# Impacts of forest management on carbon stock changes in litter and soil in Swiss forests

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## Introduction

Forest are an important terrestrial carbon (C) store. Interannual variability in C sequestration and respiration by, e.g. tree growth or deadwood decomposition determines whether a forest acts temporary as a sink or a source of C. Fluctuations in the C stock of forests are monitored by many countries and are reported in national greenhouse gas inventories (GHGI), which have to be published under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (KP). To account for carbon stock changes (CSC) in forests, the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC 2003; Tab. 3.1.2) distinguishes five pools: above- and belowground living biomass, dead wood, litter and soil organic matter. The ability of C sequestration in litter and soil can be influenced by forest management (Jandl et al. 2011). Most research on impacts of forest management on C stock dynamics has focused on the effect of land use change including afforestation and deforestation (Thuille and Schulze 2006, Wäldchen et al. 2013). Fewer investigations exist on the impact of a change in silvicultural practices such as from an even-aged to an uneven-aged silvicultural system on C stocks in forest litter and soil.

The purpose of this report is to assess the role of silvicultural practices on C stock change (CSC) in litter and mineral soil in forests in Switzerland. The report will draw on pertaining literature and case studies and will examine how Switzerland accounts for the impact of forest management on C storage in forest litter and soil. The special case of organic soils is not considered here firstly, because of the lack of information on forest management impacts in such ecosystems (cf. Minkkinen and Laine 1998) and, secondly, because drainage of forests is not permitted in Switzerland.

## Forest management effects on carbon storage in litter and soil

Through silvicultural practices including stand tending and regeneration systems, forest management can affect changes in the structure and composition of forests such as age-class distribution and tree species composition. In Switzerland, the available forest management options are restricted by law and explicitly exclude clearcuts and certain site preparation techniques such as fertilizing and liming.

### *Soil*

The soil C store is controlled by inputs from decaying dead biomass and respiration to the atmosphere. The major drivers of the these flows are assumed to be climate and soil texture. Soil C stocks are typically estimated to 1 meter depth of the soil profile.

Meta-analyses such as by Jandl et al. (2007) and Nave et al. (2010) presented extensive reviews of the available information on how forest management can influence soil C sequestration in forests. For regional and national scales, which are relevant for GHGI reporting, the authors concluded that silvicultural practices do not significantly affect soil C stocks (cf. Jandl et al. 2011). Findings of more recent studies on drivers of change in soil C stocks (e.g., Nilsen and Strand 2008, Pötzelsberger and

Hasenauer 2012, Wäldchen et al. 2013) support the conclusion that forest management has only minimal effects on C sequestration in forest soils. The timeframes that these studies considered ranged from decades to few hundred years (e.g., Wäldchen et al. 2013).

The studies provided several reasons why soil C stocks are little affected by changes in silvicultural practices: Most of the soil C is part of stable, mineral-associated soil organic matter (Schöning et al. 2013) that is assumed to be more sensitive to soil properties such as clay content than to changes in silvicultural practice (Nave et al. 2010, Schöning et al. 2013). Also, the rate of C accumulation in the soil is low compared to above-ground C pools (Schlesinger and Lichter 2001).

Furthermore, the detection of a change in soil C stocks is difficult due to the high spatial variability (e.g., Falloon and Smith 2003, Heim et al. 2009, Nave et al. 2010) and methodological limitations. For example, Baritz et al. (2006) found that based on monitoring on a 4 by 4 km grid, the minimum change that can be detected is 4.1 to 4.8 t C $ha^{-1}$ for the mineral soil.

### *Litter*

Litter as defined in the IPCC Good Practice Guidance (IPCC 2003) includes all above-ground non-living biomass below a minimum size. Information on the effect of forest management on the litter pool generally comes from studies on the consequences for soil C stocks. These typically included the non-woody part only, including leaves and needles, and referred to the organic layer (e.g., Wäldchen et al. 2013) or forest floor (e.g., Nave et al. 2010).

The production of leave and needle litter is directly affected by silvicultural practices since the removal of trees results in harvest residues, on the one hand, and a decrease in the amount of remaining foliage on the other (e.g., Van Miegroet and Olsson 2011). Also, a change in stand structure resulting from silvicultural interventions modifies conditions for decomposition on the forest floor such as temperature and humidity. In Norway spruce (*Picae abies* (L.) Karst.) stands in Denmark, Vesterdal et al. (1995) found a negative correlation between C store in the forest floor and thinning intensity that could be explained by the more favorable micro-climatic conditions for litter decomposition in heavier thinned stands.

Generally, the impact of forest management on litter production is temporary (e.g., a few years in the case of thinning, Vesterdal et al. 1995)and losses of litter C can be rapidly replaced (Nave et al. 2010). A continuous input of fresh litter to the existing pool is important since litter C has a high decay rate due to mostly readily soluble C compounds (Tuomi et al. 2009). Besides litter quality, climate is an important driver of litter decomposition (Berg 2000, Hagedorn et al. 2010a, Hagedorn et al. 2010b). The interaction of drivers of litter CSC including forest management can result in in litter C changes that are large compared to the comparably small litter C stock. Hence, a detection of litter CSC is more likely (Baritz et al. 2006, Nave et al. 2010).

Following the IPCC definition, finer deadwood debris is also a component of litter. It can be expected that the effect of forest management on deadwood production is similarly to that of non-woody litter. Due to the differences in chemical composition and size between non-woody and woody litter (Tuomi et al. 2011), the impact of changes in silvicultural practices on C stocks in the two types of dead organic matter may be different. Nevertheless, a change in forest management measurably affects the total litter C stock.

### *Implications for Switzerland*

The majority of studies indicated no significant effect of forest management on soil C stocks with the exception of clearcutting (cf. Jandl et al. 2007, Nave et al. 2010). Since silvicultural practices in Switzerland are regulated by law and exclude intensive management options such as clearcuts, no or only minor forest management impacts on soil C stocks can be expected. Although pertaining studies from Switzerland do not exist, the findings from the discussed studies are valid since they were conducted in forest ecosystems that correspond with the dominant forest types and silvicultural practices in Switzerland (Brändli 2010), i.e., Norway spruce dominated stands with thinning in Denmark (Vesterdal et al. 1995) and Norway (Nilsen and Strand 2008) and selective harvesting in Austria (Pötzelsberger and Hasenauer 2012), and European beech (*Fagus sylvatica*) dominated stands with selective harvesting in Germany (Wäldchen et al. 2013).

The available information also shows that changes in soil C stocks are difficult to detect (e.g., Van Miegroet and Olsson 2011). In Switzerland a permanent monitoring of soils is carried out on 105 sites including 28 sites in forests (Keller et al. 2006), which corresponds to 1 site per ca. 29,000 ha (ca. 39,000 ha in forests) setting limits to representativeness and minimum detectable levels of change: the 95% confidence interval obtained from the 28 Swiss forest monitoring sites is an order of magnitude larger than the modeled SOC pool changes.

Since forest soils store large amounts of C, minor and statistically not significant changes can correspond to large C fluxes (Baritz et al. 2011). Compared to the stable and large soil C pool, the litter C pool presents a more variable and small C store that dominates the interannual variability in CSC in Switzerland (FOEN 2013) and elsewhere (e.g., Liski et al. 2006). The size of these pools in Switzerland are ca. 125 Mg C $ha^{-1}$ for mineral soil in forests and ca. 17 Mg C $ha^{-1}$ in forest litter (Nussbaum et al. in review).

Carbon from deadwood and non-woody litter presents the largest input to the soil C pool. Since the litter C stock is small compared to the soil C pool, changes in litter C stocks have only a small effect on soil C (Nave et al. 2010). The cessation of the traditional practice of litter raking in forests during the 20th century may lead to an increase in soil C stocks in Switzerland (Gimmi et al. 2013).

## Accounting of forest management effects on carbon storage in litter and soil in Switzerland's GHGI

To estimate C stocks and C stock changes in litter and soil, Switzerland uses the C cycling model Yasso07 (cf. Didion et al. 2012, 2013). Inputs to the model include C deriving from annually produced litter. The C inputs are obtained for each plot in the National Forest Inventory (NFI) that is simulated with Yasso07.

The NFI plots have been repeatedly measured since the first inventory in 1985 and, hence, observed changes in the volume of living and dead biomass reflect, among other, the site-specific impact of forest management. Based on harvesting statistics and allometric relationships, the production of deadwood (incl. dead roots, stems, stumps and branches) and litter from living trees (i.e., controlled by forest management) and as harvest residues are estimated. Thus, results from the Yasso07-Model reflect the impact of forest management.

## Conclusion

The available information indicates that a change in silvicultural practices differs in the magnitude of the effects on C stocks in mineral soil and in litter. With the exception of clearcutting, no or only minor effects of a change in forest management are expected for the soil C pool. This is very true for Switzerland since intensive silvicultural practices including fertilizing, liming and clearcutting are not permitted by law. The effect of forest management on the litter C pool is more temporary and the magnitude of the impact relative to the comparatively small total litter C stock can be higher than is the case for soil.

The Swiss NFI is the basis of carbon stock change estimates for Switzerland's GHGI. The effect of forest management are reflected in the observed data on woody and non-woody litter production that drive the simulation of annual carbon stock changes with Yasso07. Thus, forest management effects on C stocks in litter (including non-woody and woody material) and soil are fully accounted for in the Swiss GHGI.

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