Historical land use in Scandinavia and its influence on carbon storage in soil and peat in the boreal landscape

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Abstract

The history of land utilization in Scandinavia is characterized by two major periods of open landscape. The first one temporal ranged from cal. AD 0-500 and the second one ranged from cal. AD 1200-1900 including the medieval crisis in Scandinavia. Both periods were characterized by animal husbandry and intensive grazing as well as cultivation. However, slash-and-burn-cultivation and hay production on mires and meadows were prevailing during the medieval crisis. These activities significantly altered the concentration of transported organic carbon (OC) from the terrestrial ecosystem to inland waters. Burning and grazing decreased the terrestrial OC and water table, due to reduction of biomass, whereby burning has a greater effect. Biennial scything of mires for hay production reduced the biomass as well, hence resulting in a decreasing water table and peat accumulation. Even though two periods of open landscape has been present in the historical land utilization of Scandinavia, only the latest one resulted in a decreasing OC concentration in surface water in boreal lake. This indicates that especially the slash-and-burn cultivation and hay production on mires are very important components of altering the carbon storage in soils and peat due to lowering the terrestrial OC pool.

Keywords: *active pipe concept, hay production, medieval crisis, shieling, slash-and-burn cultivation*

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1 Introduction

1.1 Background

Organic carbon (OC) in lakes and rivers plays a major role in the global carbon (C)-cycle. It influences the drinking water quality (Matileinen, Vepsäläinen and Sillanpä 2010) and determines the light conditions (Ask et al. 2009), water acidity (Driscoll, Fuller and Schecher 1989), and transport of metal and pollutants (Macdonald, Harner and Fyfe 2005) of inland waters. Besides these properties the terrestrial carbon is transported downstream through the freshwater ecosystems to the oceans. Thereby inland waters are not only counted as a natural pipe. Instead they are an active player in the global C-cycle characterized by C input, outgassing, sequestration and output (Battin et al. 2009, Cole et al. 2007). It is assumed, that Earth's surface is covered by inland waters with nearly 1%, but their contribution to the global C-cycle is significant. The global annual emission of CO_2 from the inland waters is similar to the CO_2 uptake from the oceans. The global sequestration rate of OC in inland water sediments even exceeds the sequestration rate of OC on the ocean floor (Tranvik et al. 2009).

Lake-sediment studies in southern and central Sweden detected two different trends in total organic carbon (TOC) concentration. After a period of stagnation for approximately 8800 years a decreasing trend since at least 1650 can be detected. But a short-term increasing trend developed from 1940 until 1970 (Meyer-Jacob et al 2015, p. 6581). Besides, different monitoring programs also detected a common increase of OC concentration in surface water in parts of Europe and North America during the last decades (e.g. Monteith et al. 2007, Worrall and Burt 2007). But it is still in discussion which main factors are responsible for this significant chance in surface water OC concentration. Some studies (Meyer-Jacob et al. 2015, Anderson et al. 2013) resulted, that climate and land use are partly some of the components. Another component could be the declining rates of acid deposition. Therefore decreasing sulfur depositions would alter soils right up to increasing OC leaching (Meyer-Jacob et al. 2015, Monteith et al. 2007).

1.2 Aim

Previous studies were working separately on long-term vegetation changes (Segerström and Emanuelsson 2002) and long-term TOC decline in surface waters (Meyer-Jacob et al. 2015) due to historical land utilization in Scandinavia. This theoretical work focuses on to clarify how historical land utilization in Scandinavia altered the delivery of terrestrial carbon from soils and peat land to the surface water. Therefore the aim of this work is to outline a schematic model of the carbon cycling in lakes and their catchments based on current studies. Additionally it is examined how animal husbandry and hay-making alter the C storage in forest soils and mires.

2 Material and Methods

This theoretical work is a compilation of recent study results and discussions about historical land utilization in Scandinavia, its effect on the vegetation and the general carbon cycle in inland waters. In order to achieve the aim of this review numerous scientific papers were accessed on scientific databases and journal homepages. Permission to access was either given by Umeå University Library or by Universität Leipzig Hauptbibliothek. Key words like "global carbon cycle", "grazing", "historical land utilization", "Scandinavia" were used to limit the search results. Moreover articles were consulted, which cited to read article or were cited in read article. The title of this theoretical work mentions Scandinavia as the study area. Even though some scientific papers from Norway or Finland were involved in the results and discussion a strong focus on Sweden developed during the literature research. This decision was made deliberately because Scandinavia is a large-scale defined study area. A precise literature research would have exceeded the limited working time.

3 Results

3.1 Carbon cycle in a lake

Two different main ways are known for carbon (C) to enter the aquatic inland system. It either enters through runoff and erosion as well as weathering from the terrestrial ecosystem or through direct uptake of pelagic organism from the atmosphere (figure 1). Previous studies (e.g. Degens et al. 1991, cited in Cole et al. 2007, Schlesinger and Melack 1981) saw inland waters as natural riverine pipes to transport the C from the terrestrial ecosystems to the oceans. But this "neutral pipe" hypothesis (figure 2a) does not take long-term burial in sediments and outgassing specifically from surface water to the atmosphere into account, which hence results in an overestimation of the terrestrial ecosystem as a carbon sink (Battin et al. 2009, Cole et al. 2007). Based on this insight Cole et al. (2007) reviewed, that the "neutral pipe" hypothesis should be replaced with a more accurate concept. The suggested "active pipe" concept involves the three major pathways of transport, sequestration and gaseous efflux of C from the inland water system (figure 2b). The relative importance of each pathway determines whether freshwater ecosystems are a C sink or source (Tranvik et al. 2009). Each pathway is influenced by other factors. Especially in high-latitudes ecosystems the dissolved organic carbon (DOC) concentrations in lakes show a positive correlation to the terrestrial net primary production (Jansson et al. 2008). The sequestration rate of OC is naturally determined for example by climate and geology. But land utilization and corresponding conversions to another land use system additionally alter the C burial by affecting the lake's productivity (Anderson, Dietz and Engstorm 2013), whereby the secondary production of lakes get propeled (Battin et al. 2009). OC can also be degraded by microbial and photochemical processes, which mostly lead to mineralization of OC to CH_4, CO, and CO_2 and hence to gas-efflux to the atmosphere (Tranvik et al. 2009). 30 till 80% of OC that entered the aquatic inland system in the boreal zone are lost in lakes. CO_2 emissions to the atmosphere are the most crucial factor in boreal lakes, which clarifies them as a C source (figure 2c). The hydrology is the major influencing variable (Algesten et al. 2003).

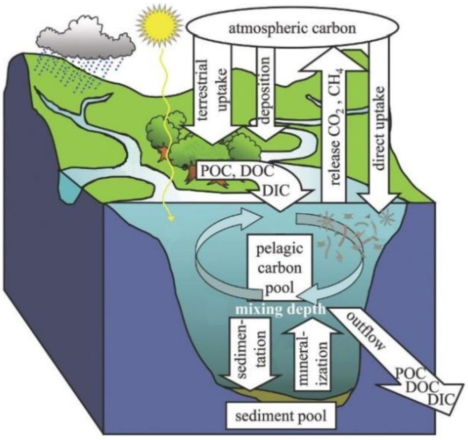

Figure 1: Schematic diagram showing pathways of carbon cycling mediated by lakes and other continental waters (Tranvik et al. 2009)

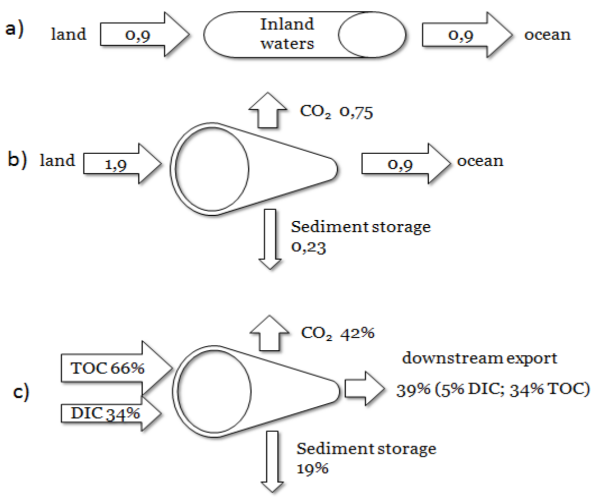

Figure 2: schematic model of C-cycle in inland waters **a)** "neutral pipe" hypothesis, values are reported delivery of 0.7 Pg C^{-1} y^{-1} from rivers to the sea and 0.2 Pg C^{-1} y^{-1} in addition due to direct ground water loads (Cole et al. 2007)

b) "active pipe" concept with values suggested by Cole et al. (2007)

c) annual carbon budget for the Lake Frisksjo¨n, in the boreal forest of Sweden, from Sobek et al. (2006). The total organic carbon (TOC) inputs arise primarily from both catchment export and macrophyte production in the littoral zone of the lake (after Tranvik et al. 2009).

3.2 Historical land use

Because the soil C storage is seen as an important component of OC transported into the streams (Aitkenhead, Hope and Billett 1999) and hence into the whole inland water system, the alteration of these stocks has to take into account. Guo and Gifford (2002) reviewed on a global scale how conversion of land use systems affects the soil C storage. They concluded that overall land use change reduced the soil C stock by 9%. Depending on the conversion it can cause decreases and increases in soil C storage (figure 3). A conversion from a forest area to pasture land increases the soil C storage in average by 8%. Within this conversion precipitation is a determining component. In regions with an annual precipitation of 2000-3000 mm a conversion from forest to pasture increases the soil C storage by 24%. But an annual precipitation of >3000mm or <1000mm decreases the storage. A change of land utilization from forest land or pasture to crops can decrease the soil C storage by 40% or 60%. Converting crop to a secondary forest results in a decreasing soil C storage, where as a conversion from pasture to secondary forest increases the soil C storage by 20%.

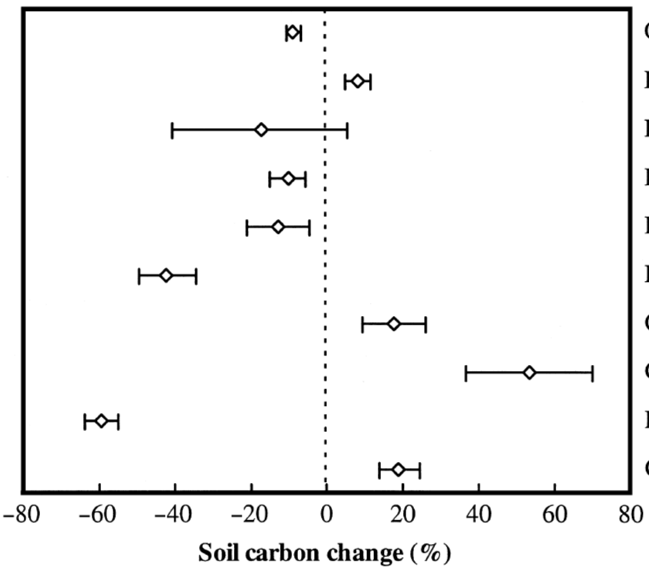

Figure 3: Soil carbon response to various land use changes (95% confidence intervals are shown and of observations are in parentheses (Guo and Gifford 2002).

The history of land utilization in Scandinavia is marked by shifts between forest land and agrarian expansion. The latter initiated by forest opening and a greater abundance of herbs and grasses (Lagerås 1996). Since the Early Iron Age summer farms were seasonally in use in the outlying forest and upland (Figure 4) (Berglund et al. 2009, Berglund et al. 2014, Lagerås 1996). Trees in forest were cut or burned down to establish an open area for pasture and field. Additionally the livestock grazed in the opening forest. At the same time biennially scything was perform on mires to for example provide winter fodder for the livestock (Moen et al. 1999). Lagerås (1996) resulted in two main periods of open landscape in southern Sweden. The first one during the Early Iron Age (cal. AD 0–500) is characterized by forest clearance on both, dry till and damp soils, intensive grazing until an open and pastoral landscape, as well as shifting cultivation. The second main period of open landscape (cal. AD 1200-1900) is first characterized by an expansion of arable land (cal. AD 1200-1300) and second by an expansion of grassland (cal. AD 1300-1500). It is mainly characterized by the medieval crisis starting during the 14th century, which overall resulted in a time of economical changes. It is recorded as a period of forest clearance and expansion of pastures for cultivation and livestock breeding towards self-sufficient but extensive farming during cal. AD 1600 and 1900 (Berglund et al. 2009). In contrast to the first main period the landscape was strictly divided into almost untouched forest vegetation on wet areas and forest clearance on dry till. Another difference is seen in the established slash-and-burn cultivation (Lagerås 1996). Starting in the 1890's grazing and summer farming became less important and

Figure 4: Infield/outland in southern Sweden, a reconstructed landscape image from Late Iron Age AD 500–1000. Infield on fertile soils with meadows and fields surrounded by a main fence. Outland a half-open wood pasture with a swidden field. Arrows indicate transport of hay and leaves from meadows, straw from fields to the barn, manure from the barn to the fields, and cereals from the field to the farm house. Drawing by Nils Forshed (Ekstam et al. 1988, cited in Berglund et al. 2014)

register a rapid decrease (Larsson 2013). In some regions that self-sufficient farming system remained until the 1940s (Swedish National Heritage Board database, http://www.fmis.raa.se/cocoon/fornsok/search.html, cited in Meyer-Jacob et al. 2015). Starting with the 20th century a period of reforestation is noticeable with a slight increase of *Picea* and *Pinus* (Lagerås 1996.). Nowadays forestry and at some point tourism are the important activities on outlying land (Moen et al. 1999). The forest tree canopy already recovered but not the original forest vegetation. The originally mixed deciduous-coniferous forests in boreal Sweden were replaced by *Pinus* as the predominant tree in most areas of boreal forests.

Forests were mainly cleared to get fire wood or even building materials (Moen et al. 1999). Pastures and meadows resulted due to this opening of the area. Additionally grazing occurred in the already opening forest. The effects of grazing on OC dynamics can be triggered through three different ways. The most obvious one is the selective feeding. That resulted in vegetation's composition shift from shrub dominated to grass dominated (Chuckran and Frank 2013). It suppressed the regeneration of trees, which also opens the forest and its canopy (Segerström and Emanuelsson 2002). Another important factor is the trampling, which damaged the vegetation and even exposed soil. Hence soil was able to warm up and to dry (Väre, Ohtonen and Mikkola 1996). Exposed soil is more vulnerable to erosion and C loss (Falk, Schmidt and Ström 2014). Nutrients were redistributed (Moen et al. 1999) or even added through livestock's excrements (Falk, Schmidt and Ström 2014). Summing up a reduction of biomass and hence a reduction of litter production was a common cause of grazing. Due to this reduction a decreasing CO_2 uptake and labile soil OC pool was given (Falk, Schmidt and Ström 2014, Meyer-Jacob et al. 2015). As a long-term effect grazing causes a replacing of deciduous trees with *Pinus* (Segerström and Emanualsson 2002).

Hay production provided food supply for the winter and was done on meadows and mires (Lagerås 1996). It also changed the vegetation composition, whereas shrubs were reduced and the proportion of herbs and grasses changed in favor of grasses (Moen et al. 1999). The removal of vegetation resulted in a decreasing litter production (Moen et al. 1999) and reduced belowground biomass, which hence changed the hydrology and water table level on mires and affects the peat growing rate (Segerström and Emanuelsson 2002).

4 Discussions

4.1 Effects of land use conversion

Shift between forest land and pasture characterize the landscape development of Scandinavia during the last 2000 years. Gradually changes in landscape and vegetation composition are mostly explained by natural processes like climate. But dramatic changes are clearly assigned to human activities (Lagerås 1996). A reduction of a soil C storage additionally results in a reduction of the labile soil C stock and hence to a decreasing transportable amount of OC. A conversion from native forest to pasture occurred during the medieval crisis (Berglund et al. 2009, Lagerås 1996). The system of shieling was established once again to create a self-sufficient agriculture (Moe et al. 1999). Due to grazing the forest canopy opened and pasture land was able to expand (Segerström and Emanuelsson). Such a conversion increases the soil C storage by an average value of 8%. This value is depended on precipitation. With an annual precipitation of between 2000 and 3000 mm a maximum of +24% can be reached (Guo and Gifford 2002). In Scandinavia most parts have an annual precipitation of less than 1000mm (Climatic Research Unit, University of East Anglia, cited in European Travel Weather). This could even result in a decreasing soil C stock of -5%. Cultivation of soils plays another role in the medieval land utilization. A conversion from native forest or pasture to crop decreases the soil C storage by 40% or 60% (Guo and Gifford 2002).

4.2 Effects of historical land use

Meyer-Jacob et al. (2015) detected decreasing TOC concentration in lake-sediments starting circa 1450 AD. At the same time Segerström and Emanuelsson (2002) classified a period of extensive agrarian land use starting between 1300 and 1500. The slash-and-burn cultivation and the utilization of summer farm were performed during this time (Lagerås 1996). Hence vegetation composition in forests and mires changed. The forest canopy opened and even changes in the hydrology on mires followed. While Meyer-Jacob et al. (2015) concluded one period of anthropogenic disturbance, Lagerås (1996) concluded two major periods of open landscape with similar land utilization. Both periods are characterized by cultivation and intensive grazing. But there are major differences in cultivation types. From cal. AD 0-500 shifting cultivation was performed. During the second period (cal. AD 1200-1900) slash-and-burn cultivation established. Worrall, Armstrong and Adamson (2007) resulted that on burned plots lower DOC concentration can be found. They explain, that this effect correspondents to changes in hydrology. Both grazing and burning reduce the water table, whereas burning causes a greater effect. Trampling and hence soil compaction cause in a small reduction of the water table. Burning lowers the water table due to vegetation changes. Another natural consequence of burning is the reduction of DOC. It hampers the soil water to interact with the organic matter (OM), hence resulting in a lower DOC concentration in soil water (Worrall, Armstrong and Adamson 2007). The idea that grazing has a lower effect than burning explains why even though Lagerås (1996) resulted in two major periods of open landscape, only the period initiated by the medieval crisis resulted in decreasing TOC concentration in surface waters.

Mires are known to be highly supersaturated with C. The major part is buried, but a specific part is transported downstream as DOC (Cole et al. 2007). Hay production was first ascertained between cal. AD 1200 and 1900 (Lagerås 1996). Performed on mires and meadows it lowers the water table due to biomass reduction. It additionally affects the peat accumulation (Segerström and Emanuelsson 2002). Peat cover is a major factor when it comes to stream water DOC in small- and large catchment scales (Aitkenhead, Hope and Billett 1999). Because mires were drastically altered by reducing biomass and litter as well as peat accumulation a massive reduction of the OC and labile OC resulted.

Land utilization of summer farming started to become less important during the 1890's but lasted in some parts until the 1950's (Segerström and Emanuelsson 2002). Vegetation changes from an open towards a forested landscape are currently prevailing (Lagerås 1996). Even though the forest canopy recovered the previous deciduous-coniferous mixed forest is now dominated by *Pinus* (Segerström and Emanuelsson 2002). The outlying land is now used for today's important activities like forestry and tourism (Moen et al. 1999). At the same time the TOC concentration in surface water in boreal lakes rapidly increases (Meyer-Jacob et al. 2015).

5 Conclusions

Inland waters play a significant role in the global C-cycle. They transport, sequester and outgas C. The relative importance of these pathways determine whether lakes are C-source or –sink. Productivity and respiration of lakes are strongly coupled to the terrestrial primary production and hence to its vegetation composition, which got altered through historical land utilization. Animal husbandry and hay production were the prevailing land utilization during the medieval crisis in Scandinavia starting in the 14^{th} century. Grazing in forests, slash-and-burn cultivation and hay production on mires significantly reduced biomass and litter production. Hence the hydrology resulted in a lower water table. However, the cultivation had a greater effect on lowering the water table than grazing. Additionally the burning decreased DOC in soil water, because it prevents water interacting with the OM. Due to biomass reduction peat accumulation decreased as well. Especially slash-and-burn cultivation and hay production significantly altered the concentration of transported OC from the terrestrial ecosystem to inland waters. They are determining components altering the carbon storage in soils and peat due to lowering the terrestrial OC pool.

6 References

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