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Research paper

Human appropriation of net primary production in Finland during 1990–2010

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ABSTRACT

Land-use environmental impacts are gaining attention as global demand for land is increasing. Human appropriation of net primary production (HANPP) is a useful measure to estimate how much of the net primary production (NPP) available for ecosystem processes is appropriated by humans annually. It accounts for the NPP extracted by biomass harvest, and the NPP losses due to land conversion. Finland is a forested country with good availability of detailed data for calculating HANPP. We estimated HANPP for Finland for a period from 1990 to 2010. Human appropriation of net primary production in Finland was on average 59% of the potential net primary production during the 1990's and then decreased fairly steadily to 50% in 2010. Net primary production harvested by humans, $HANPP_{harv}$, remained fairly constant over the study period, on average 25 Mt carbon. HANPP due to land use change ($HANPP_{luc}$) decreased from 50 Mt to 38 Mt carbon during the past 20 years. The difference between the actual NPP of forests and the potential NPP without any human intervention decreased, mainly due to the growth of wood biomass stock in forests yielding larger amounts of litter production and further larger NPP. Forest $HANPP_{luc}$, however contributed as much as 50% of the Finnish total HANPP in 2010. Our study shows for the first time the importance of calculating potential NPP for forests in detail.

1. Introduction

Land is a scarce resource with competing uses for human food, feed, and fibre. Changes in the type of land use and land use intensity greatly affect biodiversity and numerous ecosystem services [1]. Environmental impacts of land use related to producing goods and services are gaining more and more attention. To assess these effects, several methods have been applied. For instance, global characterization factors for assessing biodiversity in life cycle assessment biodiversity have been recently developed [2–4]. However, these can currently applied only at a very coarse land use scale.

Human appropriation of net primary production, HANPP, is one useful measure to estimate human impact related to land use [5,6]. For instance, HANPP has been proposed as possible resource-efficiency indicator to assess environmental impacts of land use [7] in the work related to The Roadmap to a Resource Efficient Europe [8]. HANPP measures how much of the net primary production (NPP) available per year for ecosystem processes is appropriated by humans, and how much of the trophic energy would available for ecosystems in the absence of human influence. Net primary production is measured in total biomass carbon produced annually by plant growth. HANPP accounts for the NPP extracted by biomass harvest, and the NPP losses due to land use change. Land use change impact is calculated by comparing actual NPP levels with NPP levels of potential ecosystems (i.e. NPP which would prevail without human land use). Besides total amount of carbon related to harvests and land use change, HANPP can be presented as a share of potential net primary production.

There are a few studies that have estimated the global human appropriation of net primary production [5,6,9,10]. National studies have been conducted recently for Italy [11], Germany [12] and New Zealand [13] and earlier for example for Austria, Hungary, the Philippines, South Africa, Spain and UK, see Ref. [14]. These studies use long-time national time series on harvests and land-use types, complemented with national and more general factors in calculating HANPP (e.g. given in Ref. [5]). The studies show, that in the Western industrialized region (including Canada, US, Australia, New Zealand, and 18 European countries, also Finland), HANPP has been recently around 25% of the potential primary production [6].

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Finland is a northern country with a forest-dominated landscape. Forests cover about 228 000 km^2 of the land area of 304 000 km^2 in Finland [15]. The country has an intensive import-oriented forest industry. Open peat lands cover 20 000–30 000 km^2: 1000 km^2 are used for peat extraction. The area of agricultural land in Finland was 23 000 km^2 in 2010, a minor decrease in the area of 1000 km^2 was experienced during the past 20 years [16]. The Finnish population amounted to 5.4 million in 2010. Finland is also a country with extensive data and published research on natural resources, especially on forests.

HANPP for Finland has been estimated crudely in the earlier global studies [5,6]. Global studies in general have assumed the NPP losses due to land use change as zero for forest land. In Finland, the land cover is mainly forestry land. Also, coarse coefficients are given for quite large regions (e.g. Western Europe) to e.g. calculate unused extraction of harvested HANPP. An earlier study [17] for Finland included HANPP in a comparison of life cycle land use impacts (for the year 2002 only), but used the default HANPP factors. The earlier study also based the analysis on land areas and usage intensities, resulting potentially in an overestimate of grazing damage by reindeer, which occupy a vast area but are managed very extensively. There is therefore a need to increase the depth of previous studies both over time and by using more detailed input data and at the same time also provide estimates for land cover change due to forestry for future local and global HANPP calculations.

In this paper, the changes in the Finnish land use in terms of harvested net primary production (NPP) and NPP losses due to land use change during 1990–2010 are studied. In particular, the changes in net primary production and human appropriation of forests, harvested timber, harvest residues as well as net primary production and human appropriation in agriculture are studied. We use mostly such detailed data that has not been applied earlier for Finland, or for other countries in respective calculations. We compare the use of country-specific factors to calculating HANPP using the factors given in earlier literature on HANPP [5,6].

2. Methods

2.1. HANPP, human appropriation of net primary production

HANPP accounts for the NPP extracted by biomass harvest ($HANPP_{harv}$), and the NPP losses due to land use change ($HANPP_{luc}$). Here we follow the HANPP concept as defined by Haberl et al. [5] and further by Krausmann et al. [6].

$HANPP_{harv}$ is the quantity of carbon in biomass consumed by humans including used extraction and unused extraction. Used extraction includes: harvested timber; used logging residues, stumps and bark; harvested primary crops, used crop residues, and forage consumed by livestock. Unused extraction includes: unused logging residues, unused crop residues and belowground biomass, unused harvested biomass from urban areas and biomass lost in human induced fires.

$HANPP_{luc}$ is the quantity of carbon lost as a result of land conversion. $HANPP_{luc}$ is measured by estimating the net primary production of potential vegetation that would prevail without human influence, NPP_{pot}, and using that as a reference for the current actual net primary production, NPP_{act}. NPP_{act} refers to the "human managed" levels of productivity and consists of harvested NPP ($HANPP_{harv}$) and remaining productivity (NPP_{eco}). Assuming that NPP_{act} remains unchanged, increasing HANPP levels indicate decreasing shares of NPP_{eco}, i.e. the share of annual biomass remaining in ecosystems after human land use available for other food webs. However, in the case of for example cropland fertilization, NPP_{harv} can increase along with NPP_{act}, thus allowing NPP_{eco} to remain unchanged or even to increase as well.

Calculation of HANPP can be presented as follows:

$$HANPP = HANPP_{luc} + HANPP_{harv},$$

where

$$HANPP_{luc} = NPP_{pot} - NPP_{act}$$

$$HANPP_{harv} = \text{used extraction} + \text{unused extraction}$$

Remaining productivity NPP_{eco} can be calculated as follows.

$$NPP_{eco} = NPP_{act} - HANPP_{harv}$$

From equations above, it follows, that

$$HANPP_{luc} + HANPP_{harv} + HANPP_{eco} = NPP_{pot}$$

HANPP is measured as carbon biomass (e.g. t a^{-1}), or carbon biomass per land area (e.g. g m^{-2} a^{-1}). Furthermore, HANPP can be presented as a share of NPP_{pot}, denoted with HANPP%.

2.2. System boundaries

In this study, forests, cropland, grazing, built-up areas, and peat extraction sites were included to calculate the HANPP of Finland. The study area covers 88% of the total land area in Finland [18]. Forests include all forest land, also conservation areas, following the approach of national greenhouse gas inventory, where all the forests are regarded as influenced by human activity [19]. Human-induced fires are unimportant in Finland, and excluded from the study, varying annually from 200 to 1600 ha between 1990 and 2010 (compared to 220 800 km^2 of forest land in 2010) [15]. Peat extraction includes only mined peat excavation areas, following the approach of national greenhouse gas inventory, where peat extraction is separated from peat land [19].

The remaining land area, not included in the calculations is natural land that has minimal past and current economic use, leading to negligible $HANPP_{luc}$ and $HANPP_{harv}$.The remaining 12% of Finnish land area consists mostly of natural peatlands. Other land cover classes excluded are natural grassland, moors and heathland, beaches, dunes and sand plains and bare rock. This remaining land area has low natural productivity, thus also low NPP_{pot}. Land cover types not under human land use ("wilderness"), and thus not included in the study, were calculated for reference based on the Corine land cover data base for 2006 [18].

2.3. Data and calculations

2.3.1. NPP_{pot}

First, the potential net primary production (NPP_{pot}) was estimated (Supplementary Table S1). The net primary production of a forest in a natural status was assumed as a reference for NPP_{act} in managed forests, croplands, grazing land and urban areas. The estimation of NPP_{pot} was based on the assumption that no biomass was extracted by humans from the natural forests. The NPP_{pot} was estimated as presented by Liski et al. [20] according to the equation: $NPP = \Delta GS + \Delta B + L + M + F$ [20]. The change in the growing stock ΔGS, annual litter production L, natural mortality M and fellings F of trees (equal to none in the natural forests) were summed over the forest rotation and the change in the biomass of ground vegetation ΔB was added to these estimates. Forest inventory term gross annual increment $GAI = DGS + F + M$ and net annual increment $NAI = GAI - M$. It was thus necessary to add the litter production of living trees to these forestry terms to estimate NPP.

The average NPP_{pot} was estimated as the area-weighted mean