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How are fluxes of greenhouse gases between boreal forest ecosystems and the atmosphere affected by uneven-aged forestry?

A pilot study

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Background

Forestry practices are currently under intense debate in Sweden. One of the more central subjects of this debate is whether various forms of selective cutting (often collectively referred to as 'uneven-aged forestry' or 'continuous-cover forestry') would be preferable to the even-aged forestry (involving simultaneous harvesting of entire stands) that has been totally predominant in Sweden since the 1950s. Proponents of even-aged forestry usually maintain that it is economically superior due to high efficiency and high timber yield, whereas supporters of uneven-aged forest management point out that alternative methods of this kind may preserve natural values that clearcutting would eliminate.

Using a systematic approach, Kuuluvainen *et al.* (2012) have recently investigated the scientific basis for both of these arguments. Reviewing a number of studies made in central or northern Fennoscandia, they found evidence that uneven-aged forest management is less detrimental than even-aged forestry to the flora and fauna. However, they found no straightforward support for the view that uneven-aged forestry is characterised by inferior economic performance. Several conventional literature reviews (e.g. Cedergren, 2008; Olsson *et al.*, 2012) have concluded that selective cutting does not on the average result in lower productivity than clearcutting, at least not in forest types that are suitable for such management.

Different kinds of forest management could also have different effects on the fluxes of carbon dioxide and other greenhouse gases between the forest ecosystem and the atmosphere. Seen as a whole, Swedish forests currently act as a major sink of carbon dioxide, offsetting more than half of the country's emissions of carbon dioxide from fossil fuels. However, this sink is highly variable at least on a local scale, being sensitive both to natural disturbances such as windthrow and forest fires and to human interventions such as felling and various practices intended to enhance timber production.

For instance, clearcutting a forest stand will usually turn the site into a source of carbon dioxide rather than a sink (e.g. Magnani *et al.*, 2007; Lindroth, 2009). This is because little vegetation capable of absorbing CO_2 then remains on the site, whereas the release of CO_2 from decomposing litter and other dead organic matter continues as before (possibly even at an increased rate). Only when the growth rate of the next forest generation has reached significant levels will the site gradually become a CO_2 sink again. Any disturbance or intervention in a forest stand is also potentially capable of affecting the release of other greenhouses – notably methane and nitrous oxide – from the soil.

Since the net emissions of carbon dioxide that are caused by clearcutting can be avoided in uneven-aged forestry, there may be reason to believe that this kind of management is more beneficial from a climatic point of view than even-aged forestry (Lindroth, 2009; Olsson, 2011). Opinions are divided in this case too, however. If uneven-aged forestry does produce less timber than conventional forest management, it could impede efforts to decrease carbon dioxide emissions through substitution of fossil fuels by wood, logging residues and similar biofuels (Örlander, 2010).

So, while there is little doubt that forest management can have very important climatic impacts, the actual size and nature of those impacts remain uncertain. A systematic review of how different kinds of forestry affect fluxes of carbon dioxide and other greenhouse gases between the atmosphere and boreal forests might therefore potentially be very useful and attract considerable interest from laypeople, environmental scientists and foresters alike.

Available data and current research

Much of what is known about how forests and forestry affect the carbon balance between the atmosphere and the terrestrial environment is based on inventories of the volumes of standing timber. An increase of the timber volume translates directly to a sink of carbon dioxide (and vice versa). Biometric data of this kind are available in great quantity, not least in Sweden, where large-scale forest inventories have been carried out more or less regularly since the 1920s (Ståhl *et al.*, 2004).

On the other hand, since data on timber volumes give no information about whether the amounts of carbon stored in ground vegetation, litter or soil are changing, they cannot give a full picture of the CO_2 exchange between forest ecosystems and the atmosphere. Nor can they be used to quantify releases of other greenhouse gases from forest soils. Moreover, since trees need decades or even centuries to reach maturity, timber volumes in a growing forest stand usually respond slowly to various interventions. It may therefore be difficult to detect such responses and identify their precise causes. For this reason, studies of how different kinds of forestry affect timber quantities and carbon fluxes in the long-term often rely heavily on model calculations. Changes of the quantities of carbon stored on or below the forest floor can in principle be followed by repeated analyses of e.g. soil samples, but such data remain fairly sparse.

However, net fluxes of CO_2 and other greenhouse gases between forest ecosystems and the atmosphere can also be measured directly hour by hour, especially using micrometeorological sensors placed in towers (Ståhl *et al.*, 2004). These 'eddy-flux' or 'eddy-covariance' sensors detect differences in gas concentrations of air in turbulent motion above the forest canopy. Another common technique uses chambers placed on the ground for measuring emission or absorption of gases by the soil, but this method is not capable of quantifying exchanges between the atmosphere and the entire forest ecosystem.

Flux measurements of these kinds have often been used to detect short-term effects of human interventions or natural disturbances in forests. A fair amount of data is thus available on how net fluxes of CO_2 are affected by clearcutting or forest fires. None of these studies covers more than a few years, though. Conclusions regarding how gas fluxes are affected in the longer term by e.g. clearcutting are therefore based on compilations of data from forest stands of different age. This approach has been used to show that mature forests generally continue to absorb CO_2 even at ages of several hundred years (Luyssaert *et al.*, 2008).

A database known as FLUXNET (http://fluxnet.ornl.gov/) has been created to coordinate and improve the availability of micrometeorological flux data. Data on forest ecosystem carbon budgets (based on model studies as well as various kinds of measurements) have also been compiled by Luyssaert *et al.* (2007) (http://daac.ornl.gov/VEGETATION/guides/forest_carbon_flux.html). Moreover, the European Commission recently initiated a project known as ICOS (http://www.icos-sweden.se/index.html) that aims to improve monitoring of the exchange of greenhouse gases between ecosystems and the atmosphere in Europe.

The Swedish part of ICOS is coordinated by Anders Lindroth, Lund University. Other scientists who have studied the climatic impact of forestry in Sweden include Achim Grelle, Riitta Hyvönen and Mats Olsson, Swedish University of Agricultural Sciences. Some studies of continuous-cover forestry are included in the current Swedish research programme Future Forests (http://www.futureforests.se/engelskwebbplats/home/componentprojects/forestmanagement/continuouscoverforestry.4.373a4c5113540591b74e1b.html).

Scientific basis

A search on the Web of Science for primary field measurements of how various forestry practices in the boreal region affect fluxes of greenhouse gases has been carried out using the following search terms:

(co2 OR carbon OR methane OR nitrous OR greenhouse)
AND (boreal OR hemiboreal OR conifer*)
AND (forestry OR "forest management" OR fell* OR clearcut* OR clear-cut* OR thin* OR "site preparation" OR fertili* OR selective OR harvest* OR drain* OR *even-aged)
AND (eddy OR flux* OR efflux OR NEE OR NEP OR chamber* OR sequestr*)

This search produced 664 hits. Titles and abstracts of the roughly 450 articles published since 2005 indicate that some 25 of these studies include flux measurements after harvest (mainly clearcutting). About 13 articles cover effects of forest drainage, while about 7 report effects of thinning. A few studies also contain data on greenhouse-gas fluxes after site preparation (scarification), fertilisation, dispersal of wood ash etc. Most of the measurements have been carried out in Finland or North America.

Some additional studies of these kinds may be found in literature reviews or annotated bibliographies of how various forms of land use affect carbon stores or greenhouse-gas exchange (e.g. Hines *et al.*, 2010; Hyvönen *et al.*, 2007; Jandl *et al.*, 2007; Johnson and Curtis, 2001; Maljanen *et al.*, 2010, Mander *et al.*, 2010; Seedre *et al.*, 2010).

Nevertheless, it is clear that measurements of how more uncommon silvicultural practices affect the exchange of greenhouse gases between forest ecosystems and the atmosphere are still rare or non-existent. Thus, almost no such investigations of uneven-aged forestry seem to have been made. One of the very few exceptions is a study of a mixed boreal forest in Canada (Lee *et al.*, 2002) – there, the influence of clearcutting and partial cutting on carbon stores above and below the ground was measured by biometry and analyses of soil, litter and ground vegetation before and up to 5 years after harvest. Another case is a chamber-based study of methane uptake in clearcut and selectively cut coniferous forest stands in a semi-boreal part of Siberia (Morishita *et al.*, 2005). None of these studies is likely to be very informative when it comes to long-term climatic consequences of selective cutting.

Model studies of such aspects of uneven-aged forestry do exist (e.g. Pukkala *et al.*, 2011), but it would be unwise to base a systematic review on them. Model outputs may depend as much on the assumptions in the model as on the input data, and they do not retain any information about the relative strength of evidence (Bussell *et al.*, 2010).

Conclusions

A systematic review of the climatic significance of uneven-aged (continuous-cover) forestry is clearly not feasible due to the almost complete lack of measurements of greenhouse-gas fluxes, carbon stores etc. in forests under such management. As pointed out by Olsson *et al.* (2012), there is an important research gap here.

However, one way of shedding some light on the climatic effects of selective cutting would be to investigate how *thinning* of forest stands affects the exchange of greenhouse gases between forest ecosystems and the atmosphere – uneven-aged forestry can in many respects be seen as repeated thinning (Lindroth, 2009). The scientific basis for a review of the climatic consequences of forest thinning is quite limited but possibly adequate (thinning once or twice before the final harvest is routine in conventional even-aged forestry). Most available data seem to indicate that thinning has considerably smaller effects than clearcutting on the exchange of carbon dioxide.

It must be kept in mind, though, that studies of the short-term effects of thinning will not tell the whole truth about the longer-term significance of uneven-aged forestry for the exchange of greenhouse gases. Moreover, the total climatic impact of such forestry will also depend on other factors, notably fuel consumption during harvest and the long-term timber yield (which affects the potential for substituting fossil fuels with biofuels). Indirect effects of such kinds could be difficult to include in a systematic review, since estimates of their sizes tend to be based on assumptions rather than measurements.

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Mistra EviEM Pilot Studies

PS1 Pilot Study: **How are fluxes of greenhouse gases between boreal forest ecosystems and the atmosphere affected by uneven-aged forestry?** (November 2013)

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