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Effects of low thinning on carbon dioxide fluxes in a mixed hemiboreal forest

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ABSTRACT

We used eddy-covariance (EC) measurements of net ecosystem exchange (NEE) above canopy to assess the effects of thinning on CO_2 fluxes at the ICOS Sweden site Norunda in central Sweden. This forest site consists of mixed pine and spruce stands approx. 100 years old. The thinning during late autumn 2008, performed in a semicircle from the mast extending 200 m outwards harvested about 25% of the volume. Measurements were conducted from 2007 to 2016 and thus, above canopy fluxes were recorded two years before and eight years after the thinning. We also measured the net flux from the forest floor with automatic chambers in three locations and with below-canopy EC during shorter periods before and after thinning. The chamber measurements during the first part of the growing season after thinning showed strongly enhanced effluxes in the order of 150–250% of the pre-thinning values. These chamber measurements were made on drier places within the thinned area because waterlogging made it impossible to use chambers at all available locations. The below-canopy EC measurements, which had a larger footprint as compared to the chambers, showed less enhanced fluxes (in the order of 35%). This footprint included also wetter areas.

The above canopy EC measurements showed a reduction of daytime net flux by approx. 30% during the first summer after thinning. The median growing season fluxes then slowly increased but were not restored to the pre-thinning levels eight years after thinning. There was also a small decrease in growing season ecosystem respiration during the first summer after thinning and with a continued decreasing trend over time. It was concluded that this decrease in respiration was caused by successively decreasing decomposition of coarse organic substrates resulting from the thinning. This respiration decrease over time persisted even under gradual biomass increase, which otherwise would indicate increasing autotrophic respiration. The light-response and respiration models fitted to all data did not show any trends in daytime or nighttime fluxes so the conclusion was that the trends were caused by the thinning and not because of trends in meteorological drivers. The annual values contrasted with the summertime results since only a minor effect was observed on the annual NEE. Both ecosystem respiration and gross primary productivity were reduced as an effect of thinning. We explained the different summertime versus annual effects to be caused by the decrease in ecosystem respiration since respiration is dominating the NEE during non-growing season periods when photosynthesis is very low or even zero. Our results are a strong indication that the NEE of a forest could be maintained over time with harvesting practices that avoids clear-cutting and thereby enhance the total carbon uptake of forests.

1. Introduction

Forests constitute an important sink in the global carbon budget (Canadell and Raupach, 2008; Pan et al., 2011; Sitch et al., 2015) and, thus, act to mitigate a significant part of the fossil fuel emissions (Le Quere et al., 2016). The highest carbon uptake occurs in intact forests in the tropical region but, as a whole, the tropical region is a source because of emissions from deforestation (Pan et al., 2011). The net carbon uptake in boreal forests is 0.5 ± 0.08 Pg C yr^{-1} according to Pan et al. (2011), which corresponds to about 20% of the net uptake in the global established forests (see Pan et al. (2011) for definition).

The role of forests in the global carbon cycle is two-fold; they act as a storage of carbon and its harvestable products can be used to substitute fossil fuels and to replace cement and steel in constructions.

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Unmanaged forests generally hold larger stocks of carbon as compared to managed forests (Noormets et al., 2015) but the net ecosystem productivity is generally lower (Noormets et al., 2015). The reason for the lower carbon storage in managed forests is the regular removal of stem wood at harvest and removal of logging residues, which result in less input of organic material to the soil. Consequently long-term storage in managed forests can only occur in soils and in the aboveground litter pool. There are strong indications that the soil carbon stocks are decreasing in most land-use change types, including conversion of native forest to plantation forests (Deng et al., 2016). However, after conversion to managed forest, conventional forest management seems to conserve soil carbon stocks rather well while more intensive biomass harvesting, i.e. logging including removal of residues, so called whole-tree harvest, leads to losses of soil carbon (Achat et al., 2015). Helmisaari et al. (2011) reported that whole-tree harvest of pine and spruce stands reduced volume increment for 10–20 years after that the stands had reached the first thinning stage, as compared to conventional stem harvesting.

In the boreal region, the main management induced disturbance is clear-cut harvesting, which is the dominating logging procedure. In many cases, the soil is further disturbed by soil scarification, which is used to enhance plant survival and growth. However, even if severe disturbance (e.g., clear-cutting) can have positive effects on the productivity, it has also some adverse effects on the climate; it causes large emissions of CO_2 to the atmosphere during several years after the clear-cutting. Studies in North America (Bergeron et al., 2008; Amiro et al., 2010; Coursolle et al., 2012) and Europe (Lindroth et al., 2009) have shown that net CO_2 emissions continue for approx. 10 years after the harvest and that it takes at least another 10 years for the stand to compensate for the initial emissions. Thus, a relevant question is whether other management systems than clear-cutting can avoid these initial emissions and still maintain aboveground productivity and possibly also result in higher net ecosystem productivity over time. Continuous cover forestry with a selective cutting system in un-even aged stands could potentially be an alternative. However, a literature search did not reveal any studies on the effect of selective cutting on the net ecosystem exchange (NEE) in such systems. The closest one can get are studies on the effect of thinning on the ecosystem CO_2 exchanges in conventional even aged forests.

Wilkinson et al. (2016) studied the effects of thinning in an oak forest in southeastern England using eddy-covariance (EC) measurements before and after thinning. Half of the footprint area was left unthinned and the other half was thinned by removal of 22% of the trees (24% reduction in basal area) with the logging residues left on the ground. Measurements were conducted between 2004 and 2012 and the thinning was made in the middle of the growing season 2007. Surprisingly small and non-significant effects were found on the NEE during daytime. A small increase in ecosystem respiration was observed after the thinning and this effect remained throughout the observation period. They attributed the lack of significant effects to a compensatory effect by the ground vegetation, which received more resources in terms of light and temperature. Granier et al. (2008) analyzed ten years of EC flux measurements in a beech forest in France with thinnings occurring three times during the measurement period. Each thinning reduced the basal area by about 25% and only stems were removed from the stand with residues left on the ground. Granier at al. (2008) could not find any effect of the thinning on either gross primary productivity or on ecosystem respiration on an annual basis. They concluded that thinning had a positive effect on the photosynthesis and on the soil water availability of the remaining trees, which also were manifested through a higher diameter growth rate after the thinning.

There are only a few studies on thinning effects at the ecosystem level in coniferous forests. Dore et al. (2012) studied the effects of thinning in a ponderosa pine ecosystem in Arizona, USA, using EC measurements one year before and four years after treatment. In this type of ecosystem, thinning is used to reduce the likelihood of wildfires with treatments aiming at removing trees with small diameter. The treatment reduced basal area with 35% and tree density by 70%. Parallel measurements were made in an undisturbed nearby forest stand and the NEE during the year before treatments were similar in the two stands. During the first year after thinning, NEE was strongly reduced, which turned the stand into a source of CO_2. However, the productivity recovered quickly and after four post-treatment years, the net uptake in the thinned stand was slightly higher as compared to the un-thinned stand (Dore et al., 2012). This effect was partly caused by weather conditions, leaving the thinned stand to cope better with the dry growing conditions in the area. Saunders et al. (2012) studied effects of thinning in a Sitka spruce stand in Ireland using EC measurements before and after treatment. Measurements started in 2002 and continued until the end of 2009. Two thinnings with different strategies were performed; the first one in winter 2006/2007 with a 15% reduction of basal area from trees across all size classes. The harvested stems were removed but the residues were left on the ground. In autumn 2008 a second thinning was performed where larger trees were harvested, resulting in a total thinning strength of 27% relative to basal area. Saunders et al. (2012) did not find any significant difference in NEE between pre-thinning and post-thinning periods, a result which they attributed to increased photosynthesis of the remaining trees. The most noticeable effect was an increase in the inter-annual variability after thinning.

The only study conducted in a boreal forest we found was by Vesala et al. (2005) in the Hyytiälä pine forest in southern Finland. A first commercial low thinning, following standard silvicultural procedures, was made in winter 2001/2002 reducing the basal area by 26% and leaving residues on the ground after stem removal. The thinning was made sector-wise to allow a comparison of fluxes from unthinned and thinned sectors. No significant differences in NEE between unthinned and thinned sectors could be detected. Vesala et al. (2005) attributed this to an increased uptake by ground vegetation compensating for reduced canopy photosynthesis.

There are a number of studies concerning effects of thinning or selective cutting on soil respiration or soil efflux. The results from these studies points in different directions; some studies show decreased soil efflux after thinning (e.g., Laporte et al., 2003; Sullivan et al., 2008), while other studies have reported increased soil efflux, especially during the first few years after thinning (e.g., Selig et al., 2007; Cheng et al., 2015). Others found no significant effects of thinning (e.g., Stoffel et al., 2010; Shabaga et al., 2015). Most of these studies were short-term studies, measuring a season or two before and after thinning while a few measured longer periods after the thinning in order to follow the recovery. Tian et al. (2009) followed the development eight years after a thinning event in a Chinese fir stand and showed that the soil efflux increased significantly immediately after the thinning and returned slowly to pre-thinning conditions after 4–6 years. Similar results were obtained by Ohashi et al. (1999) in a Japanese cedar forest. The variation in effects is probably due to a combination of changes in drivers such as soil temperature and soil moisture, and changes in processes such as autotrophic and heterotrophic respiration which in turn depends on species types, litter quality etc. It is thus not straightforward to predict what the effect on soil efflux will be after a specific thinning operation.

The aim of this study was to assess the effects on daytime and nighttime ecosystem fluxes as well as on soil effluxes of a thinning in a hemiboreal forest consisting of old growth mixed pine and spruce in Norunda, Sweden. Thinning is a kind of selective harvest which resembles the management in continuous cover forestry. We hypothesize that selective harvest of low volume, similar to typical thinning strength, will have minor impact on the NEE, and therefore a higher NEE over time can be obtained as compared to clear-cut harvest which causes large emissions in the beginning of each new cycle. A continuous cover forestry has also other benefits such as reduced risk of nutrient leakage and higher degree of biodiversity as compared to clear-cut