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Forest harvest index: Accounting for global gross forest cover loss of wood production and an application of trade analysis

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ABSTRACT

Forest cover loss is a major cause of both the decline in global biodiversity and the increase in carbon emissions into the atmosphere. Focusing on the effects of logging, this study introduces an index of wood production, the forest harvest index (FHI), which calculates the expected gross forest cover loss (GFCL) reflecting the demand for timber and wood products at the global scale. We examined the accuracy and precision of the index by investigating the relationship between the FHI and actual GFCL measured through remote sensing. The index incorporates wood- and climate-specific biomass expansion factors and country-specific growing stock densities to convert wood production volume to expected GFCL. We quantitatively examined the effect of data uncertainty in the growing stock density values obtain from FRA 2010 on the predicted relationship between the FHI and actual GFCL. We quantified the FHI for both industrial roundwood and wood fuel during a 5-year period (FY2000–FY2004) in each of the 139 nations considered. Results demonstrated that the FHI of industrial roundwood (18.6 million ha yr^{-1}) corresponds well to actual GFCL (19.3 million ha yr^{-1}) during the same period. The data uncertainty analysis suggested that increasing the frequency of forest monitoring at the national level can improve the precision and accuracy of the FHI, but discrepancies between the FHI and actual GFCL were also identified. Furthermore, to demonstrate the utility of our index as a metric of virtual GFCL of wood products, we disaggregated the FHI into export, import and domestic based on global wood trade data and compared the strength of the relationship with actual GFCL. Export FHI had a strong positive relationship with GFCL, which effect far exceeded the compensating effect of import FHI, indicating that wood trade overall increased GFCL at the global scale.

Abbreviations: AIC, Akaike Information Criterion; BEF, Biomass Expansion Factor; DIC, Deviance Information Criterion; FAO, Food and Agriculture Organization of the United Nations; FHI, Forest harvest index; FRA, Global Forest Resources Assessment; GFCL, Gross forest cover loss; GIS, Geographic information system; IOV, Importance of Variable; MCMC, Markov-chain Monte Carlo; REDD+, Reducing emissions from deforestation and forest degradation in developing countries; SE, Standard Error; VIF, Variance inflation factor.

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1. Introduction

Over the past several centuries, humanity has increasingly altered the terrestrial biosphere, leaving only the most remote areas untouched (Ellis et al., 2012). Human activities appropriate nearly one fourth of potential net primary productivity through harvest and changes in land use/land cover (Haberl et al., 2007). This proportion is expected to increase given projections of human population growth. Anthropogenic impacts on the global environment have caused a global biodiversity crisis and the erosion of numerous ecosystem services (Foley et al., 2005; Rockström et al., 2009). Understanding the relationship between extractive resource production and the alteration of the land surface is essential in developing long-term strategies to preserve the natural environment and sustain the resources fundamental to humans.

Forest ecosystems are amongst the most pristine natural ecosystems on earth (Potapov et al., 2008a,b). Forest cover has been used as a proxy for forest biodiversity (Butchart et al., 2010) and for estimating carbon emissions from the forest sector (Hirata et al., 2012; Miles and Kapos, 2008). Forest cover can be lost temporarily through timber harvests or for a prolonged period through the conversion of forests for other land uses. The latter, defined as deforestation, has been the focus of international policies (Rosenqvist et al., 2003). Although less weight is given to the temporal losses of forest cover in the policy arena, it can also significantly impact forest biodiversity and carbon dynamics (Gibson et al., 2011; Hirata et al., 2012). Different agents are usually responsible for temporal forest cover loss and deforestation (e.g., loggers vs. farmers and ranchers). However, the effect of these activities are closely related as logged forests are more prone to land conversion than intact forests (Asner et al., 2006), not to mention that logging can also cause deforestation (Abood et al., 2015; Geist and Lambin, 2002; Rudel et al., 2009). In this study, we focus on gross forest cover loss (GFCL) which includes both temporal forest cover loss and deforestation (Hansen et al., 2010; Rosenqvist et al., 2003).

Given the increase in the international trade of wood commodities (Erb et al., 2009), forest cover dynamics and associated environmental impacts in one country are increasingly affected by the consumption of wood products in another (Mayer et al., 2005; Meyfroidt et al., 2013; Mills Busa, 2013). Calculating the expected GFCL of wood production and comparing that to actual GFCL measured through remote sensing might be a good starting point to evaluate the land cover impacts of logging. The extent of forest area affected by wood production is often available from forestry databases in countries with effective forest monitoring schemes (Masek et al., 2011), but this data is not available for every country and lacks the connection with wood consumption. For the calculated metric to have a consumer perspective, it should be able to evaluate the virtual GFCL embodied in wood products. In other words, the index should be based on data that can relate wood production and consumption.

In this study, we propose an index named the forest harvest index (FHI) that calculates the gross loss of forest area reflecting the demand for wood products. Since the index does not consider whether forest cover returns after harvest, it represents expected GFCL as a result of logging. Wood products can be categorized into industrial roundwood (including derived products) and wood fuel. The majority of industrial roundwood is harvested through large-scale operations, while household-level harvests are common for wood fuel especially in developing countries (Furukawa et al., 2011; Naughtontreves et al., 2007). Because our calculation assumes the removal of most aboveground biomass from an area during wood extraction (i.e., clear-cut harvest), we hypothesized that the FHI of industrial roundwood would be a stronger indicator of GFCL than the FHI of wood fuel. Furthermore, since the validity of global indices summarizing complex human activities might be constrained by the availability and quality of data for calculation (Blomqvist et al., 2013), we examined whether data quality affects our results. We tested these hypotheses by comparing the FHI of industrial roundwood and wood fuel against actual GFCL based on remotely sensed data. Finally, to demonstrate the applicability of the index from a consumer perspective, we incorporated data from a bilateral wood trade analysis (Kastner et al., 2011a), and tested whether wood trade might exacerbate or curb GFCL at the global scale.

2. Materials and methods

Data on actual gross forest cover loss (GFCL) for each country between 2000 and 2005 (a five year total) was obtained from Hansen et al. (2010). GFCL was estimated at a resolution of 18.5 by 18.5 km based on regression estimators between Landsat and MODIS. Data on the production of industrial roundwood and wood fuel in roundwood-equivalent volumes by wood type (conifer/non-conifer) were obtained from FAOSTAT (http://faostat.fao.org/) for all available countries during the corresponding five years (FY2000–FY2004).

The forest harvest index of country i (FHI_i; ha) was calculated as

$$FHI_i = \sum_{jk} \left(V_{ijk} \cdot BEF_k / D_{ij} \right) \tag{1}$$

where V is the volume of wood produced (either industrial roundwood or wood fuel; m^3), BEF is the biomass expansion factor (unitless), and D is growing stock density (m^3 ha^{-1}). Subscripts j and k depict year (from FY2000 to FY2004) and wood type (i.e., conifer and non-conifer) under each climatic zone (i.e., boreal, temperate, and tropics), respectively. The BEF is the ratio between roundwood volume and the aboveground biomass of an entire tree, including its branches and leaves, and is usually calculated from volume-yield relationships using proposed equations (Schroeder et al., 1997). We adopted default BEF values to use in connection with growing stock data for each climate and wood type from the IPCC good practice