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Development of allometric models for above and belowground biomass in swidden cultivation fallows of Northern Laos

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ABSTRACT

Shifting, or swidden, cultivation remains an important land use across Southeast Asia and other parts of the tropics, albeit under pressures from other land uses. The swidden cycle of cultivation and regrowth creates mosaic landscapes with regrowing fallows of various age interspersed with active fields and patches of mature forest. Quantifying tree biomass in these landscapes is limited by the availability of reliable allometric models, hindering accurate carbon stock estimation and thus quantification of GHG emission associated with land use transitions. We therefore developed new allometric models for the prediction of both above- and below-ground woody biomass in swidden systems based on a destructive harvest of 150 trees in Luang Prabang Province, Laos People's Democratic Republic (PDR). This study is the first to develop allometric models of root biomass for swidden landscapes in this region, which we hypothesised would be a major carbon pool given that resprouting, and associated high root biomass, is a common physiological/morphological trait in regularly disturbed ecosystems. We found that a general model including tree diameter (DBH, cm) and height (H, m) was best for estimating aboveground biomass (AGB, kg) for both resprouts and trees growing from seed ($AGB = 1.09 + 0.027D^2H$) though the inclusion of H only resulted in a marginal increase in model performance meaning a DBH-only model is acceptable to use in the absence of height data ($AGB = 0.1286DBH^{2.134}$). Tree height was less important for estimating root biomass, with models including only DBH performing best. Re-sprouting trees exhibited greater root biomass ($BGB = 0.355DBH^{1.732}$) compared to those growing from seed ($0.016DBH^{2.597}$) meaning different root allometric models were developed for each tree type. Thus, we suggest that field efforts should be directed towards checking resprouting status over the estimation of tree height. We also found that models fit using non-linear regression provided equally good fits to the data compared to the traditional approach of log-transforming the data. Our models were subsequently applied to 12 nearby plots spanning a chronosequence of fallows to examine the impact of re-sprouting allometry on biomass estimation. Root biomass stocks were on average 58% higher after accounting for the allometry of resprouting trees, resulting in an average 9% increase in total biomass stocks, highlighting the importance of choosing root allometrics based on growth form in swidden fallows. If re-sprouting status is unknown, a stand-level root:shoot ratio of 0.32 can be applied. Our analysis suggests that using our models will substantially improve the accuracy of estimates of tree biomass and its distribution among different pools in swidden fallows. This information is crucial in better quantifying carbon stock changes resulting from the conversion of swidden land to other land uses.

1. Introduction

Reducing emissions from deforestation and forest degradation (REDD+) is a proposed policy mechanism through which developing countries could potentially receive performance related payments for avoiding greenhouse gas emissions, or enhancing carbon stocks through land use and land cover change. Countries across Southeast (SE) Asia are currently undergoing some of the most rapid rates of deforestation and forest degradation globally (Hansen et al., 2013) and REDD+ is seen as way of encouraging more sustainable land uses.

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Yet in the upland regions of SE Asia, defined as lands between 300 and 3000 m a.s.l ('Montane Mainland Southeast Asia'; Ziegler et al., 2009), changes in vegetation carbon stocks and the resultant emissions from common land use transitions remain poorly quantified (Bruun et al., 2009; Ziegler et al., 2012) leading to uncertainty as to whether REDD+ interventions in these areas will effectively reduce emissions (Mertz et al., 2012). Shifting, or swidden cultivation, has long been a principal cause of land cover change in these upland areas, but is rapidly being transformed as other, more profitable land uses, such as rubber cultivation, replace former swidden areas (Padoch et al., 2007; Müller et al., 2014; Vongvisouk et al., 2014). However, this agricultural practice still forms a major part of local livelihoods in many areas (Cramb et al., 2009; Hurni et al., 2012) and produces landscapes high in biodiversity (Rerkasem et al., 2009) that support a wide variety of ecosystem services (Bruun et al., 2009; Ziegler et al., 2009). Swidden cultivation involves clearing a small patch of land using a mixture of cutting and fire ('slash and burn'), after which the land is cultivated for one or more years before eventually being abandoned and the natural vegetation allowed to regrow. Cultivation is commonly practiced between short (<5 years), intermediate (5–10) or long (20+ years) periods of fallow before the land is re-cultivated (Ziegler et al., 2012), resulting in a complex mosaic of land covers with agricultural fallows in various stages of regrowth interspersed with active fields and patches of mature forests. In Laos PDR – the focal country of this study – these dynamic landscapes make up approximately 30% of the total land area (Messerli et al., 2009). Their areal extent means that emission reductions from avoided degradation and carbon uptake from forest regeneration associated with changes in land management could make a significant contribution towards REDD+. However, in order to quantify potential emission reductions and removals, an accurate quantification of carbon stocks across these landscapes is required (Ziegler et al., 2011).

The estimation of tree biomass ultimately relies on the use of allometric equations to convert forest inventory data (diameter, height) to its total biomass (in kg dry matter). The choice of allometric model is therefore a critical step in the estimation of forest biomass, and by extension, carbon emissions that occur via land use and land cover change (Chave et al., 2004; Skole et al., 2011; Picard et al., 2014). In order to generate accurate predictions of biomass, the chosen allometric model should ideally represent the growth form of trees in the area being surveyed, which often requires a site-specific or regionally developed model. However, allometric models for predicting aboveground woody biomass for swidden systems in SE Asia are still few in number (Ketterings et al., 2001; Chan et al., 2013), while none exist for estimating belowground root biomass, with the best alternatives based on harvest data collected from lowland tropical forests (Yuen et al., 2013). Harvesting trees and weighing their components is a time-consuming process meaning new projects may decide to apply one or more of the current regional models (e.g. Shanmughavel et al., 2001; Kenzo et al., 2009; Chan et al., 2013). However these models are typically developed from a small number of trees with a narrow diameter range, which may represent only a fraction of the allometric variability within a forest type and could result in potentially spurious predictions when applied to broader diameter ranges (Chave et al., 2004; Gotelli and Ellison, 2004; Picard et al., 2012; Rutishauser et al., 2013). To avoid any potential bias in the estimation of large tree biomass, some projects instead decide to use generic pan-tropical allometric models based on large datasets obtained from multiple regions across the tropics (e.g. Chave et al., 2005, 2014). Recent studies have shown that these generic models can result in more accurate predictions of biomass compared with regionally derived models when applied to inventories of SE Asian dipterocarp (Rutishauser et al., 2013), and peat forests (Manuri et al., 2014).

However, these global/pantropical allometric equations are largely parameterised using data from relatively undisturbed forests and include few secondary forest stands, introducing the potential for bias if applied to more disturbed forest types (Chave et al., 2014). Swidden fallows are subject to regular disturbance, thus trees growing in these areas are likely to have very different architecture, traits and biomass allocation strategies compared to those found in either undisturbed or logged forests. Highly intense and/or extremely frequent disturbance is often needed to completely eradicate individual trees and roots can persist over multiple cycles of disturbance and re-sprout when fields are left fallow (Bond and Midgley, 2001). This is a common physiological trait in ecosystems where disturbance is a regular occurrence, allowing rapid regeneration and trees to persist following the destruction of aboveground parts (Bond and Midgley, 2001; Clarke et al., 2012; Nzunda et al., 2014). Resprouting may also occur in places where nutrient availability and soil stability is a key constraint to growth, as may be expected in low input upland ecosystems (Brearley, 2011). The ability to re-sprout, however, may come at the detriment of height or canopy growth as more resources are held in reserve to support future regeneration (Clarke et al., 2012; Nzunda et al., 2014) leading to different allometries between trees which have re-sprouted and those which grow from seed. This suggests that aboveground tree biomass in fallows may be overestimated by equations developed in primary forests where disturbance is less common (van Breugel et al., 2011). In contrast, it is hypothesised that root biomass stocks in fallows will be considerably greater than is predicted by allometric models developed in non-swidden areas where re-sprouting trees are less common (Shanmughavel et al., 2001; Kenzo et al., 2009; Niiyama et al., 2010).

The objective of this paper is to provide a way of better quantifying the carbon stock changes that are likely to result from the intensification of swidden agriculture and the conversion of swidden land to other land uses. The specific aims of this paper are to:

(1) Develop allometric models for above- and below-ground tree biomass for swidden fallow trees in Northern Laos
(2) Examine the impact of applying these new models to estimate woody biomass across a chronosequence of swidden fallows located in the same landscape, and compare these estimates to those derived from regional and pan-tropical allometric models

This study is the first to develop allometric models of below-ground biomass for swidden cultivation landscapes of SE Asia. To construct our allometric models we used a combination of approaches involving non-linear regression, and linear regressions fit to log-transformed data. The conventional decision to log-transform the data has been the subject of considerable debate in the literature (Cunia, 1964; Xiao et al., 2011; Packard, 2013), yet many published papers fail to provide a rigorous examination of whether this is a necessary step (Návar, 2009; Mascaro et al., 2011) with most studies only applying the log-transformed version of the power-law function in order to try stabilise the residual variance, a key assumption when fitting regression models. The increasing availability of non-linear techniques have led to greater use of non-linear models fit to untransformed data (Litton and Kauffman, 2008; Ritz and Streibig, 2008; Návar, 2009; Mascaro et al., 2011; Mugasha et al., 2013), with studies also showing that log-transformation does not always result in a stabilisation of the residual variance (Packard, 2012), or necessarily result in a better fit compared to fitting non-linear models (Niklas, 2006; Litton and Kauffman, 2008; Návar, 2009; Packard, 2013). Therefore in is