon cycle forests have been in focus due to their large productivity, while grasslands have received less attention /Valentini et al. 2000/. Grasslands are important for the global carbon cycle since approximately 40% of the world's surface is grassland /White et al. 2000/. Most grasslands are grazed and it is therefore important to understand the carbon cycle of meadows /LeCain 2002/.

Especially soil respiration can be increased due to global warming /Kirschbaum 1995/. Soil carbon fluxes represent around 70% of total forest ecosystem respiration /Janssens et al. 2001/. All respiration in grasslands comes from the ground level. Ground carbon fluxes are therefore an important part of the total carbon exchange with the atmosphere. During daytime, soil respiration is diminished by photosynthesis of the ground vegetation /Widén 2002/. Where there are sufficient light conditions for photosynthesis by ground vegetation, ground carbon fluxes are affected /Widén 2002/.

Different methods to calculate annual carbon fluxes of forest floors have been used, and among them different regression equations with carbon fluxes against abiotic factors /Janssens et al. 2003, Olsrud and Christensen 2004/. /Janssens et al. 2003/ found that regression functions, with respiration against soil temperature and soil moisture gave similar results as total annual flux. /Olsrud and Christensen 2004/ used Photosynthetically Active Radiation (PAR) to calculate Gross Primary Production (GPP).

More advanced modelling than simple regression calculations is required to simulate responses of ecosystems to long-term climatic change. Dynamic Global Vegetation Models (DGVMs) have been developed for this type of predictions and these include both vegetation dynamics and biogeochemical processes /Cramer et al. 2001/.

1.1 Aims and hypotheses

The study sets out to investigate the carbon cycle of boreal/temperate ecosystems of Northeastern Småland. There are three general aims. First, the influence of abiotic factors on ground carbon fluxes in boreal/temperate forests and a meadow is to be analysed.

Second, to see if abiotic factors can be used to calculate ground carbon fluxes over spring 2004. Third, to use a Dynamic Global Vegetation Model to study changes in ground carbon fluxes and carbon pools in the boreal/temperate ecosystems 2001–2100. Eight specific hypothesises are set up.

1. Previous studies have indicated that soil temperature and soil moisture has an effect on ground respiration /Lloyd and Taylor 1994, Swanson and Flanagan 2001, Morén and Lindroth 2000, Davidson et al. 1998, Davidson et al. 2000/. The first specific hypothesis is that ground respiration is affected by soil temperature and soil moisture.
2. It has been shown that simple regressions are sufficient to model respiration over a longer time period /Janssens et al. 2003, Olsrud and Christensen, 2004/. The second specific hypothesis is that soil temperature can be used to calculate respiration over spring 2004.
3. Precipitation and photosynthetically active radiation (PAR) are abiotic factors influencing photosynthesis /Lambers et al. 1998/. The third specific hypothesis is that GPP is affected by PAR and soil moisture.
4. It has also been shown that simple regressions can be used to calculate GPP over a longer time period /Olsrud and Christensen 2004/. The fourth specific hypothesis is that PAR can be used to calculate GPP in meadow over spring 2004.
5. It have been shown in previous simulations with future scenarios that global warming and an increase in atmospheric concentration of carbon dioxide will result in an increase in NPP /Pussinen et al. 1997, White et al. 2000, Cramer et al. 2001/. The fifth specific hypothesis is that NPP in meadow will increase 2001–2100.
6. Simulations with different types of DGVM and different futures scenarios have shown an increase in the vegetation carbon pool over the next century /White et al. 2000, White et al. 1999, Cramer et al. 2001, Pussinen et al. 1997/. The sixth specific hypothesis is that the tree layer carbon pool will increase 2001–2100.
7. Global warming will increase the temperature and this increases soil respiration /Kirschbaum 1995/, which has also been shown in simulations with future scenarios /White et al. 2000, White et al. 1999, Cramer et al. 2001, Cox et al. 2000, Pussinen et al. 1997/. The seventh specific hypothesis is that soil respiration will increase 2001–2100.
8. Earlier future simulations have shown that global warming and an increase in soil respiration can result in a decrease in soil organic carbon pools /Cox et al. 2000, White et al. 2000/. The eighth specific hypothesis is that fast decomposing soil organic carbon pool will decrease 2001–2100.

The study is divided into two parts, field measurements and DGVM simulations. First, ground carbon fluxes and abiotic factors will be investigated in a pine forest, a meadow, a spruce forest and two deciduous forests in the Simpevarp region in Northeastern Småland. To investigate the first and the third hypothesises measured ground carbon fluxes will be analysed against abiotic factors. Soil temperature will be used to calculate ground respiration in all ecosystems over spring 2004 and PAR will be used to calculate GPP. Comparing the calculated results with the field measurements will test the second and fourth hypothesis.

In the second part a DGVM (LPJ-GUESS) will be downscaled to the Simpevarp region and hereby be valid for the same ecosystems measured at. Results from the downscaled DGVM with simulations for spring 2004 will be evaluated against field-measured results for spring 2004. Simulations for 2001–2100 will be done to test the fifth, sixth, seventh and eight hypotheses.

2 The carbon cycle in terrestrial ecosystems

All living tissues are composed of carbon and all life on Earth is depending on processes in the carbon cycle. Photosynthesis and respiration are together with mortality and different disturbance regimes (fire, storms, drought etc) the processes of main importance for the carbon cycle /Schlesinger 1997/.

2.1 Gross Primary Production, GPP

The total uptake of carbon through photosynthesis is called Gross Primary Production, GPP. 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.

$6\ CO_2 + 6\ H_2O + \text{sunlight} = C_6H_{12}0_6 + 6\ O_2$

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

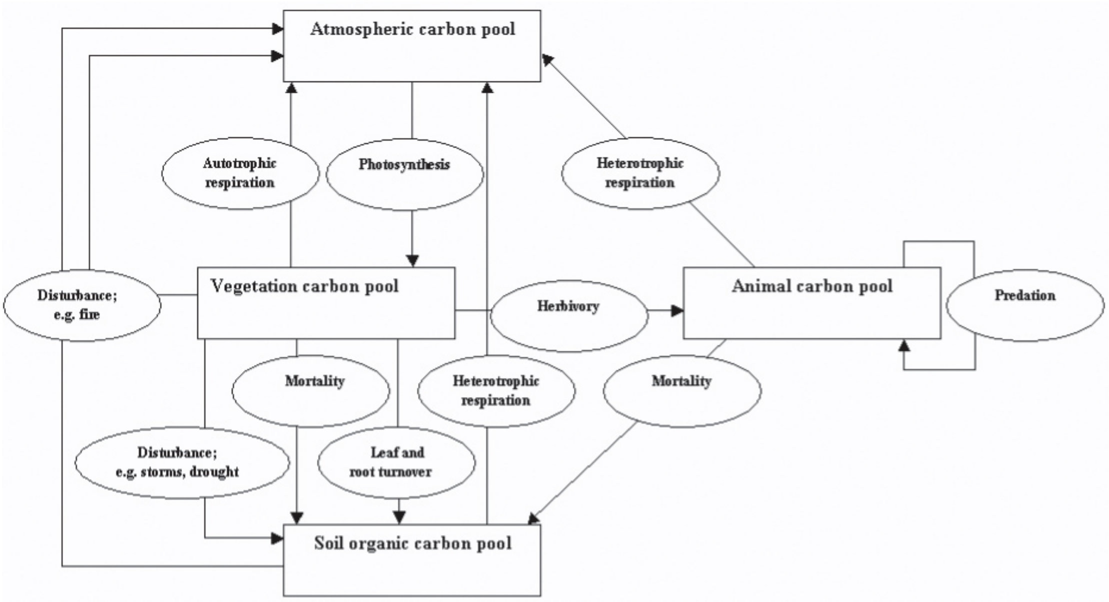


Figure 2-1. *Flowchart over carbon cycle in terrestrial ecosystems. Squares are carbon pools; arrows and circles are processes moving carbon between the pools.*

2.2 Respiration

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

$C_6H_{12}0_6 + 6\ O_2 = 6\ CO_2 + 6\ H_2O$ + energy

The plants use about half of GPP for their own maintenance and the carbon dioxide is then released back to the atmosphere through autotrophic respiration /Schlesinger 1997/. Twenty percent of GPP is consumed by herbivores and becomes a part of the animal carbon pool /Cyr and Face 1993/; 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 is either released to the atmosphere through disturbance, such as fire, or transported to the soil through mortality of the vegetation. Part of the carbon transported to the soil is decomposed and released to the atmosphere through heterotrophic soil respiration.

Soil respiration rate 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 2001/.

Soil respiration and soil moisture has different relationships at different moisture ranges /Davidson et al. 2000, Janssens et al. 2003/. In dry soils there is a positive linear relationship. Soil respiration can be inhibited due to dryness. 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 1981/. Nitrogen and lignin content in litter will speed up respectively slow down the breakdown processes /Yao 2003/. In soil organic matter there are different acids that are more or less easy to decompose /Schlesinger 1997/.

2.3 Net Primary Production, NPP

Net Primary Production, NPP, is here defined as the rate at which plants accumulate carbon in their living tissues, GPP minus autotrophic respiration.

$NPP = GPP – R_p$
R_p = autotrophic respiration

NEP – Net Ecosystem Production is net primary production on an ecosystem level.

$NEP = GPP – R_t$
$R_t = (R_p + R_h + R_d)$
R_t = total respiration, R_d = heterotrophic respiration,
R_h = herbivore respiration.

In ecosystems being young or exposed to disturbances, most of the NEP goes to the production of new plant tissues /Giese et al. 2003/. In old and stable ecosystems GPP mainly goes to the maintenance of the vegetation and most of NEP will be allocated to the soil organic carbon pool /Giese et al. 2003/.

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/.

2.4 Vegetation carbon pool

The terrestrial biosphere has an important role in the carbon cycle. Ecosystems can be sources and release carbon to the atmosphere, or they can be sinks and take up carbon from the atmosphere. Different amount of carbon is taken up by the vegetation depending on biotic factors like species of vegetation, age and production of the ecosystem /Grace 2003/. Abiotic factors of importance are temperature, humidity, nutrients, incoming solar radiation and disturbances /Schlesinger 1997/.

2.5 Soil organic carbon pool

NEP is delivered to the soil organic carbon pool as litter fall. Litter is undecomposed dead organic material. Decomposition of litter is a two-part process. It is the breakdown of litter at the soil surface and it is the accumulation of soil organic matter /Olsson et al. 2002/. Decomposition results in release of carbon dioxide, water and nutrients. Soil organic matter is highly resistant humus and it can be divided into two parts /Olsson et al. 2002/. About 15% of the soil organic matter is in the bulk of the soil, slowly decomposing and having an age of thousands of years /Schlesinger 1997/. The remaining 85% is closer to the surface, fast decomposing and of much more recent origin.

2.6 Human influences

Humans have influenced the carbon cycle since they started to use land for rising crops /IPCC 2001/. Carbon stored in the soil can be released back to the atmosphere when land-use is changed and forests are clear-cut. Since industrial revolution, humans have started a large-scale influence on the carbon cycle. By using fossil fuels, carbon stored in the lithosphere is released back to the atmosphere. Carbon dioxide is a greenhouse gas and it has impact on the global climate. The mean global temperature increased 0.8°C 1860–2000 /IPCC 2001/. A reason could be the rise in concentration of greenhouse gases due to anthropogenic emissions.

The atmospheric concentration of greenhouse gases will continue to increase well into the next century /IPCC 2001/. Different future scenarios have been developed for forecasting climate due to future emissions of greenhouse gases. The different scenarios are depending on how the economic, social and environmental situation will develop. Two basic types exist; A-scenarios are more economic and technological orientated compared to the B-scenarios, which describes more of a service society. These are then divided into A1- and B1-scenarios that have a faster development and a more global approach compared to the A2- and B2-scenarios, which are more regional in their economic, technological and environmental development /IPCC 2001/.

3 Description of DGVM

The model used is a dynamic global vegetation model, LPJ (Lund Potsdam Jena)-GUESS (General Ecosystem Simulator). A Dynamic Global Vegetation Model, DGVM, combines the dynamic ecological processes with the biogeochemical processes /Sitch et al. 2003/. The biogeochemical processes are photosynthesis, respiration and transpiration and they are responsible for the movement of material between the different compartments of the environment. The dynamic ecological processes are for example growth, resource competition, tissue turnover, demographic processes and disturbance.

DGVMs developed for simulations on a continental or global scale uses plant functional types as basic unit /Smith et al. 2001/. Plant functional types are the species in an ecosystem with the same type of function and structure. The competition between plant functional types does well for broader scale simulations, but it is too coarse on a smaller scale /Sitch et al. 2003/. Other models uses a more individual approach and they have been shown to do well for simulations on a local scale /Smith et al. 2001/. An individual approach demands much capacity of the computer and these models are not capable of larger scale simulations /Smith et al. 2001/. In LPJ-GUESS a cohort mode can be used; a cohort is a group of individuals of the same species and at the same age. In LPJ-GUESS these are competing with each other and this can be used for intermediate scale simulations, such as on a regional scale /Smith et al. 2001/.

3.1 Abiotic parameters

The simulations are driven by the abiotic input parameters, latitude, soil texture, precipitation, temperature, solar insolation and atmospheric concentration of carbon dioxide. Out of these input parameters are important factors such as day length, growing season, photosynthetically active radiation (PAR), soil temperature, soil water, potential evapotranspiration, snow accumulation and snowmelt derived /Sitch et al. 2003/. The abiotic factors are driving the model and they set the limits for production and maintenance of the vegetation /Sitch et al. 2003/.

3.2 Individual properties

Each species entering the model has input parameters, the properties of the species /Smith et al. 2001/. Tree individuals are characterized by their allocation of carbon to the trunk, roots, branches and leaves. The allocation gives the individual its characteristics of height, crown area, bole height and leaf area index (LAI) /Smith et al. 2001/. The uptake of light and hereby the competition between the individuals is depending on this structure and the LAI /Smith et al. 2001/. Herbaceous plant functional types are not treated on an individual basis /Smith et al. 2001/. The properties of the species also controls establishment rate and climatic limitations, i.e. the conditions where the species can survive /Smith et al. 2001/.

3.3 NPP

Gross Primary Production (GPP) of ecosystems is depending on individual properties and abiotic parameters. The main features of GPP are photosynthesis and water balance /Sitch et al. 2003/. The photosynthesis of the plants is depending on LAI and PAR /Smith et al. 2001/. The fraction of PAR taken up by the woody individuals is depending on LAI at a given height /Smith et al. 2001/. Herbaceous plant functional types take up the PAR that reaches ground level /Smith et al. 2001/. Water balance is divided into two parts, soil water content and evapotranspiration. Soil water content is depending on soil hydrology and precipitation /Sitch et al. 2003/. Soil hydrology depends on an input parameter with 10 different soil texture types. Evapotranspiration is depending on the supply of soil water, water demand of the plant and water demand of the atmosphere. Evapotranspiration can be a limiting factor for photosynthesis if atmospheric demand exceeds water supply of the plant /Sitch et al. 2003/.

Net Primary Production (NPP) is the part of GPP left for tissue production and reproduction. Subtracting autotrophic respiration from GPP gives NPP for each plant /Sitch et al. 2003/. From NPP ten percent of the carbon is taken for reproduction, the rest will be allocated as leaf mass, sapwood mass or root mass /Sitch et al. 2003/. The tissue pools will be reduced due to mortality and tissue turnover /Sitch et al. 2003/.

3.4 Soil organic matter and litter decomposition

Dead leaves, dead roots and all biomass from killed individuals are transferred to the above and below ground litter /Sitch et al. 2003/. When litter is decomposing seventy percent is respired to the atmosphere and the rest is transformed into soil organic matter /Sitch et al. 2003/. Two soil organic matter pools exist, the fast decomposing soil organic matter pool and the slowly decomposing soil organic matter pool /Sitch et al. 2003/. Of the remaining 30 percent decomposed litter, 0.985 enters the fast decomposing soil organic matter pool and 0.015 enters the slowly decomposing soil organic matter pool /Sitch et al. 2003/. The material has turnover times 2.86 years in the litter pool, 33.3 years in the fast decomposing soil organic matter pool and 1000 years in the slowly decomposing soil organic matter pool /Sitch et al. 2003/.

Abiotic factors influencing decomposition is soil temperature and soil moisture. Aboveground decomposition is depending on air temperature and belowground decomposition is related to soil temperature /Sitch et al. 2003/. The temperature dependence follows an exponential relationship. Soil moisture dependence is linear /Sitch et al. 2003/. Total soil respiration is given by summation of respiration from the three pools /Sitch et al. 2003/.

4 Method

4.1 Site description

The investigation took place during spring 2004 at five sites in the Simpevarp investigation area. The Simpevarp investigation area is in the region of Oskarshamn in southern Sweden (57°5’N, 34°55’E). The examined area is 273 km^2. For the period 1st of March to 31st of May, the average temperature was 5.8°C and the average monthly precipitation was 35 mm. Simpevarp investigation area contains a large variety of ecosystems with different types of vegetation. The main ecosystems are coniferous forest, deciduous forest and cultivated land. The region and the sites investigated have been subject to extensive ecological, hydrological, meteorological and geological studies /Lindborg 2005/.

SKB had chosen representative ecosystems for the examined area; a pine forest (pine), a meadow (meadow), a spruce forest (spruce) and two different deciduous forests (deciduous 1 and deciduous 2). A homogeneous area in each ecosystem was used for the measurements. The area was 625 m^2 for spruce and 306 m^2 for pine, meadow, deciduous 1 and deciduous 2.

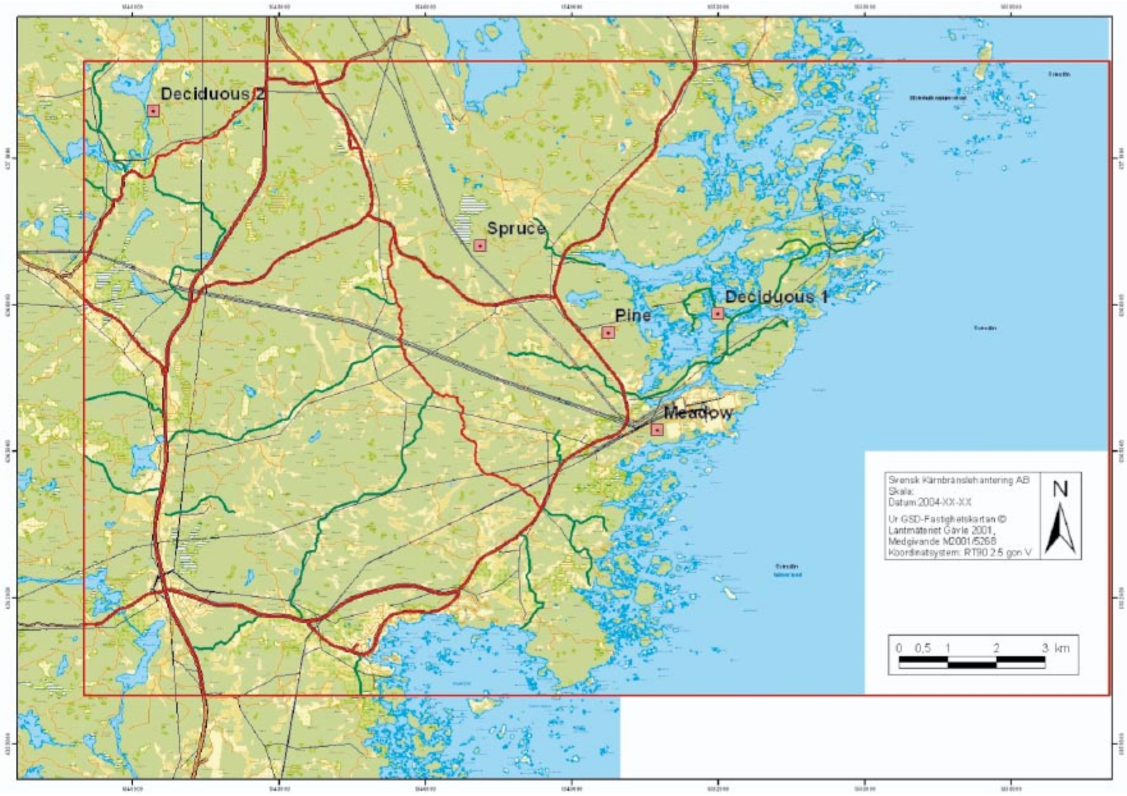


Figure 4-1. Map over Simpevarp investigation area. Dots mark the site of the ecosystems investigated. The red line marks the borders of the Simpevarp investigation area.

4.2 Carbon fluxes at ground ecosystems

The area of each ecosystem was divided into nine equally large parts. Spots to be investigated were randomly selected by taking a certain number of steps into each part spinning around and throwing a stick randomly. The measurement was done where the stick landed. The stick was left to mark the exact location of the plot. The carbon dioxide fluxes between the atmosphere and the ground layer were measured at each plot with the closed chamber technique. An infrared gas analyzer (EGM-4, Environmental Gas Monitor) together with a canopy assimilation chamber (CPY-2) from pp-systems was used /PP-systems 2003/. NEE was measured by placing the canopy assimilation chamber on the ground either for four minutes or when the difference in carbon dioxide concentration had changed 50 ppm in the chamber. Respiration was measured directly afterwards by making a new measurement with a dark hood over the chamber placed on the ground. Meanwhile the soil temperature was measured at a depth of ten cm. A thermometer was left in the pine forest for logging the soil temperature every third hour at a depth of ten cm from the 24th of March until 31st of May.

The NEE and respiration measurements were done three times through spring 2004, the 20th–24th of March, the 16th–20th of April and the 10th–14th of May. In April and May, soil moisture was measured with a moisture meter (Delta-T devices, HH2-moisture meter with a Theta probe, type ML2X). At each plot three different soil moisture measurements were taken and the median value was used.

The 9th–10th of May, NEE and respiration were measured over a 24-hour period in the meadow. Measurements were taken every third hour at three of the plots, the furthest to the south, the one in the middle and the furthest to the North. Soil temperature and soil moisture were also measured.

4.2.1 Data treatment

Some values were very different from the average of the values, probably due to human respiration. Outliers were therefore tested for with the boxplot function in MINITAB 13.0. Boxplots were done for respiration and for NEE with each ecosystem separated. Outliers were taken away from the rest of the analysis. To receive GPP, respiration was subtracted from NEE. Theoretically impossible values, i.e. positive GPP values and negative respiration values, were also excluded.

Exponential regressions with respiration against soil temperature were done /Lloyd and Taylor 1994/. All data measured during spring were included in the analysis. Q_{10}, the relative increase in respiration when soil temperature is increased by 10°C, was calculated by using the formula $Q_{10} = e^{10k}$ /Strömgren 2001/.

The exponential regression equations were used to normalize the respiration values to a soil temperature of 7.28°C, the average value of all soil temperature measurements. Linear regressions with normalized respiration values against soil moisture were calculated /Heal 1981/.

Multiple linear regressions, with measured respiration against soil temperature and soil moisture, were also calculated.

The thermometer used for logging the soil temperature was not properly calibrated. Logged soil temperature was lower than soil temperature measured in the field. The difference between logged soil temperature and field measured soil temperature were calculated for the different ecosystems. The difference between measured soil temperature and logged soil temperature were added to the logged soil temperature for each ecosystem.

Exponential regression equations between respiration and soil temperature were used on the calculated logged soil temperature for each ecosystem; this calculated respiration for the period of 1st of April–31st of May. Average respiration for a 24-hour period was done with the regression calculated respiration for April and May. The regression calculated 24-hour average respiration for meadow in May was tested with a linear regression against the 24-hour period respiration measurements done in meadow in May.

Logarithmic regressions with GPP against PAR /Olsrud and Christensen 2004/ and linear regressions with GPP against soil moisture were done.

At Äspö climate station the total radiation is measured every thirtieth minute /Lärke et al. 2005/. It is given in W m^{-2}, but was changed to micromoles (m^2 and second)$^{-1}$ by multiplication by 4.6 (Hickler, personal communication). PAR is calculated by taking 0.45 of the total radiation /Monteith and Unsworth 1990/. The GPP-PAR logarithmic equation was used to calculate spring GPP for the meadow 1st of March–31st of May. It was only done in meadow since it is the only ground ecosystem without a shading canopy. Average 24-hour period GPP for March, April and May was done with regression calculated GPP values for meadow. A linear regression between the regression calculated 24-hour average GPP for meadow in May against 24-hour measurements from meadow is done.

4.3 Tree layer carbon pool

4.3.1 Field measurements

In each ecosystem the number of trees was counted. Only trees taller than man height (186 cm) were included, these are the trees included in the tree layer. The height and the circumference were measured at ten of the trees. The height was measured at the distance of 15 metres with a clinometer. The circumference was measured at breast height. The ten trees chosen were to represent the different species of the tree population in the area. If there were less than ten trees in the square the closest trees to the area were measured until ten trees had been measured.

4.3.2 Data treatment

Equations from /Marklund 1988/ were used to calculate the biomass of Pine, Spruce and Birch. /Son et al. 2004/ developed equations for the calculation of oak biomass at an oak forest in central Korea. Two different oak equations for two different species (*Quercus variabilis* and *Quercus mongolica*) existed. To see if these equations could be used for a Swedish forest, tables for volume calculations of the stem from /Hagberg and Matérn 1975/, were used. By multiplying the volume by the density of 0.66 kg dm^{-3} found in /Träinformation AB 1970/ the stem biomass was received. The stem values calculated were compared with the stem values from the Korean equations. The Swedish value was in between the values of the two equations from /Son et al. 2004/. An average of the two equations was therefore used.

An equation for root biomass was missing in the equations from /Son et al. 2004/, but they have the amount of root biomass and total biomass of the stands they investigated. The relative amount of roots of the total biomass was used to calculate the root biomass. The root biomass was added to the total biomass calculated with the equations. Equations for biomass of leaves and roots in the birch equations from Marklund were also missing. The relative amount of leaves of total biomass and the relative amount of roots of total biomass from the oak calculations were used for biomass calculation of leaves and roots for the birch. The biomass of roots and leaves for birch were added to the total biomass calculated with the equations.

The average biomass from the ten trees in each ecosystem was calculated. The number of trees in each area was multiplied by the average biomass of the ten trees to get the total biomass in the area. The amount of carbon in the total biomass was received by multiplying the biomass by 0.5 /Lamlom and Savidge 2003/. The total amount of carbon was divided by the area to get carbon m^{-2}.

4.4 Fast decomposing soil organic carbon pool

4.4.1 Field measurements

Five 1-litre soil samples were taken in each area at every second plot where carbon flux measurements were taken. To stop biodegradation of the organic acids the five soil samples were kept in a fridge until 2 hours before centrifugation.

4.4.2 Temperature controlled high-speed centrifugation

Between 200 and 500 g soil was taken out from each sample and weighed in a test tube. The test tubes were centrifuged with 10,000 rev min^{-1} for 30 minutes. The first samples to be centrifuged were drier and to get the soil water out of these samples the centrifuge was set to 12,000 rev min^{-1} for 45 minutes. The obtained soil solutions were transferred to test tubes and kept in a refrigerator at 2°C for three days. They were then placed in a freezer for another six days before the analysis of organic acids.

4.4.3 Organic acid analysis

0.7 ml of each soil solution was analysed in a high-pressure liquid chromatograph. The column used was Dionex ICE-AS6 and the eluent was 0.4 mM Heptaflurobutyric acid. The flow rate was set to 1.0 mL per minute and the injection volume was 50 µL. The organic acids analysed for were oxalic, tartaric, citric, malic, glycolic, formic, lactic, acetic and succinic acid.

4.4.4 Data treatment

The results of the acids were given in µM. To calculate the amount of carbon in the soil solution, the number of carbons in each acid was multiplied with the organic acid concentration. The amount of carbon from all acids was added together. To be able to compare the ecosystems, the differences in soil moisture between the ecosystems were needed. The soil moisture measured at each plot divided by the average soil moisture of all plots in all ecosystems gave a relative value of soil moisture for each plot. By multiplying this relative value with the amount of carbon in the soil water, a relative value of carbon in the soil at each plot was obtained. An average relative value of each ecosystem was calculated and this average value could be compared between the different ecosystems.

4.5 DGVM simulations

4.5.1 Climate parameters

The climate data were found at NORDKLIM, NORDisk KLIMasamarbeid /SMHI 2003/. Climate stations near the Simpevarp investigation area were chosen; these were Växjö, Kalmar, Krokshult and Ölands norra udde. Precipitation data for 1912–2001 were taken from Krokshult. Mean percentage cloudiness, 1890–2000, was found from Växjö. Subtracting part cloudiness from 1 gives solar input.

Calculated temperature 1979–2000 could be found at the global data set for the Balance project /Balance 2002/. Reference values for the temperature 1912–1979 could be calculated for the Simpevarp investigation area /Alexandersson and Moberg 1997/. The calculated temperature set 1979–2000 from the balance project and the nearby stations of Kalmar, Växjö and Ölands Norra Udde were used for the reference value calculations. The reference values were used as input parameter for temperature.

For the 2004-simulations a climate data set for October 2003–May 2004 could be found at Äspö climate station /Lärke et al. 2005/. Radiation at Äspö climate station is given in W m^{-2} and the DGVM is set to use radiation in W m^{-2} instead of part sunshine for the last two years. Average monthly radiation was calculated with data larger than 10 W m^{-2}. The radiation above 10 W m^{-2} is measured during daytime (Smith, personal communication). Average temperature and precipitation 1980–2000 were taken for the missing months, January–September of 2003 and June–December 2004. Radiation values were taken from Äspö climate station 2001.

4.5.2 Carbon dioxide

An annual data set from 1901–1998 for the atmospheric concentration of the carbon dioxide were found from the Carbon Cycle Model Linkage Project /McGuire et al. 2001/. The missing years 1999–2000 and 2003–2004 were taken from /Joos et al. 2001/.

4.5.3 Soil texture

The Simpevarp investigation area contains a wide variation of soil texture. The most common soil type at the plots for my investigations is a sandy moraine soil /Lindborg 2005/. Soil texture in the DGVM was set to soil type 4, a medium-coarse texture type /Sitch et al. 2003/.

4.5.4 Vegetation parameters

The types of vegetation used were spruce (*Picea abies*), pine (*Pinus sylvestris*), beech (*Fagus sylvatica*), silver birch (*Betula pendula*), oak (*Quercus robur*) and grass. For the properties of the vegetation, input parameters from articles were used /Prentice and Helmisaari 1991, Haxeltine and Prentice 1996, Sitch et al. 2003, Smith et al. 2001, Hickler et al. 2004, Sykes et al. 1996, Bugmann 1994, Tutin et al. 1964–1980, Dahl 1990, Bradshaw et al. 2000, Fulton 1991, Skre 1972, Koca et al. unpubl/.

4.5.5 Disturbances

The DGVM is modified so there is an average return time of fire disturbance once every 20th year, this fire regime stops 220 years ago as in the Oskarshamn region. /Niklasson and Drakenberg 2001/. The last 220 years the fire disturbance is set to have an average return time of 250 year. Other disturbances are set to have an average return time of every 100th year; it could for example be withdrawal of trees.

4.5.6 DGVM 2004 simulations

The DGVM is set to start the spin-up period 4500 years ago. The spin-up period uses the first 30 years of the climate and carbon dioxide dataset for 4412 years. The simulations start after the spin-up period, 1912 AD and goes on until 2000 AD. The climate data for 2001 and 2002 were missing so after 2000 comes the dataset for 2003 and 2004.

The species used for the different simulations can be seen in Table 4-1.

Table 4-1. Species entered at different time periods of the simulations.

Simulation	0–3300	3300–4300	4300–4500
Pine	Pine, grass	Pine, grass	Pine, grass
Meadow	Pine, oak, birch, beech, grass	Pine, spruce, oak, birch, beech, grass	Grass
Spruce	Pine, oak, birch, beech, grass	Spruce, grass	Spruce, grass
Deciduous	Oak, birch, beech, grass	Oak, birch, beech, grass	Oak, birch, beech, grass

The species used for the different time periods in the four simulations done in the DGVM.

Four simulations with the ecosystems investigated in the field were done: pine, meadow, spruce and deciduous. Different species were switch on in the simulations depending on when they entered the Simpevarp region. For the different simulations see Table 4-1. According to pollen analysis pine, oak, birch, beech and grass have existed since the last glacial period /Berglund 1968, Lagerås 1996, 2002/. Spruce entered 1200 years ago /Berglund 1968, Lagerås 1996, 2002/.

The meadow simulation has specific settings. 1800 AD is a time period of expansive grassing in the Simpevarp investigation area /Jansson et al. unpubl/. The DGVM is set to only have grass the last 200 years. In the meadow simulations, the disturbance is set to every third year after 1800 AD to simulate grazing.

4.5.7 DGVM evaluation

Average values of measured and regression calculated ground respiration for April and May were calculated. Soil respiration from March, April and May 2004 from the DGVM were plotted against the average measured and regression calculated ground respiration. The 95% confidence intervals of the measured respiration and the regression calculated respiration were compared to the theoretical relationship between the DGVM respiration and field respiration.

In the DGVM, GPP was not obtained, but NPP was. The measured and regression calculated GPP values of meadow in March, April and May were divided by two to obtain measured and regression calculated NPP /Schlesinger 1997/. NPP is defined to be positive and the negative GPP values were changed to be positive. Average values were calculated.

NPP from the DGVM for March, April and May 2004 were tested against the average measured NPP and the average regression calculated NPP. The 95% confidence intervals of measured NPP and regression calculated NPP were compared to the theoretical relationship between DGVM NPP and field NPP.

Tree layer carbon pools of the DGVM were plotted against measured tree layer carbon pool. Only one value for the total ecosystem is given in the field measurements of tree layer carbon pool. A 95% confidence interval can therefore not be calculated and the DGVM tree layer carbon pools were instead divided with measured tree layer carbon pools.

The organic acids measured are fast decomposing but they are not the total fast decomposing soil organic carbon pool /Ström et al. 1994/. To be able to compare field measured soil organic acids with fast decomposing soil organic carbon pool of the DGVM, relative values of soil organic carbon in one ecosystem against soil organic carbon in one of the other ecosystems were calculated. It was done by dividing the amount of soil organic carbon in one ecosystem with the sum of soil organic carbon of two ecosystems. Relative values were calculated for all ecosystems against all other ecosystems. It was done both with the field measured soil organic acids and the fast decomposing soil organic carbon pools of the DGVM. Average relative value for each ecosystem was calculated both for the measured soil organic acids and the DGVM fast decomposing soil organic carbon pools. Average relative values of the DGVM were plotted against average relative values of the measurements. The 95% confidence intervals of the relative values from measured soil organic acids were compared to the theoretical relationship between the DGVM results and the measured results.

4.5.8 DGVM future simulations

Simulations with future scenarios were done. They go from 2001 until 2100. SWECLIM, at SMHI, have used two global climate model predictions, the HadCM3_A2 and the HadCM3_B2, to develop a future climate dataset for the monthly average temperature, monthly precipitation sum and monthly mean solar input /Räisänen et al. 2003/. Climate data for the Simpevarp region were chosen. The data set for carbon dioxide were taken from /Joos et al. 2001/. The future climate dataset for the two simulations, A2 and B2, were used for 2001–2100. The same four ecosystem set-ups were used as for the 2004 simulations, Pine, Meadow, Spruce and Deciduous.

4.5.9 Data treatment

Linear regression analyses were done for changes 2001–2100 in soil respiration, NEE, and fast decomposing soil organic carbon pool for all ecosystems. For meadow a linear regression 2001–2100 was done for NPP. For the forest ecosystems a linear regression 2001–2100 was done for the tree layer carbon pool. All linear regressions were done for both A2- and B2-simulations. The linear regression coefficient gives an average annual change 2001–2100.

5 Result

5.1 Effect of soil temperature and soil moisture on respiration

Soil temperature at 10 cm depth had a significant effect on ground respiration for all ecosystems but pine and spruce. A trend could be seen in the effect of soil temperature on respiration in spruce while soil temperature did not have any effect on ground respiration in pine. Even though there was an effect of soil temperature on ground respiration in spruce and both the deciduous ecosystems, the relationship was weak. Soil temperature only explained a part of the variation in ground respiration, 13.8% for spruce, 18.0% for deciduous 2 and 33.5% for deciduous 1. In meadow, ground respiration was better explained with 78.5% of the variation in respiration predicted by soil temperature. See Table 5-1.

The variation in ground respiration was not only better explained by soil temperature in meadow and deciduous 1; its effect was also stronger here. For these ecosystems, a 10°C change in soil temperature increased ground respiration around six times in the temperature range in which the respiration was measured. A 10°C increase gave more than twice the ground respiration in spruce and deciduous 2 and for pine it resulted in 1.14 times the ground respiration. See Table 5-2.

Table 5-1. Exponential regressions with measured respiration against soil temperature at 10 cm depth.

Ecosystem	DF	a	B	F-value	P-value	R^2
Pine	26	0.0535	0.0135	0.12	0.735	4.7
Meadow	25	0.0325	0.1792	87.63	0.000	78.5
Spruce	25	0.0178	0.0761	3.83	0.062	13.8
Deciduous 1	24	0.0109	0.1718	11.60	0.002	33.5
Deciduous 2	24	0.0235	0.0812	5.05	0.035	18.0

Equations follow the form $Y = a\, e^{bx}$ where Y is respiration in g C (m^2 and hour)$^{-1}$ and x is temperature in °C. R^2 is in %.

Table 5-2. Q_{10}, the relative increase in respiration when soil temperature is increased by 10°C.

Ecosystem	DF	Q_{10}	Soil temperature range (°C)
Pine	26	1.14	2.5–10.1
Meadow	25	6.00	1.2–10.6
Spruce	25	2.14	0.0–8.4
Deciduous 1	24	5.57	2.1 –10.4
Deciduous 2	24	2.25	1.3 –8.8

$Q_{10} = e^{10k}$ /Strömgren 2001/, k is from the exponential regression equations. Soil temperature range is the temperature range measured in the field.

Soil moisture had a significant effect on ground respiration for spruce and deciduous 2. There was no effect of soil moisture on ground respiration in pine, meadow and deciduous 1. Soil moisture explained 25.4% of the variation in ground respiration for spruce and 35.8% of that for deciduous 2. See Table 5-3.

The joint effect of soil temperature and soil moisture on ground respiration was significant in meadow, spruce and deciduous 2, while there was no joint effect in pine and deciduous 1. Ground respiration was better explained with a multiple linear regression in spruce and deciduous 2 than with the single factor equations. In spruce and deciduous 1, 39.5% and 56.2% of the variation in ground respiration was explained, respectively. Ground respiration in meadow was also well explained by a multiple linear regression, but the exponential regression with soil temperature alone explained the variation in ground respiration even better. See Table 5-4.

Table 5-3. Linear regressions with normalized values of measured respiration against soil moisture.

Ecosystem	DF	k	m	F-value	P-value	R^2
Pine	17	0.00021	0.0595	0.23	0.641	1.4
Meadow	16	0.00210	0.0522	0.44	0.519	2.8
Spruce	16	–0.00040	0.0519	5.09	0.039	25.4
Deciduous 1	16	0.00230	–0.0338	1.62	0.223	9.7
Deciduous 2	17	0.00330	–0.0640	8.92	0.009	35.8

The equation follows the form $Y = kx + m$, where Y is respiration in g C (m^2 and hour)$^{-1}$ and x is soil moisture in %vol. R^2 is in %.

Table 5-4. Multiple linear regressions with measured respiration against soil moisture and soil temperature at 10 cm depth.

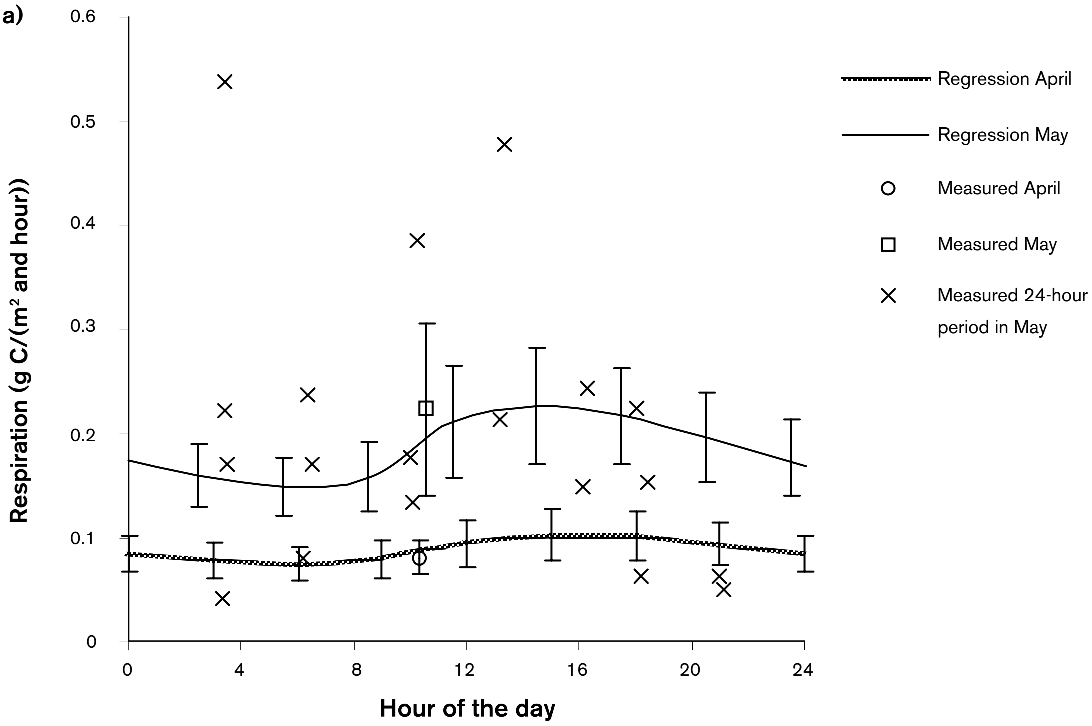
Ecosystem	DF	k_1	k_2	m	F-value	P-value	R^2
Pine	17	–0.00159	0.00004	0.0773	0.12	0.888	1.6
Meadow	16	0.02650	0.00369	–0.1860	11.22	0.001	61.6
Spruce	16	–0.00200	–0.00045	0.0636	4.56	0.030	39.5
Deciduous 1	16	0.00763	0.00244	–0.0928	2.20	0.148	23.9
Deciduous 2	17	–0.00795	0.00252	0.0198	9.64	0.002	56.2

The equations follow the form $Y = k_1x + k_2z + m$, where Y is respiration in g C (m^2 and hour)$^{-1}$, x is soil temperature (°C) and z is soil moisture (%vol). R^2 is in %.

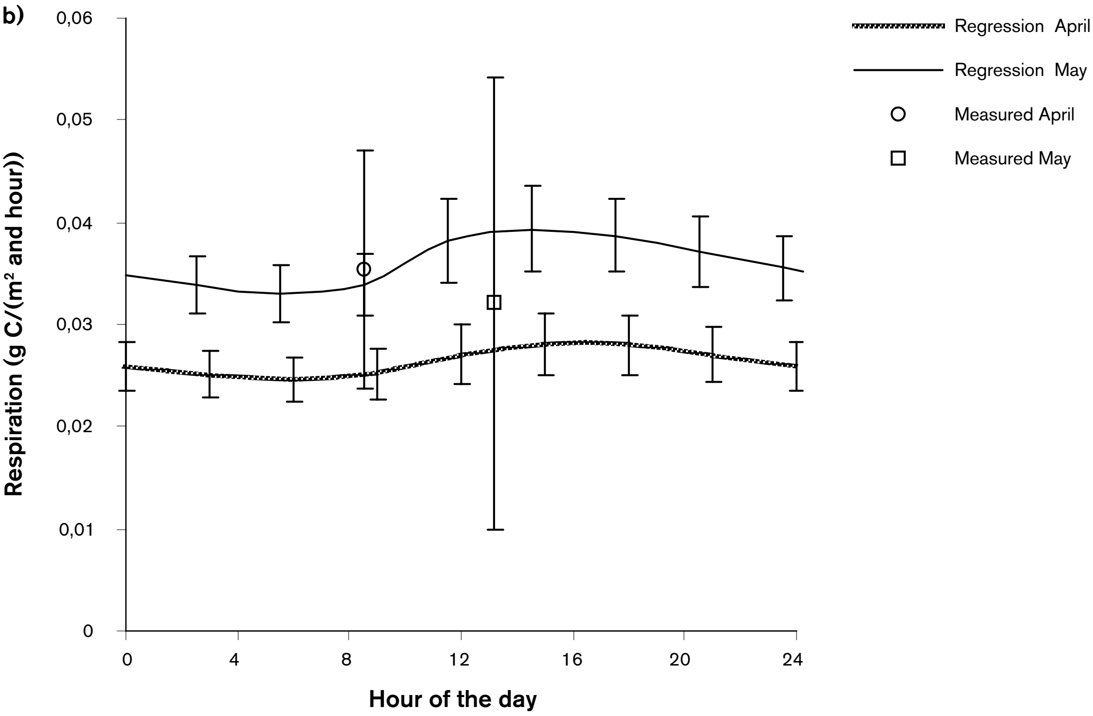
5.2 Respiration calculated over spring 2004

The exponential regression equation with ground respiration against soil temperature was used to calculate ground respiration for April and May in the ecosystems where there were significant relationships. The average 24-hour period regression calculated respiration is within the 68.6% confidence interval of the field measurements, which indicates that the regression equations can be used to calculate ground respiration (Figure 5-1a–d). An extra test was done with the regression calculated respiration for meadow against measured 24-hour period respiration from May and it indicated that the regression equations cannot be used to calculate the respiration.

a)


Respiration (g C/(m² and hour))
0.6
0.5
0.4
0.3
0.2
0.1
0
0
4
8
12
16
20
24
Hour of the day
Regression April
Regression May
Measured April
Measured May
Measured 24-hour period in May

b)


Respiration (g C/(m² and hour))
0,06
0,05
0,04
0,03
0,02
0,01
0
0
4
8
12
16
20
24
Hour of the day
Regression April
Regression May
Measured April
Measured May

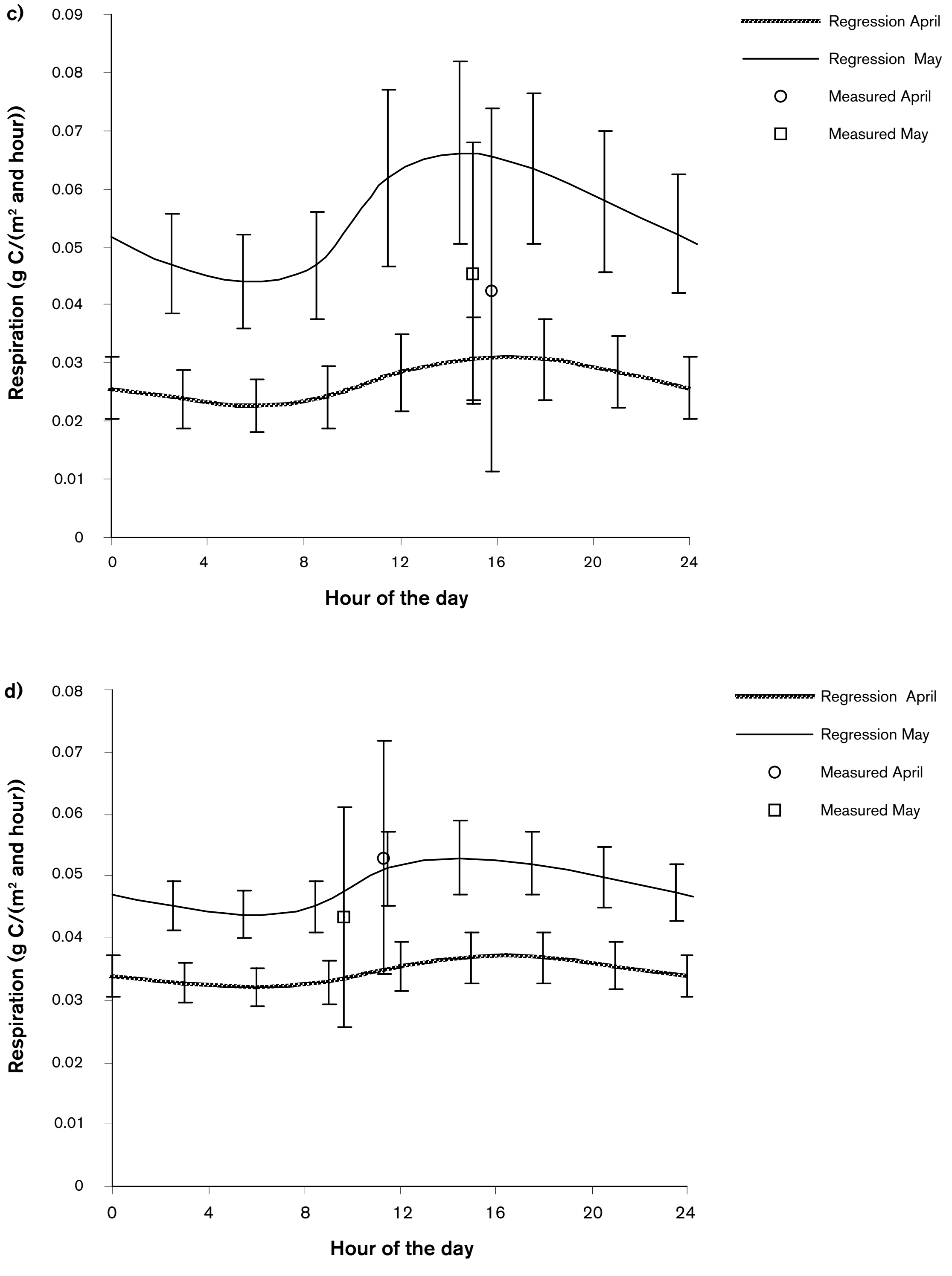


Figure 5-1. *Daily variation in respiration. The lines are average regression calculated respiration in g C (m^2 and hour)$^{-1}$ for April and May for (a) meadow, (b) spruce, (c) deciduous 1 and (d) deciduous 2. The dots are average measured values from (a) the 13th of April and 10th of May, (b) the 15th of April and 12th of May, (c) the 13th, 14th April and 12th of May and (d) the 15th of April and 12th of May. The error bars show 1 standard deviation (68.6% confidence interval) from the average values. For meadow the measured 24-hour period from May are also shown. Notice the difference in scale at the y-axis.*

5.3 Effect of PAR and soil moisture on ground GPP

PAR had significant effects on ground GPP in all ecosystems but pine, where PAR did not affect GPP. For the ecosystems with a significant relationship GPP was reasonably well explained by PAR, between 31.8 and 44.7% of the variation in GPP was explained by PAR. See Table 5-5.

Soil moisture on the other hand did not seem to have any significant effect on GPP in the ecosystems measured at. There was however a trend in meadow and here 21.4% of the variation in GPP was explained by soil moisture. See Table 5-6.

Table 5-5. Logarithmic regressions with measured GPP against PAR.

Ecosystem	DF	k	m	F-value	P-value	R^2
Pine	22	–0.0076	–0.0014	1.52	0.231	6.8
Meadow	23	–0.0659	0.2544	14.08	0.001	39.0
Spruce	19	–0.0076	0.0125	8.38	0.010	31.8
Deciduous 1	18	–0.0327	0.1412	13.72	0.002	44.7
Deciduous 2	22	–0.0185	0.0586	11.66	0.003	35.7

The equation follows the form Y = k Ln (x) + m, where Y is GPP in g C (m^2 and hour)$^{-1}$ and x is PAR in micromoles (m^2 and second)$^{-1}$. R^2 is in %.

Table 5-6. Linear regressions with measured GPP against soil moisture.

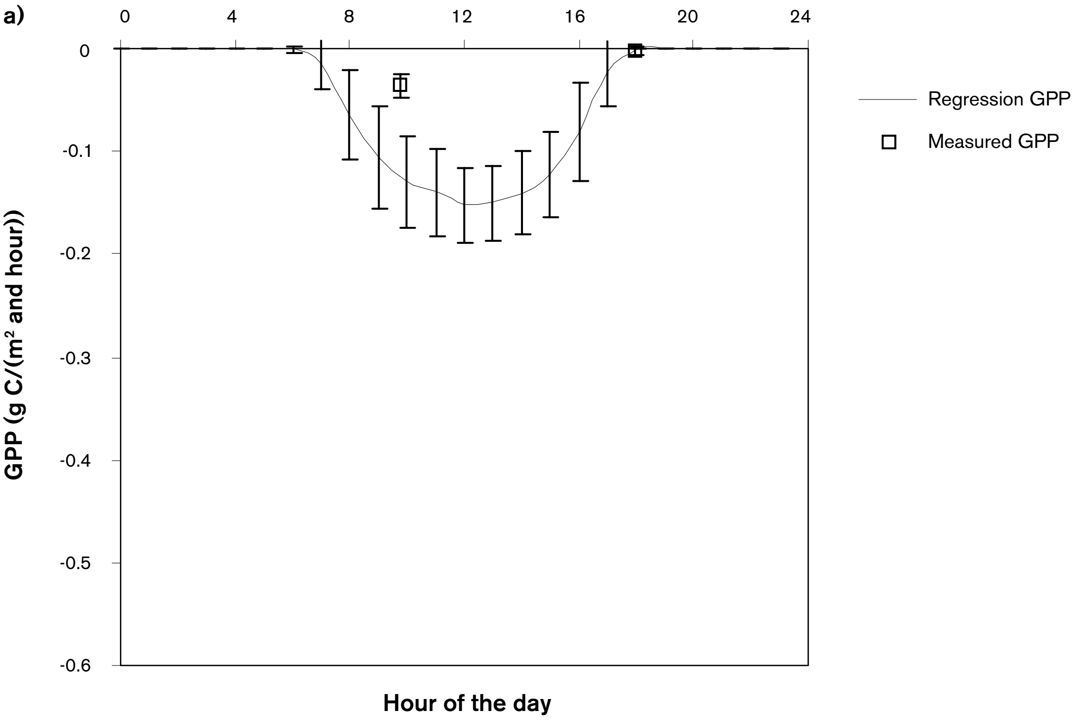
Ecosystem	DF	k	m	F-value	P-value	R^2
Pine	14	–0.00027	–0.0316	0.33	0.576	2.5
Meadow	16	0.10300	–0.5780	4.09	0.061	21.4
Spruce	10	0.00023	–0.0267	2.02	0.189	18.3
Deciduous 1	12	–0.00082	–0.0187	0.15	0.707	1.3
Deciduous 2	15	–0.00250	0.0330	1.85	0.196	11.7

The equation follows the form Y = kx + m, where Y is GPP in g C (m^2 and hour)$^{-1}$ and x is soil moisture in %vol. R^2 in %.

5.4 GPP in meadow calculated over spring 2004

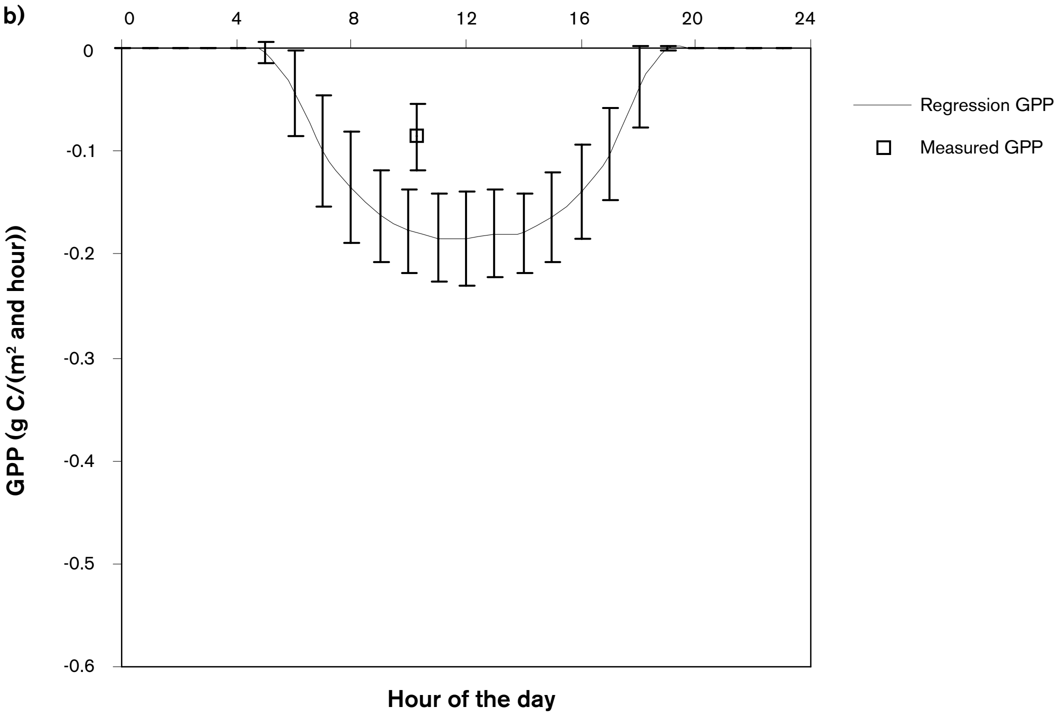
The logarithmic regression between GPP and PAR were used to calculate ground GPP for March, April and May in meadow. The average 24-hour period regression calculated GPP was lower than measured GPP in March and April; they were also outside the 95% confidence interval of the measured values. In May, regression calculated values are higher than measured GPP and they are within the 95% confidence interval of the measured GPP. The average 24-hour period regression calculated GPP for May were also tested against 24-hour period measurements from May and this indicated that the regression calculated results gave the same results as field measurements did. The regression calculated 24-hour average GPP curves for meadow in March, April and May can be seen in Figure 5-2a–c.

a)



0
4
8
12
16
20
24
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
GPP (g C/(m² and hour))
Hour of the day
Regression GPP
Measured GPP

b)



0
4
8
12
16
20
24
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
GPP (g C/(m² and hour))
Hour of the day
Regression GPP
Measured GPP

c)

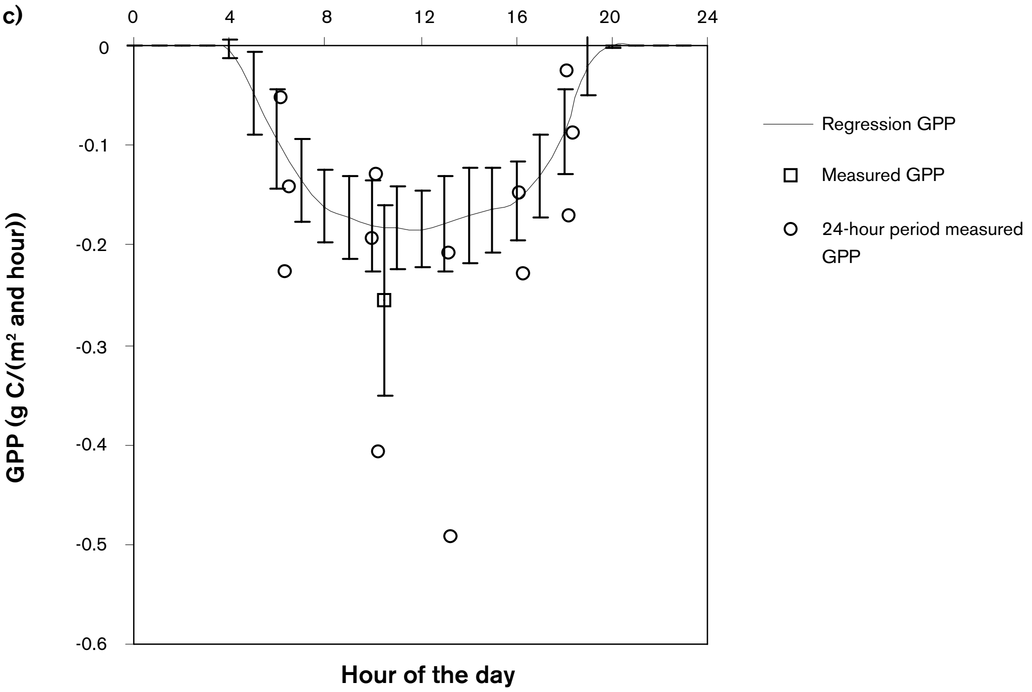


Figure 5-2. Daily variation in GPP. The lines are average GPP calculated with logarithmic regression equations for (a) March, (b) April and (c) May. The squares are average measured GPP (a) the 25th of March, (b) the 13th of April and (c) the 10th of May. The circles are 24-hour period measured GPP in May. The error bars show 1 standard deviation (68.6% confidence interval).

5.5 Evaluation of DGVM

NPP was calculated from the field measured GPP in meadow to be able to compare field results with NPP from DGVM simulations. The comparison indicated that March and April are simulated lower in the DGVM than both measured and regression calculated NPP. In May, NPP was well simulated in the comparison with the field measured NPP but it was too high compared to the regression calculated NPP.

A comparison between tree layer carbon pools measured in the field with tree layer carbon pool in the DGVM was done. It indicated that the simulations for the coniferous ecosystems were reasonably close to the tree layer carbon pool of the ecosystems in the field; they were 1.48 times the measured pine tree layer carbon pool and 1.15 times the measured spruce tree layer carbon pool. The simulated deciduous tree layer carbon pool was much lower than field measured tree layer carbon pool of the two deciduous ecosystems. It was 0.32 of the tree layer carbon pool in deciduous 1 and 0.15 of the tree layer carbon pool in deciduous 2.

To be able to compare the field measured fast decomposing soil organic acids with the fast decomposing soil organic carbon pool, relative values had to be calculated. The comparison indicates that the fast decomposing soil organic carbon pool of spruce and deciduous 2 were very well simulated. Pine and deciduous 1 were simulated higher than the field results but they were still within a reasonable limit to the field values. Meadow was simulated lower than the field results and its simulation ends up outside the 95% confidence interval of the field results.

The comparison between the DGVM soil respiration and the 95% confidence interval of measured and regression calculated ground respiration indicated that soil respiration was well simulated for some ecosystems while not for others. All DGVM simulations gave reasonably similar results compared to the field measurements except meadow that was simulated too low. In the comparison with DGVM, simulated soil respiration against regression calculated ground respiration meadow was still lower while spruce was higher in the DGVM simulations. The DGVM simulations performed well for the deciduous ecosystems in May while soil respiration was lower in April compared to the regression calculated ground respiration. The field results have a larger variation than the DGVM simulations, the DGVM soil respiration were 0.02–0.07 g C (m^2 and $hour)^{-1}$ while field related ground respiration were between 0.02–0.22 g C (m^2 and $hour)^{-1}$.

5.6 NPP in meadow 2001–2100

The factors influencing NPP in the future simulations were atmospheric concentration of carbon dioxide, PAR, air temperature and precipitation /Sitch et al. 2003/. In the future simulations air temperature and concentration of carbon dioxide will increase, while precipitation will decrease. It will result in an increase in NPP during this coming century in meadow. The average annual change in NPP 2001–2100 is slightly larger in the B2-scenario compared to the A2-scenario. It is 1.14 g C m^{-2} for the A2-scenario and 1.23 g C m^{-2} for the B2-scenario.

5.7 Tree layer carbon pool 2001–2100

When NPP increases, more carbon is accumulated by vegetation and the tree layer carbon pool will increase 2001–2100. The increase is larger in the B2-scenario than in the A2-scenario for all forest ecosystems. See Table 5-7.

5.8 Soil respiration 2001–2100

Two factors influence the soil respiration, an increased soil temperature and an increase in NPP /Janssens et al. 2001, Kirschbaum 1995/. Soil respiration was predicted to increase over the coming century in both the scenarios for all ecosystems. The increase was larger in the B2-scenario for all ecosystems but meadow, where the A2-scenario had a larger annual change in soil respiration. See Table 5-7.

5.9 Fast decomposing soil organic carbon pool 2001–2100

The increase in vegetation results in a larger input of dead organic material to the soil organic carbon pools. The fast decomposing soil organic carbon pool will increase for all ecosystems in both scenarios 2001–2100. The simulated ecosystems hereby have a sink function for the increased concentration of atmospheric CO_2. The fast decomposing soil organic carbon pool will increase more in the B2-scenario than in the A2-scenario for all ecosystems but pine where the increase is largest in the A2-scenario. See Table 5-7.

Table 5-7. Average annual change in tree layer carbon pool, soil respiration and fast decomposing soil organic carbon, 2001–2100.

Ecosystem	Future scenario	Tree layer carbon pool	Soil respiration	Fast decomposing soil organic carbon pool
Pine	A	34.1	10.5	23.0
Pine	B	45.5	14.0	22.0
Meadow	A	–	12.3	19.2
Meadow	B	–	10.5	21.3
Spruce	A	9.7	4.4	14.2
Spruce	B	12.6	7.0	24.6
Deciduous	A	48.9	4.4	9.7
Deciduous	B	49.4	8.8	15.6

The average annual change 2001–2100 is in g C m^{-2}. The meadow has no tree layer carbon pool.

6 Discussion

6.1 Effect of soil temperature and soil moisture on respiration

Most studies done in temperate regions have shown that temperature is the main factor affecting respiration /Swanson and Flanagan 2001, Morén and Lindroth 2000, Davidson et al. 1998/. In Simpevarp all ecosystems but pine are affected by soil temperature. Soil respiration is about 70% of the total forest ecosystem respiration /Janssens et al. 2001/ and in a meadow ground respiration is the total ecosystem respiration. In case global warming will increase soil temperature, ground respiration from these ecosystems of Simpevarp will be enlarged.

All ecosystems but meadow have relatively low R^2-values, 13.8–33.5%, indicating that more factors than temperature influence respiration in these ecosystems. Respiration rate is also influenced by moisture, quality and age of substrate to be decomposed and mineral and clay content of the soil /Giardina and Ryan 2000/. Thickness of active soil layer is another factor affecting ground respiration /Rayment and Jarvis 2000/. Ecological factors are also of main importance for respiration /Strömgren 2001/. /Janssens et al. 2001/ showed that NPP is the main factor affecting respiration, it results in more fresh dead organic material and the main part of heterotrophic respiration is decomposition of young organic material. Second a large NPP results in more root production, which raises root respiration /Janssens et al. 2001/. The amount and turnover rate of vegetation, roots, mycorrhizae and microbes are other examples of ecological factors /Strömgren 2001/. In Pine it might be that there is a large variation within the area of these different factors, hereby do neither soil temperature nor soil moisture give a significant effect on ground respiration in pine.

The effect of soil temperature on ground respiration is larger in meadow and deciduous 1 compared to the other ecosystems. Q_{10}, the relative increase in respiration when soil temperature is raised 10°C, is derived out of exponential regressions from field measurements done in a certain temperature range. The temperature range of meadow and deciduous 1 go one to two degrees higher compared to the temperature range of deciduous 2 and spruce and this can make a big difference for an exponential regression. Another factor that could raise Q_{10} is ground vegetation. There is more ground vegetation in meadow and deciduous 1. Temperature shifts are larger up in air and living biomass up in air is hereby more affected by the temperature shifts than decomposers living down in the bulk of the soil.

In spruce and deciduous 1, Q_{10} are similar to Q_{10} from other studies done in the same temperature range /Lavigne et al. 1997, Rayment and Jarvis 1997, Morén and Lindroth 2000, Pilegaard et al. 2001, Davidson et al. 1998, Hollinger et al. 1998/. For deciduous 2, Q_{10} is lower compared to studies in Denmark and Massachusetts /Pilegaard et al. 2001, Davidson et al. 1998/. Q_{10} is unusually high at the Soroe study site in Denmark /Pilegaard et al. 2001/. In the Harvard forest, Massachusetts, Q_{10} was 5.6–3.4 /Davidson et al. 1998/. In deciduous 2 it is 2.25. Respiration in deciduous 2 is measured in the temperature range 1.3–8.8°C, it is a small temperature range and Q_{10} should normally be derived from a temperature range larger than 10°C.

Meadow has a Q_{10} of 6.00 and /Luo 2001/ found a Q_{10} of 2.1–2.7 at prairie ecosystems in the Midwest, USA. Q_{10} is temperature dependent and decreasing with increasing temperature /Kirschbaum 1995/. Q_{10} of about 2.5 at 20°C is about 6.0 at 5°C, possibly explaining the difference between the meadow in the Simpevarp investigation area and the prairie studied by Luo. The fact that Q_{10} is larger at a lower temperature indicates that ecosystems at higher latitude are more sensitive to global warming and these ecosystems could speed up global warming by releasing their stored soil organic carbon.

Ground respiration is significantly affected by soil moisture in spruce and deciduous 2. In meadow and deciduous 1, soil temperature is the factor of main importance and its effect on respiration overshadows the effect from soil moisture. In meadow and deciduous 1, the main part of respiration is due to ground vegetation and vegetation is not significantly affected by soil moisture. In spruce and deciduous 2 there is not very much ground vegetation and the main part of the respiration comes from decomposers. Both soil temperature and soil moisture affects decomposers. Spruce and deciduous 2 are better explained by a multiple linear regression while meadow and deciduous 1 are not.

6.2 Respiration calculated over spring 2004

Regression calculated respiration follows within one standard deviation from the field measured respiration. Regression calculated respiration is soil temperature dependent, while respiration measured in the field also depends on the other factors mentioned above. There is a risk in miscalculating respiration over spring when using a single factor equation. For example spruce and deciduous 2 were significantly affected by soil moisture and this is another factor that should be used when calculating respiration over spring 2004.

The logged soil temperature had a larger temperature range than the field measurements. The exponential regression from measured respiration is only valid for a part of the logged temperature range. The relationship between soil temperature and respiration is temperature dependent /Kirschbaum 1995/. The regression equation should be valid for the whole temperature range of the logged temperature.

All respiration measurements, measured during seasonally varied periods, were entered in the regression. Respiration varies over the season due to differences in the amount of living biomass, amount of roots, water availability, litter quality and active soil layer /Strömgren 2001, Rayment and Jarvis 2000/. The exponential regression should be calculated for different parts of the season. The temperature range was too small and there were too few measurements for different correlations at different parts of the season.

Regression calculated respiration does not follow the 24-hour field measurements in meadow. The problem is probably the field measurements. Measurements done during nighttime looked very strange and it could be that dew entered the EGM-4 and disturbed the measurements. During daytime the measurements worked better.

6.3 Effect of PAR and soil moisture on GPP

All field measurements are normally distributed around an average value. By taking away the theoretically impossible GPP values, i.e. the positive ones, a part of the normal distribution curve is not included and the average value then calculated turns more negative than the true average value would be. Still, the measured GPP rates are in the same order as other studies have shown /Lambers et al. 1998, Rothstein and Zak 2001/ and taking away the positive GPP values has hopefully not affected the analysis of GPP against the abiotic factors too much. The same problem exists for respiration, but there were hardly any negative values and it should only have a minor effect here.

The relationship between GPP and PAR is significant for all ecosystems but pine. Different light conditions give different relationships. Studies have shown that plants acclimatise to different PAR levels and this can be seen at the levelling of in the GPP-PAR logarithmic relationship /Lambers et al. 1998/. Shaded sub canopies have a levelling of at a lower PAR level. The logarithmic regressions of the ecosystems studied are levelling of at the same PAR level as similar ecosystems studied /Widén 2002, Rothstein and Zak 2001, Lambers et al. 1998/.

Pine did not have any significant relationship and a possible explanation could be a large variation in ground vegetation at the different plots. The differences in ground vegetation are then not linked to the amount of sun but to other factors that affect vegetation, e.g. nutrients, moisture and temperature /Lambers et al. 1998/.

GPP against soil moisture did not show significance for any of the ecosystems. There was a trend in meadow. At the PAR level of these ecosystems, PAR is the most important abiotic factor controlling GPP /Lambers et al. 1998/. In bright solar conditions, PAR is no longer the limiting factor for GPP /Lambers et al. 1998/ and it could be the reason for soil moisture to have a trend in meadow, the brightest of the ecosystems. In ecosystems adapted to dry conditions the relationship would probably be different /Janssens et al. 2003/.

6.4 GPP in meadow calculated over spring 2004

Meadow is the only ground ecosystem without a canopy above it and incoming radiation can be used to calculate GPP in meadow. The average regression calculated GPP is above average field measurements in March and April; in May it is below. There are other factors affecting GPP than PAR. An explanation could be the ground vegetation; there is more the later in spring. Ground vegetation increases GPP. All GPP values measured over spring are included in the logarithmic regression used for the calculation. The vegetation in May and April raises the regression calculated GPP value for March and the vegetation in May raises regression calculated GPP in April. The lack off vegetation in March and April lowers GPP in May and the lack of vegetation in March lowers GPP in April.

Another factor affecting GPP is air temperature /Lambers et al. 1998/. In March and April, air temperature is much lower compared to May. The vegetation takes up less carbon at lower temperature even if there is enough PAR. It could result in lower GPP at the field measurements of March and April compared to regression calculated values.

The regression calculated GPP-curve from May is well correlated to the measured 24-hour period GPP in meadow. The 24-hour period GPP is measured during daytime. The EGM-4 was working properly during daytime and these values work better than the 24-hour period respiration measured during both day- and nighttime.

6.5 Evaluation of DGVM

/Sitch et al. 2003/ compared the DGVM carbon exchange with measured values at six different EUROFLUX sites /Valentini et al. 2000/. DGVM values were within a reasonable limit of measured values. In the Simpevarp region, there is larger variation in ground respiration in the field than in the DGVM soil respiration. The main reason is the autotrophic respiration from the ground vegetation in the field that is not included in the DGVM heterotrophic soil respiration. In the ecosystems with much vegetation, such as meadow, the field measured ground vegetation is larger than the DGVM simulated soil respiration. There is hardly any vegetation in the spruce ecosystem and the DGVM has simulated a larger soil respiration than the field measurements indicated. The quality of biomass that enters the litter pool is not taken into account in the DGVM. Litter is acidic in a spruce forest and hard to decompose /Albers et al. 2004/, which leads to a lower respiration in the field measurements.

In April, DGVM respiration is higher than regression calculated respiration for the two deciduous ecosystems. Regression calculated respiration follows soil temperature. If logged soil temperature is low in April, regression calculated respiration will be low. Climate was favorable in April and it gives a high respiration in the DGVM.

The DGVM simulated NPP, while field measurements resulted in GPP. The constant 0.5 was used to convert measured GPP to NPP. 0.5 is the fraction of GPP on a global level that turns into NPP /Schlesinger 1997/. It does not necessarily apply on a smaller temporal or spatial scale, as in this investigation. The conversion factor is depending on factors such as species of vegetation, temperature, water balance and time of the season. This evaluation can therefore not be done.

Coniferous tree layer carbon pools are well simulated in the DGVM compared to measured results, deciduous are not. The main problem with the deciduous tree layer carbon pools is probably not the DGVM but the field measurements. The biomass equations were originally designed for Korea /Son et al. 2004/. It could be that the average of the two equations cannot be used for a Swedish forest. Another source of error is that the deciduous forests measured at are young ecosystems and they contain a wide variation in sizes of the trees. It could be that larger trees were measured than the average sized tree of the area. This extra biomass could be magnified when multiplying it with all small trees in the ecosystem.

Fast decomposing soil organic carbon pools in DGVM simulations of spruce and deciduous 2 are close to the field measured fast decomposing soil organic acids. Spruce and deciduous 2 are a couple of kilometres into the land. It could be that they have had time to build up a proper soil organic carbon pool. Pine and deciduous 1 are close to the shore and the soil profiles are of young character. Deciduous 1 is a shore-situated ecosystem with a rocky and stony ground and it also has the lowest amount of field measured soil organic acids. Meadow is also close to the shore, but it is still the ecosystem with most soil organic acids. It is the only ecosystem where the theoretical relationship to the DGVM is outside the 95% confidence interval of the field measurements. The meadow has a full cover ground layer of vegetation with lots of roots. Roots exude organic acids /Ström et al. 1994/ and this could result in a higher concentration of organic acids in the soil of meadow.

6.6 NPP in meadow 2001–2100

There are many uncertainties with simulations predicting the future development of ecosystems. Using the absolute values predicted by the model cannot be done. However, trends can be seen in the predictions and observed changes can be useful.

NPP is only studied in meadow and there will be an increase over the coming century 2001–2100. Other studies with all types of ecosystems have also shown an increase in NPP in temperate regions /Pussinen et al. 1997, White et al. 2000, Cramer et al. 2001/. Plants have their optimal temperature close to their normal growth temperature /Lambers et al.

1998/. In the A2-scenario air temperature will increase more than in the B2-scenario and this can be a stress factor for the plants, hereby NPP in meadow is increased more in the B2-scenario than in the A2-scenario.

6.7 Tree layer carbon pool 2001–2100

Simulations with different types of DGVM and different futures scenarios have shown an increase in the vegetation carbon pool over the next century /White et al. 2000, White et al. 1999, Cramer et al. 2001, Pussinen et al. 1997/. In Simpevarp, the tree layer carbon pool will increase for all forest ecosystems in both future scenarios. The tree layer carbon pool will increase more in the B2-scenario than in the A2-scenario for all forest ecosystems. NPP is probably larger in the B2-scenario and the large increase in temperature in the A2-scenario stresses the vegetation.

6.8 Soil respiration 2001–2100

Soil respirations from future simulations in Simpevarp are similar to the results of simulations done in other studies. Simulations have shown that soil respiration will increase over the next century both on a global and on a regional scale. /White et al. 2000, White et al. 1999, Cramer et al. 2001, Cox et al. 2000, Pussinen et al. 1997/. The main explanation is the consequences of climatic change with an increase in temperature /Cox et al. 2000, Pussinen et al. 1997/. The increase in NPP, due to the rise in atmospheric concentration of carbon dioxide, is another factor affecting soil respiration /Pussinen et al. 1997, Cramer et al. 2001, White et al. 2000, White et al. 1999/.

In meadow, soil respiration increases most in the A2-scenario, indicating that soil temperature is a main factor affecting the future development of soil respiration. In the forest ecosystems the main increase is in the B2-scenario, and this indicates that the forest ecosystems are more affected by the increase in NPP than by soil temperature. An increase in NPP in forests has a larger influence since there is more vegetation than in a meadow.

6.9 Soil organic carbon pool 2001–2100

Different studies have different changes over the next century in the soil organic carbon pool. The soil organic carbon pool will increase over the next century in simulations by /Cramer et al. 2001/ and in most of the simulations by /Pussinen et al. 1997/. /White et al. 1999/ did not have any change in the soil organic carbon pool while /White et al. 2000/ showed a slight decrease over the next century. /Cox et al. 2000/ showed a decrease in the soil organic carbon pool.

The decrease for /Cox et al. 2000/ is explained by a carbon dioxide saturation of the vegetation. The increase in carbon dioxide in the atmosphere reaches the point where it does not result in an increase in NPP. When NPP is decreasing there is less carbon coming to the soil organic carbon pool. Still, soil respiration increases due to the rise in temperature and soil organic carbon pool is therefore decreasing. It might be that the vegetation of the Simpevarp investigation area did not reach the point of carbon dioxide saturation and the soil organic carbon pool keeps on increasing since NPP is still large.

Most studies are done on a global scale. /Cox et al. 2000, White et al. 2000, White et al. 1999, Cramer et al. 2001/. It is only /Pussinen et al. 1997/ that did their study in a temperate region. For the global scale studies, NEP is positive in the temperate regions and it is likely that soil organic carbon is increasing in the temperate parts of the world /White et al. 2000, Cramer et al. 2001/. NEP is decreasing in tropical parts and it could be that this is the main region where the soil organic carbon pool is decreasing.

For meadow, spruce and the deciduous ecosystems, the increase in fast decomposing soil organic carbon pool is largest in the B2-scenario 2001–2100. NPP increases more in the B2-scenario and this gives a larger input to the soil organic carbon pool. Pine has a slightly larger increase in fast decomposing soil organic carbon pool in the B2-scenario compared to the A2-scenario. The difference could be due to that both NPP and soil respiration increases in both the scenarios but soil respiration will have a larger effect in the B2-scenario than in the A2-scenario.

6.10 Conclusions

The first general aim of the study was to analyze the influence of abiotic factors on ground respiration of boreal/temperate forests and a meadow. The study has given further proof that abiotic factors affect the ground respiration of temperate and boreal ecosystems of the Northern hemisphere. Soil temperature did have a significant effect for all ecosystems but pine. Soil moisture did also have an effect in spruce and one of the deciduous ecosystems. It also indicates that many other factors are of importance and for a full understanding of the ecosystems; these other factors should also be examined. The study also indicates that GPP is an essential part of the ground carbon fluxes. The amount of PAR that reaches the ground does influence GPP of the ground vegetation and it hereby affects the carbon dynamics of these ecosystems.

Second, the abiotic factors analyzed were to be used for calculation of the ground carbon fluxes over spring 2004. An exponential regression with ground respiration against soil temperature could be used for the calculation of seasonal ground respiration. The logarithmic regression with GPP against PAR could not be used for extrapolation of GPP over spring 2004. There are many factors that influence the carbon fluxes of the temperate/boreal ecosystems and these are not included in a single factor regression. In the case of GPP, there is for example a seasonal change in vegetation and in air temperature and this influence GPP differently at different parts of the spring.

Third, a DGVM were to be used to study changes in carbon fluxes and carbon pools in the temperate/boreal ecosystems. There were some problems with the evaluation of the DGVM since the thing measured in the field was not the same as was simulated for. But, the evaluation indicated that the DGVM was properly downscaled to the ecosystems measured at and the DGVM could be used for future simulations. NPP will increase 2001–2100 due to more favorable climate and an increase in atmospheric concentration of carbon dioxide. With an increase in NPP, the tree layer carbon pool will also be enlarged. With more carbon to decompose and a raised soil temperature the soil respiration will also increase. It seems like NPP has a larger effect than soil respiration on the fast decomposing soil organic carbon pool since it will be enlarged.

The following conclusions can be drawn about the set hypotheses

1. The first specific hypothesis is verified for all ecosystems but pine when it comes to that soil temperature has an effect on ground respiration, but it is only verified for spruce and deciduous 1 when it comes to that soil moisture has an effect on ground respiration.

2. The second specific hypothesis is verified, soil temperature can be used to calculate ground respiration over spring 2004.
3. The third specific hypothesis is verified for all ecosystems but pine when it comes to that PAR has an effect on GPP. But, it is falsified when it comes to soil moisture, soil moisture does not affect GPP in any of the ecosystems.
4. The fourth specific hypothesis is falsified; PAR cannot be used to calculate GPP over spring 2004.
5. The fifth specific hypothesis is verified; NPP in meadow will increase 2001–2100.
6. The sixth specific hypothesis is verified; tree layer carbon pool will increase 2001–2100.
7. The seventh specific hypothesis is verified; soil respiration will increase 2001–2100.
8. The eighth specific hypothesis is falsified; fast decomposing soil organic carbon pool will not decrease 2001–2100.

Generally most of the hypotheses were verified. Abiotic factors do influence ground carbon fluxes, in the cases were the hypotheses were falsified it was due to other abiotic factors having a larger influence on the carbon fluxes. Abiotic factors can be used to calculate ground carbon fluxes. When it does not work it is due to other factors that also has an influence and these are shifting at the different parts of the season. NPP in meadow, tree layer carbon pool and soil respiration will increase 2001–2100 and it turns out that the increase in NPP has a larger effect than the increase in soil respiration since the fast decomposing soil organic carbon pool also will increase 2001–2100. The study hereby indicates that the temperate/boreal ecosystems of Northeastern Småland will continue to have a sink function for at least this coming century and these ecosystems will not speed up global warming 2001–2100.

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