Report on suggestions for improvements of the descriptions of ozone impacts on forest carbon sequestration in GAINS

Delivery D4.5

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Introduction

One key research questions within the SCAC research program, WP4 is:

How to estimate the indirect climate effects mediated by negative impacts of ground level ozone on forest growth and carbon sequestration in northern Europe.

This question is addressed in SCAC by applying dendrochronology investigations of >20 years of historic forest growth at approximately 25 different sites with Norway spruce, Scots pine and European beech. Annual growth will be correlated with ozone exposure in combination with other explanatory variables e.g. temp, precipitation, radiation, drought days, nitrogen deposition, etc. this work is ongoing.

The is also a question of how ozone impacts on the carbon sequestration in Swedish forests can be incorporated in the GAINS model. This question is addressed in this first delivery from WP4 ozone part.

The delivery D4.5 include "suggestions for improvements of the descriptions of ozone impacts on forest carbon sequestration in GAINS" and is due month 26 in the SCAC program.

This report represents the delivery D4.5.

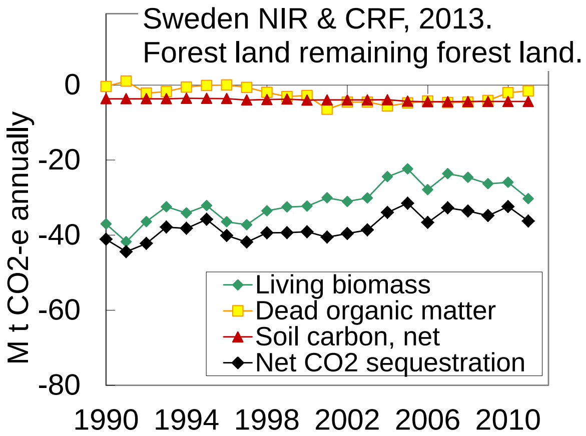
Background

The carbon sequestration by vegetation represents an important mitigation of the fossil emissions and emissions from deforestation. A recent estimate of carbon sequestration by total global forests was ca. 14000 Mt CO_2e (excluding carbon storage in harvested wood products, Pan et al., 2011), of which living biomass carbon constituted close to 80%. As a result, the annual increment in atmospheric CO_2 concentration is substantially smaller than the increment expected from anthropogenic emissions alone (Canadell et al., 2007). This is described by the so called "Airborne Fraction" (AF), which is the ratio between the annual increase in atmospheric CO_2 concentration (or pool) and the total anthropogenic emissions of CO_2 (fossil + deforestation) for the same year.

The most important aspect of forest management for carbon sequestration is the forest growth rates in relation to rate of harvests, i.e. the higher the growth rates compared to harvest rates, the higher carbon sequestration. This aspect has to be analysed on the landscape level and/or over long time periods, since individual stands are regularly harvested. Any measures that increase the productivity of temperate or boreal forest, such as e.g. fertilization or a more favourable climate, are likely to increase the forest carbon sequestration (Hyvönen et al., 2007, Eggers et al., 2008).

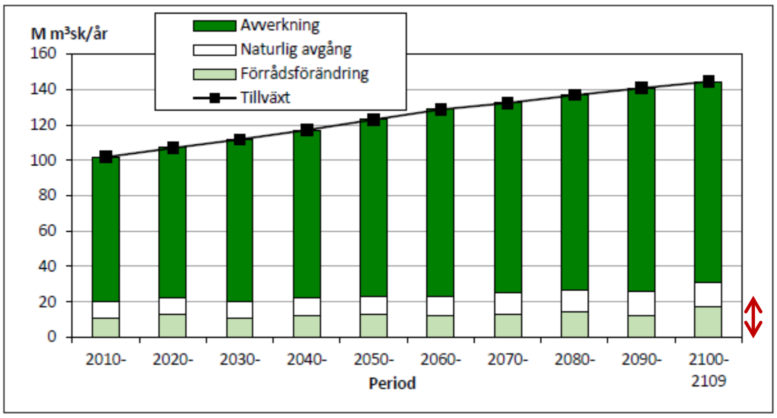
The carbon stocks in Swedish forests increase 30-40 M t CO2e/yr and the main sink is the living biomass (Figure 1A). The increase in the living biomass carbon sink in Swedish forests depends on the gap between growth and fellings, as assessed on the landscape level (Figure 1B). Hence, even a relatively small decline in the growth rates may substantially reduce forest carbon sequestration in Swedish forests.

A



B

SKA-15, scenario 90% of growth is harvested



Figur 11. Årlig tillväxt, avverkning (inklusive röjning), naturlig avgång och förrådsförändring (miljoner m³sk/år) i scenariot 90 procent avverkning, virkesproduktionsmark och alla ägare.

Figure 1. A. Illustration of the annual changes in forest ecosystem carbon stocks in Swedish forests as officially reported by Sweden to the Climate Convention for the LULUCF sector. The values are for the land use category “Forest land remaining forest land”. Source: Sweden NIR and CRF, 2013.
B. Recent projections for the annual growth rates, harvest rates, other removal and standing stock changes for the total land with productive forests in Sweden. The scenario shown is based on the assumption that 90% of the growth is harvested, which is the case today. The red double arrow indicates the standing stock change, which is the most important factor for the annual increase in the living biomass carbon stocks in Swedish forests. Source: SKA-VB 2015.

It is well established that current levels of ground-level ozone are reducing forest growth over the entire Northern Hemisphere (Wittig et al., 2009) as well as Swedish forests (Karlsson et al., 2009). Recently, it has been estimated that the growth rates of coniferous forests in southern Sweden would have been 5% higher that today in the absence of the negative impacts of prevailing ozone exposures in southern Sweden (Karlsson et al., 2014). The corresponding value for deciduous forests was an 8% higher growth rate. A first estimate of how ozone might negatively affect carbon sequestration showed that current ozone levels may reduce forest carbon sequestration in some northern and central European countries in the order of 10 % (Karlsson, 2012). However, it was concluded that knowledge about ozone impacts on mature trees under stand conditions is to a large extent incomplete and further research is strongly needed.

The scope of this delivery

In this delivery, a frame-work methodology is suggested for how to include ozone impacts on forest carbon sequestration in GAINS.

The suggested methodology

Basic approaches

Baseline scenario

For the assessment of today´s ozone impacts on forest ecosystem carbon sequestration it is necessary to define a number of presumptions and constraints for the approach. The first presumption is the choice of baseline scenario, i.e. what should the today´s ozone impacts be compared with. The issue of background ozone levels has been a matter of controversy. However, in this study the baseline ozone scenario is defined as pre-industrial ozone levels, with concentration ranging from 10-15 ppb (Royal Society, 2008) and no occurrence of ozone episodes, i.e. with AOT40 = 0.

Time horizon

The second definition that has to be considered is what time horizon over which carbon sequestration should be considered. Here we apply the general principle that is often applied in Life Cycle Analysis, i.e. that the assessment regards the current situation, as an average over a few years, and it does not involve predictions for the future. However, in northern European countries, it has been estimated that forest production might increase substantially in a future climate (e.g. Poudel et al., 2011).

Assessment limited to living biomass carbon stocks

The main changes in the forest carbon stocks today, in the decade time perspective, occur in the living biomass compartment of the ecosystem. Hence, this study focus on the living biomass and impacts of ozone on other carbon stocks will be assessed only in a qualitative manner.

Estimates of forest ozone exposure

Forest exposure to ozone can be expressed either based as the accumulated exposure on concentrations in the atmosphere close to the canopy (e.g. AOT40, Fuhrer et al., 1997) or as the phytotoxic ozone dose (POD, Mills et al., 2011), i.e. accumulated ozone uptake through the stomatal pores on the surface of leaves. The latter approach is most relevant from a physiological point of view. However, exposure – response relationships based on AOT40 are more commonly reported in the literature and therefore applied in the current study. It has been demonstrated that with a certain geographical region with limited climate gradient, AOT40 performs equally well as POD in predicting negative impacts of tree growth (Karlsson et al., 2004).

Establishing ozone dose – growth response relationships

Ozone dose – growth response relationships for forest can be derived, either from experimental studies, usually with individual young trees, or from epidemiological studies with matured trees in stands. Both approaches have their advantages and dis-advantages.

There is a fundamental difference in establishing ozone dose – growth response relationships for relatively short-lived organisms, such as agricultural crops, as compared to long-lived trees. Results from ozone impact studies on perennial plants, in contrast to annual plant species, involve a time component over which effect estimates have to be integrated. The dose-response relationships to be used have to be applicable for the metrics used for forest increment growth, which is $m^3\ yr^{-1}$, i.e. a **growth rates over a long time period**. Many studies report only the percent reduction of biomass caused by ozone at the end of the experiment and do not provide information on the biomass at the start of the experiment, so that impacts on growth rates cannot be calculated. The significance of this problem increases at low growth rates in relation to the size of the ozone effect (Karlsson, 2012).

Moreover, a change in the growth rate expressed as $m^3\ yr^{-1}$ will have a different implication for a young, small tree as compared to an adult, large tree. Hence, it is more relevant to use the relative growth rates, i. e. the percent change in e.g. stem volume over time. The response variable used for calculating the ozone effects should be the relative increment of either stem volume or total biomass, i.e. the increment during a period relative to the value at the start of the period.

The impacts on the relative stem volume or biomass increments were related to the mean, annual daylight AOT40 during the entire experimental period.

A framework methodology for how to include ozone impacts on forest carbon sequestration in GAINS

An illustration of a frame-work methodology for how to include ozone impacts on forest carbon sequestration in GAINS is shown in Figure 2.

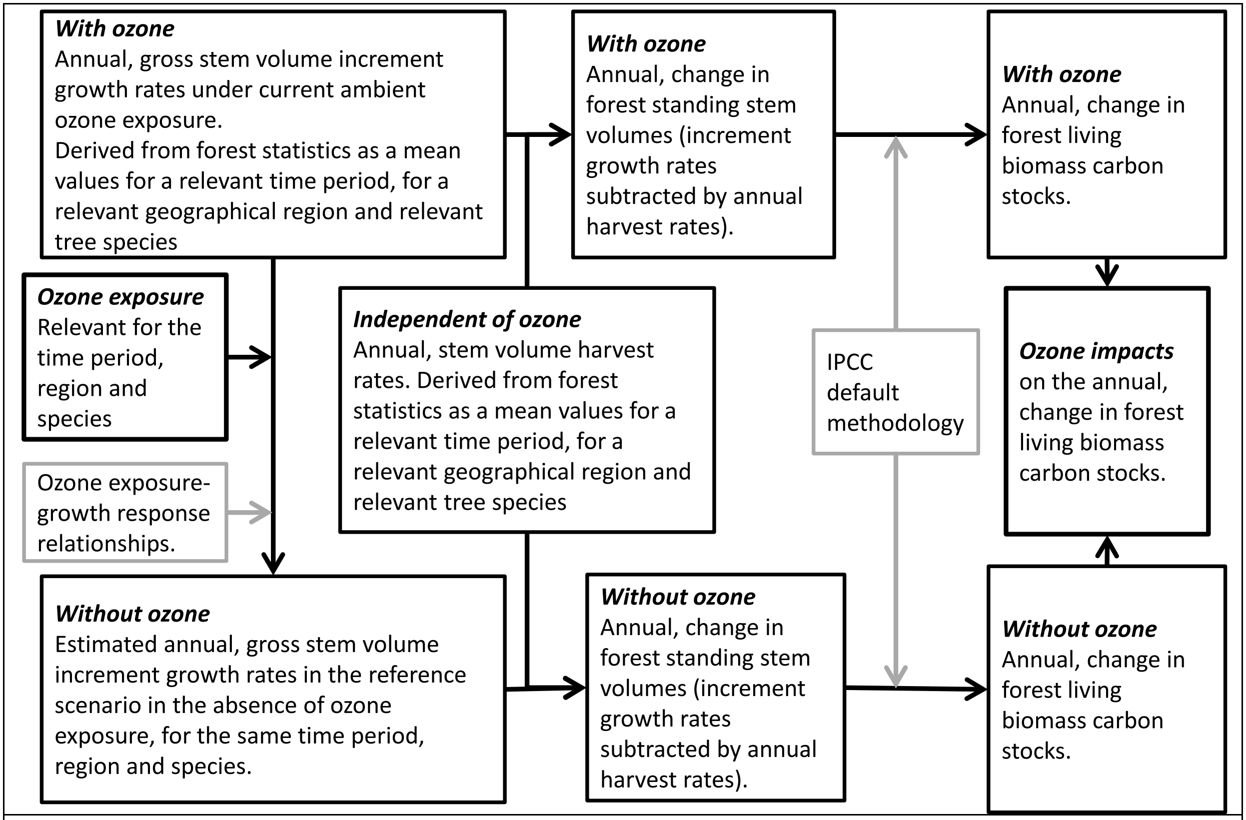


Figure 2. An illustration of a frame-work methodology for how to include ozone exposure impacts on forest carbon sequestration in GAINS.

Current growth rates under ambient ozone exposure

Information about the annual, gross stem volume increment growth rates under current ambient ozone exposure should be derived from relevant forest statistics, as a mean values for a relevant time period, for a relevant geographical region and relevant tree species. The Swedish National Forest Inventory (NFI, http://www.slu.se/sv/webbtjanster-miljoanalys/statistik-om-skog/produktiv-skogsmark/produktiv-skogsmark-tabeller/) provides information for mean annual volume increment by tree species for 5-year periods at the county level. The most recent available is for the period 2010-2014. However, as seen below it might be difficult to find relevant statistical information about annual harvest rates for with the corresponding resolution regarding tree species and geographical resolution. On the European level, country-wise information about growth and harvest rates can be derived from UN-ECE. If possible, it would be useful to divide the statistical information on forest types and age classes.

The estimated growth rates in the absence of ozone exposure

As mentioned above, the reference scenario for the assessment of current ozone exposure impacts on forest growth is defined as pre-industrial ozone levels, with concentration ranging from 10-15 ppb and no occurrence of ozone episodes, i.e. with AOT40 = 0.

The ozone dose – growth response relationships for forest should be derived from best available knowledge, either from experimental studies, usually with individual young trees, or from epidemiological studies. A major task of WP4 ozone is to derive new information about ozone impacts on the growth rates of mature trees in forest stands based epidemiological studies of annual basal area growth from around 25 different sites in southern Sweden. The results from those studies will be reported later.

As argued above, in this study the ozone exposure is expressed as AOT40.

The forest stem increment growth for the baseline scenario, i.e. the low ozone exposure, could be calculated as:

y = h/(100+(i*j)/100)

where y= annual increment growth ($m^3\ yr^{-1}$), h=annual increment growth under current ozone exposure levels ($m^3\ yr^{-1}$), i=AOT40 (ppm h), j=the slope for the correlation between AOT40 and the per cent growth reduction (% $(ppm\ h)^{-1}$, negative values implies growth reductions).

Current harvest rates

In the Swedish NFI statistics, it is difficult to find relevant statistical information about annual harvest rates for with the corresponding resolution regarding tree species and geographical resolution. However, by indirect methods, it might be possible to makes relevant estimates with proper tree species and geographical resolution.

The forests harvest rates were assumed to be the same in the high and low ozone scenarios, not taking into account the differences in the forest growth rates between the two scenarios. The underlying assumption was that harvest rates are more strongly depending on the demand for roundwood rather than on the supply, that is within the relatively small differences in growth rates between the two ozone scenarios.

Karjalainen et al. (2003) estimated the current and future European forest carbon cycles, based on different scenarios. When constructing these scenarios they listed a number of factors that may influence the current and future rates of fellings:

1. Increased demand for wood products.

2. Higher demand of wood because of large scale application for bioenergy.

3. A reduced interest of forest owners in wood production since in many cases they do not depend on the forest for their income.

4. A higher interest of forest owners in conservation values of the forests

5. Large imports of roundwood from outside Europe

None of these factors relates directly to changed growth rates. Hence, it was concluded that the assumption with identical forests harvest rates in the high and low ozone scenarios was reasonable.

Change in forest standing stem volumes

The changes in forest standing stem volumes were calculated as the increment growth rates subtracted by annual harvest rates, separately for the two scenarios with and without ozone exposure.

The land-use change from former agricultural land to productive forest (afforestation) was assumed negligible for Swedish conditions on the time-scale used. This might be different at the European level.

Conversions from stem volume to biomass

The changes in forest standing stem volumes were converted to changes in forest total living biomass, including belowground biomass, as described in IPCC's "Good Practice Guidance for Land Use, Land-Use Change and Forestry" (Penman et al., 2003), somewhat modified as described by von Arnold et al. (2005).

$$\Delta C = Iv * BEF * D * CF$$

ΔC, Carbon sequestration to tree living biomass (tonnes C ha^{-1} yr^{-1}); Iv; yearly increment of timber volume (m^3 ha^{-1} yr^{-1}; D, density stem (tonnes dry weight m^{-3}); CF, "carbon fraction", of dry matter (tonnes $tonnes^{-1}$); BEF, biomass expansion factor, converts between stem biomass and total living biomass including branches, leaves and roots. The value of ΔC was then converted to CO_2-eqvivalents (CO_2e) by multiplying with 3.67.

Ozone impacts on the annual change in forest living biomass carbon stocks

Finally, the ozone impacts on the annual change in forest living biomass carbon stocks were calculated based on the changes in forest total living biomass from the two ozone scenarios.

Discussion of the suggested framework methodology

The relative ozone impacts on the forest carbon sequestration depend strongly on the size of the gap between growth- and harvest rates for the region. If the gap is small, then a relatively modest ozone-induced growth reduction will have a relatively large impact on this gap between growth and harvest rates. This is exemplified based on statistical information for annual growth and harvest rates for the total forests in Sweden and Poland, respectively, as mean values for 5-year periods. For Sweden, the gap between growth and harvest rates is relatively small, and a modest growth reduction caused by e.g. ozone exposure will have a relatively large impact on the gap and hence on the carbon sequestration in the living biomass stocks in Swedish forests. In contrast, in Poland this gap is relatively large, so that a modest reduction in the growth rates will have a relatively smaller impact on the carbon sequestration in the living biomass stocks in Polish forests.

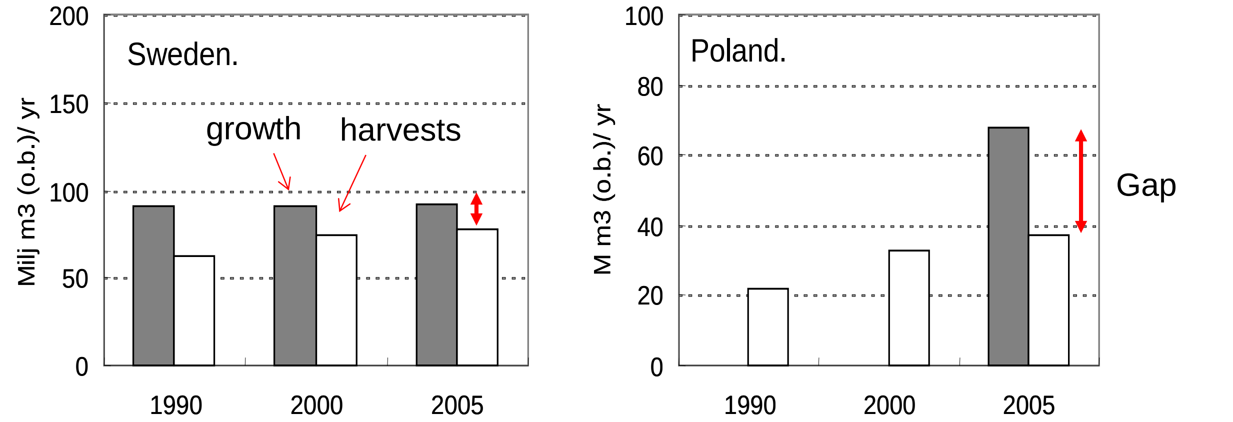


Figure 3. An illustration of the variation regarding differences in the gap between annual country-wise growth and harvest rates, for Sweden and Poland. Grey bars represent 5-year average values for the annual total forest growth rates in the respective countries. Open bars represents the corresponding harvest rates. The red double arrow illustrated the gap between growth and harvest rates. Source: UN-ECE statistics.

Other assumptions and uncertainties

- Ozone impacts on forest ecosystem carbon stock changes were assessed only as direct impacts on growth rates, no indirect impacts were included such as reduced vitality of trees etc.
- No indirect effects of reduced growth rates on the rates of litterfall and the formation of soil carbon are included.
- Forest harvest rates were assumed not to be affected by the different ozone scenarios and total harvest rates were distributed among forest types and age-classed as related to growth rates in the same classes.
- It was assumed that AOT40 could be used as a relevant ozone exposure index.
- **Knowledge about ozone impacts on mature trees understand condition is to a large extent incomplete and further research is strongly needed**. This will be provided by ongoing studies in SCAC WP4.

Conclusions

The abatement of the ozone pollution problem clearly has the co-benefit to increase the carbon sequestration in northern and central European forests for at least some decades into the future. Hence, there is a need to include this aspect in the integrated assessments made in the GAINS model. The methodology suggested in this report makes this possible.

The main uncertainty in this type of assessments will be the quantification of ozone impacts on mature trees under stand conditions. There are several ongoing studies addressing this uncertainty, of which one in under way in the SCAC program.

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