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Above ground biomass changes in the mountain birch forests and mountain heaths of Finnmarksvidda, northern Norway, in the period 1957–2006

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ABSTRACT

Birch forests cover large areas of the northern Fennoscandia and the mountain birch (*Betula pubescens* ssp. *czerepanovii*) often forming the altitudinal and Arctic forest and tree lines. Interpreting the factors leading to landscape changes in mountain birch forest involves disturbance from anthropogenic use and climate as important factors. Using vegetation maps based on aerial photographs and satellite images from 7 years in combination with statistical data and ground estimation data of biomass in the period 1957–2006, we were able to assess the transitions among mountain heaths and different types of forest, the displacement of the altitudinal forest line and hence the change in biomass. The tree biomass as well as the growing stock for birch in Finnmarksvidda doubled in the period 1957–2006. Only lichen biomass has been significantly reduced in the period 1957 to 2000, with a subsequent slight increase of lichen biomass in the period 2000 to 2006. The results presented in this paper show significant and positive relationships between measured tree biomass and the increase in reindeer population in the period 1957–2006 in the study area. The hypothesis concerning the removal of the "lichen barrier effect" by heavy reindeer grazing which leads to increased success for birch seeds to germinate and sprout is therefore considered to be valid. However, also, climate change effects like increased precipitation, moth attacks, freezing and thawing events during winter and long-transported air pollution (e.g. nitrogen) may also have reinforced the changes in biomass. Climatic variables from regional weather stations for the period 1955–2006 did not, however, reveal any consistent change except for that the increased snow depth had a negative impact on the reindeer population while increase in snow depth hindering the reindeer in grazing seemed to have a positive impact on the lichen biomass. The ongoing development of increased forest cover and hence elevated forest line will lead to reduction of open habitats, and hence decreased grazing accessibility for the reindeer. The effects on forestry and carbon sequestration are also discussed, and here one of the suggestions is to let the northern birch forests act as carbon sinks contributing to the reduction of total net emission of CO_2 in the Nordic countries. Land use like reindeer husbandry has shown to strongly affect relationships between ecological processes like tree-growth and climate. Moreover, reindeer husbandry is such a widespread human activity in the arctic and boreal region that it might affect the global carbon budget.

1. Introduction

Birch (*Betula pubescens*) is common in Fennoscandia and birch forest is the dominant forest type in the most northern and western parts where it constitute the forest line both upwards and northwards (e.g. Bohn et al., 2000). In this north-western region of Scandinavia birch reach an age up to 200 years (Kirchhefer, 1996; Millar, 1980), a height from 1 to 15 meters, and the birch forest types has an aboveground biomass in the range from 0.7 to 3 kg/m^2, depending on the local climate and nutrient conditions (e.g. Dahlberg et al., 2004; Karlsson et al., 2005; Starr et al., 1998).

There are local indications of large fluctuation in the distribution of the birch forests of north-western Scandinavia the last decades, and these fluctuations are caused by changes in land use practice, sheep grazing, insect attacks, and climate (see for instance Karlsson et al., 2005, Neuvonen et al., 1999). The region is also the central area for the indigenous Saami people's reindeer herds, and in particular, the changes in the number of reindeer highly influence both the distribution of the birch forest and the under

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story vegetation (Cairns and Moen, 2004; Gaare et al., 2006). While most studies focus on the changes on a local scale, there are rather few studies that describe the changes of the birch forest on a regional scale (Tømmervik et al., 2003, 2004; Johansen and Karlsen, 2005, 2007), and even less on the corresponding changes in biomass (Tømmervik et al., 2005). Maps and statistics of changes in the aboveground biomass over large regions are of great interest for input to forecasting carbon budgets, global change models, sustainable forest management, for estimating productivity for whole ecosystems, as well as for estimating economical impact (e.g. Hall et al., 2006).

The birch forest types in the region has been well described by Hämet-Ahti (1963), Väre (2001), and Wehherg et al. (2005), and the biomass of several types is measured by for instance Dahlberg et al. (2004) and Starr et al. (1998). The forest types with the lowest aboveground biomass (<1 kg/m^2) are found on very nutrient-poor and dry ground. The under-story vegetation is characterized by dominance of reindeer lichen (*Cladina* spp.) and crowberry (*Empetrum hermaphroditum*), and the birch trees are multi-stemmed and typically less than 3 m tall. These forest types are common in continental inland regions as Finnmarksvidda in northern Norway, and is extensively grazed and modified by reindeer. In the summer ranges, mountain birches are intensively browsed, whereas in the winter ranges, reindeer feed on ground lichens, grasses and dwarf shrubs, and the mountain birches remain intact (Stark et al., 2007). In some cases, however, there is a tendency to increased sprouting and growth of birch in areas where the thick lichen mat is partly or completely removed by overgrazing and trampling by reindeer (Tømmervik et al., 2004, 2005). The sprouting of birch may also has been caused by increase in precipitation (Wielgolaski, 2005). Somewhat higher amount of biomass has birch forest types where bilberry (*Vaccinium myrtillus*) and bryophytes is dominant to various degrees, and wavy hairgrass (*Deschampsia flexuosa*) is a constant species. In particular, in more oceanic regions dwarf cornel (*Cornus suecica*) and small ferns are also common. The birch trees in these very common forest types are multi-stemmed, on average 4–7 m tall and the aboveground biomasses are typically in the range 1–2 kg/m^2 (Dahlberg et al., 2004). Birch forest types with high biomass are found on nutrient rich ground, where the birch is single-stemmed. In forests, dominated by low herbs, biomass in the range from 1.5 to 2.5 kg/m^2 can be found, while in forests dominated by tall herbs or tall ferns the biomass is often more than 2 kg/m^2 (Starr et al., 1998). The birches easily reach more than 10 m in wind-protected areas, and the forest types are most common in the inner sub-oceanic fiord zone.

2. Background

2.1. Biomass estimation using remote sensing

To estimate the biomass over large regions, with several different forests types, remote sensing is the most useful tool. However, currently, the only quantitative biomass data available for the Scandinavian mountain ecosystem were obtained through estimations on tree or plot level for limited areas (Sveinbjörnsson, 1987; Starr et al., 1998; Bylund and Nordell, 2001; Dahlberg, 2001). For area-based estimates, we can estimate the biomass for many trees and add them up for a fixed area, or we can relate area measurements to some stand or site variables (Ståhl et al., 1999). Furthermore, Ståhl et al. (1999) stated that due to access difficulties together with high variability of the ecosystem, purely field-based methods become expensive in the mountains and forests in more remote areas. An alternative to using field measurements might be to add auxiliary information from remote sensing data in order to extrapolate the estimations from the field plots to make them valid over larger areas. This approach can in addition increase the accuracy of the statistical estimates for a given area where field plots are available (Reese and Nilsson, 1999; Steininger, 2000). Satellite remote sensing can hence be used as an effective tool for estimating the biomass of vegetation and forests in regions like Fennoscandia (Colpaert et al., 1995; Tømmervik et al., 2005).

Several methods for estimating forest biomass by remote sensing have been developed, but their comparative advantages have been rarely evaluated for large areas (Labrecque et al., 2006). According to the IPCC GPG (Intergovernmental Panel on Climate Change, Good Practice Guidance), remote sensing methods are especially suitable for independent verification of the national LULUCF (Land Use, Land-Use Change, and Forestry) carbon pool estimates, particularly the aboveground biomass (Muukkonen and Heiskanen, 2007). Hence, Muukkonen and Heiskanen (2007) used data from the satellite sensors ASTER and MODIS over large areas in order to verify carbon inventories with good results. Heiskanen (2006) used ASTER satellite data in order to estimate above ground biomass and leaf area index (LAI) in mountain birch forests in Finland. He found that the red band of the ASTER sensor was the band with the strongest correlation between the biomass and LAI, and the best models explained 85% of the variation in biomass and LAI. On the other hand the undergrowth vegetation (shrub/scrub layer, field layer and bottom layer) and background reflectance are likely to influence the observed relationships (Heiskanen, 2006) calling for refined methodology.

Labrecque et al. (2006) compared the different classification methods and one of the methods, Land Cover Classification (LCC), and this method using biomass tables applied on classified TM images. Since many remote and forested areas in northern Norway lack forest inventory data, LCC-based methods may be suitable for applications that do not require a high level of precision and seem to be an appropriate method for estimation of trends in forest biomass.

This study focuses on the changes in the aboveground biomass on Finnmarksvidda, in northern Norway, a central winter grazing area for the Saami people's reindeer herds. Recently, Johansen and Karlsen (2007) mapped the vegetation on Finnmarksvidda by the use of Landsat ETM + satellite data from the year 2006. The vegetation on Finnmarksvidda has changed dramatically since 1972, mainly due to changes in the reindeer population (Johansen and Karlsen, 2005, 2007). Previously, Tømmervik et al. (2004) have used the Landsat MSS/TM/ETM+-based vegetation maps from Johansen and Karlsen (2005) supplied with aerial photos from around 1960 (Lyftingsmo, 1965), to study the changes in vegetation cover on Finnmarksvidda in relation to climate and reindeer population data. This study goes further and the main objective is to investigate variation in biomass using vegetation maps produced by Tømmervik et al. (2004) and Johansen and Karlsen (2005) by adding two years (1957 and 2006) to the time series, and assess eventually co-variations between the number of reindeer, biomass and climate parameters. A sub-goal is to assess whether the hypothesis about the removal of the "lichen barrier effect" by heavy reindeer grazing (Tømmervik et al., 2004) is one of the significant drivers which may lead to upwards migration of the forest line and hence increased forest cover in previously lichen dominated tundra areas.

3. Study area and methods

3.1. Study area

Finnmarksvidda (Fig. 1) is Norway's largest mountain plateau, and is situated in the arctic/alpine-boreal transition zone between