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Boreal forests can have a remarkable role in reducing greenhouse gas emissions locally: Land use-related and anthropogenic greenhouse gas emissions and sinks at the municipal level

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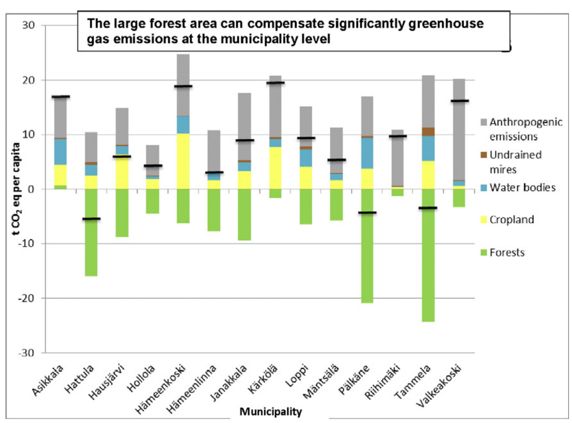
HIGHLIGHTS

- The significance of natural landscapes in the regional C budgets is shown.
- Boreal forests can be remarkable C sinks enabling net C sequestration in ecosystems.
- The large area of forest may compensate for all C emissions in the municipality.
- Forest management policy can be a key factor for mitigating municipal GHG emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

Ecosystem services have become an important concept in policy-making. Carbon (C) sequestration into ecosystems is a significant ecosystem service, whereas C losses can be considered as an ecosystem disservice. Municipalities are in a position to make decisions that affect local emissions and therefore are important when considering greenhouse gas (GHG) mitigation. Integrated estimations of fluxes at a regional level help local authorities to develop land use policies for minimising GHG emissions and maximising C sinks. In this study, the Finnish national GHG accounting system is modified and applied at the municipal level by combining emissions and sinks from agricultural land, forest areas, water bodies and mires (land use-related GHG emissions) with emissions from activities such as energy production and traffic (anthropogenic GHG emissions) into the LUONNIKAS calculation tool. The study area consists of 14 municipalities within the Vanajavesi catchment area located in Southern Finland. In these municipalities, croplands, peat extraction sites, water bodies and undrained mires are emission sources, whereas forests are large carbon sinks that turn the land use-related GHG budget negative, resulting in C sequestration into the ecosystem. The annual land use-related sink in the study area was 78 t CO_2 eq km^{-2} and 2.8 t CO_2 eq per capita. Annual anthropogenic GHG emissions from the area amounted to 250 t CO_2 eq km^{-2} and 9.2 t CO_2 eq per capita. Since forests are a significant carbon sink and the efficiency of

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this sink is heavily affected by forest management practices, forest management policy is a key contributing factor for mitigating municipal GHG emissions.

1. Introduction

To mitigate climate change, the European Union has committed itself to a reduction in greenhouse gas (GHG) emissions of at least 20% below 1990 levels by 2020 (EC, 2008). Therefore, carbon (C) sequestration into ecosystems is an important ecosystem service. Although GHG emissions from various land use types is a well-studied environmental phenomenon (e.g. Martikainen et al., 1993, Le Mer and Roger, 2001 and Dalal and Allen, 2008), there is an urgent need for integrated estimations of fluxes at the landscape and regional levels (Buffam et al., 2011). These estimates help regional and local authorities to develop measures, land use policies and landscape management practices for the minimisation of GHG emissions. Municipalities are often in a position to make decisions that affect local emissions. In particular, municipalities are responsible for land use policies. Comprehensive municipality-level information of different GHG sources and sinks is needed for mitigating GHG emissions via planning, management and decision-making.

In this study the national GHG accounting system (Statistics Finland, 2013) is modified and applied at the municipal level. In addition, the land use-related GHG emissions and sinks are combined with the anthropogenic GHG emissions at the municipal level. We define land use-related emissions and sinks as including forest areas, croplands, water bodies such as lakes, streams and rivers, and mires. Further, emissions from peat extraction sites are included as land use-related emissions. Anthropogenic GHG emissions result from human activities such as emissions from burning fossil fuels for energy (IPCC, 2001).

In Finland there is a well-developed carbon accounting system that includes anthropogenic and land use-related GHG emissions from terrestrial ecosystems, as well as regionally representative GHG evasion estimates from aquatic ecosystems (e.g. Kortelainen et al., 2006, Bergström et al., 2007 and Juutinen et al., 2009). However, holistic studies on a municipal scale are lacking.

The aim of this study was to demonstrate the variety of GHG sources at the municipal level by applying an easy-to-use calculation tool for GHG emissions and sinks of different natural and anthropogenic sources in 14 municipalities in Southern Finland. By taking advantage of several existing free data sources, it is possible to easily calculate various GHG sinks and sources in order to support local authorities in planning and implementing more sustainable actions, strategies and management practices to reduce GHG emissions. Our hypothesis is that land use-related carbon emissions and sinks at the landscape and municipal level can be significant when compared to emissions from human activities (i.e. anthropogenic emissions).

2. Methods

2.1. Study area

The study area consists of 14 municipalities within the Vanajavesi catchment area, located in boreal zone in Southern Finland (60°40′–61°20′N, 24°10′–25°20′E). The total area is 8400 km^2, comprising 13% water, including lakes and rivers. More than 70% of the land area is covered by coniferous and mixed deciduous woodland or mires. The population density ranges from 9 to 233 persons per km^2, the average density in 2013 being 28 persons per km^2. The map of municipalities with their total area and land use are shown in Fig. 1 and Table 1.

2.2. Land use-related GHG emissions and sinks

The LUONNIKAS calculation tool (Haaspuro, 2013) was used to calculate municipal-level estimates of carbon budgets for forests, cropland, mires and water bodies. LUONNIKAS calculates carbon sequestration into the ecosystem and the amount of GHG emissions for a one-year period. For the analysis we used data from year 2009 which was the most recent to achieve complete datasets. When methane (CH_4) or dinitrogen monoxide (N_2O) emissions were assumed to be significant, they were also added to the calculations, and the results presented as CO_2 equivalents.

The LUONNIKAS calculation tool consists of simple calculation methods to ensure that data needed for calculations is easily available at the municipal level. The calculation methods for GHG emissions and sinks mostly follow the methodology used in the Land Use, Land Use Change and Forestry (LULUCF) sector in Finland's national greenhouse gas inventory (Statistics Finland, 2013).

This inventory provides annual information on the national GHG emissions and removals that are reported to the United Nations Framework Convention on Climate Change (UNFCCC) and the European Commission (Statistics Finland, 2013). In the LULUCF sector, the emissions and sinks are calculated for managed land use types. It includes the carbon budgets of forest land, cropland and peat extraction sites. Inland waters and undrained mires are considered unmanaged, and therefore no emissions are estimated for those land use classes in the greenhouse gas inventory (Statistics Finland, 2013), although emissions from both these land use types can be large (Bergström et al., 2007). High nutrient concentrations have been shown to increase both CO_2 and CH_4 evasion from boreal lakes (Kortelainen et al., 2006; Juutinen et al., 2009) in agreement with recent global estimates by Lauerwald et al. (2015), which highlighted the anthropogenic drivers for CO_2 evasion from global river network. In this study carbon budgets of water bodies and undrained mires were calculated based on regionally representative studies, most of which were carried out in boreal Finland and Sweden (see Bastviken et al., 2004, Kortelainen et al., 2006, Saarnio et al., 2007, Juutinen et al., 2009 and Humborg et al., 2010). Inland waters also sequester terrestrially fixed carbon. However, permanent C pools in boreal lakes are minor compared to CO_2 evasion (Kortelainen et al., 2004; Kortelainen et al., 2006).

2.2.1. Forest

The carbon budget of the forest was calculated as a sum of forest biomass increment, forest biomass removals by forest harvesting, and the carbon storage change of the forest soil. The calculation of carbon sequestration in biomass included all forests on mineral and organic soils. The forest soil carbon budget was calculated for all mineral soils and drained organic soils.

The forest biomass increment was calculated using forest areas, region-specific growth rates for different tree species and forest land types (Statistics Finland, 2013), and biomass expansion factors (BEF) specific to geographical location, organic and mineral soils, forest land types, tree species and below and above-ground biomass. The harvest removals were calculated by transforming the municipal-level data of yearly fellings in privately-owned forests into total harvest removals. The amount of C in total harvest removals was subtracted from the amount of C in biomass increment, which gives the one-year net carbon budget, i.e. C sequestered in or removed from the biomass.

The forest soil carbon budget was calculated by multiplying the area of the mineral and organic forest soil by respective emission factors from Finland's national greenhouse gas inventory (Statistics Finland,