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Review and synthesis

Review of allometric equations for major land covers in SE Asia: Uncertainty and implications for above- and below-ground carbon estimates

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ABSTRACT

Our review of biomass studies conducted for 11 Southeast Asian countries, Papua New Guinea, and southern China uncovered 402 above-ground and 138 below-ground biomass allometric equations for the following major land covers: forest, peat swamp forest, mangrove forest, logged over forest, orchard and tree plantation, rubber plantation, oil palm plantation, bamboo, swidden fallow, and grassland/pasture/shrub land. No equations existed for non-swidden agroforest and permanent croplands, two other important land covers involved in current and projected land-cover transitions. We also found 245 stem-volume equations and 50 height-diameter equations. Applying existing allometric equations out of convenience is potentially a key source of uncertainty in above- and below-ground carbon stock estimates in many SE Asian landscapes. Differences in environmental conditions and vegetation characteristics should preclude the use of many pre-existing equations at locations outside of the geographical location where they were developed, without first verifying their applicability. While use of site-specific equations is preferred to reduce uncertainty in estimates, there are few in existence for many land covers and many geographical areas of the region. For example, few or no equations exist for Brunei, Cambodia, Laos, Papua New Guinea, Singapore, and Timor Leste. Ten or fewer above-ground biomass equations exist for rubber plantation, oil palm plantation, non-swidden agroforest, grassland/pasture/shrublands, and permanent croplands for the entire region. Even site-specific equations can introduce uncertainties to biomass estimates if they were determined from an insufficient sample size. Difficulties associated with sampling below-ground root biomass accurately often leads to allometric equations that potentially under-estimate below-ground biomass. In addition, substantial errors may be present if these below-ground equations are conveniently used by researchers in lieu of site-specific measurements. Although the importance of including wood density in allometry is increasingly recognized, only 26 of the reviewed studies did so. Ideally, when wood density values are used to estimate biomass, new on-site measurements should be taken, rather than relying on pre-existing values. This review demonstrates that more research in SE Asia is needed on biomass in general, specifically for several land covers including peat swamp forest, rubber and oil palm plantations, bamboo, swidden fallow, non-swidden agroforest, and permanent cropland. Importantly, for the purpose of informing the development and implementation of policies and programs such as REDD+, our meta-analysis highlights the pressing need to address the insufficient number of allometric equations and the possible inappropriate use of some when estimating vegetation biomass related to current and potential land cover changes in the region.

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1. Introduction

Vegetation biomass is the living organic matter that is produced by photosynthesis (Brown, 1997). Biomass can be partitioned into two components: (1) above-ground biomass, which includes the stems and any branches, leaves, flowers, and fruits above the soil surface; and (2) below-ground biomass, which is often divided for convenience into the root crowns, coarse roots (>2 mm diameter), and fine roots (<2 mm diameter) (eg., Kny, 1894; Vadeboncoeur et al., 2007; Zani and Suratman, 2011). The division of a plant into the stems, branches, leaves, flowers, fruits and roots is an established concept in botany (e.g., Nuttall, 1841; Harvard, 1884). Quantifying vegetation biomass is necessary for evaluating biological and economic productivity, fuel accumulation, and nutrient allocation. Recently, biomass measurements have become crucial for determination of carbon sequestration in vegetation and for understanding the impacts of land-cover changes on carbon fluxes (Cole and Ewel, 2006; Heryati et al., 2011b; Addo-Fordjour and Rahmad, 2013). Carbon biomass is either determined directly from harvested samples through analytical means, for example, with a carbon–nitrogen analyzer, or calculated as a fraction of measured biomass—on the order of 0.37–0.53 for various types of plants and trees (Yuen et al., 2013).

The advent of carbon accounting schemes such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation and Enhancing Carbon Stocks) has created widespread interest in determining carbon biomass in vegetation in tropical areas (http://www.un-redd.org/aboutredd). REDD+ was put forth by the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) as a means to reduce carbon dioxide emissions to the atmosphere by giving developing countries financial incentives to conserve (and increase) carbon stocks within their forests (Mertz et al., 2012). To qualify for REDD+ payouts, countries must typically monitor carbon biomass stock in the land covers in question accurately over time (Hein and van der Meer, 2012; Murdiyarso et al., 2012).

The most precise method for determining carbon biomass is to destructively harvest all plants, partition each by mass into various constituent components (e.g. stem, branches, leaves, flowers, fruits, roots) and subsequently determine the C content of the various components analytically. However, uprooting vegetation, especially trees, is time consuming, costly, and sometimes illegal. With respect to the latter, cutting forest trees often goes against the goal of conserving forests (Basuki et al., 2009; Djomo et al., 2010; Jachowski et al., 2013). An alternative approach is to use established allometric equations to estimate biomass and then calculate carbon biomass as a fraction of this value.

Allometry in the context of tree biomass estimation refers to mathematical equations relating biomass of an entire tree or individual tree components (e.g., stems, branches, leaves or roots) to one or more easily measured biophysical factors, such as tree diameter at breast height, tree height, or wood density (Kira and Shidei, 1967; Whittaker and Woodwell, 1968; Baskerville, 1972; Banaticla et al., 2007; Basuki et al., 2009; Kuyah et al., 2012). Main stem volume equations can also be developed from these variables (cf. Whittaker and Woodwell, 1968; Kusmana et al., 1992; Hiratsuka et al., 2005; Heryati et al., 2011b; Khun et al., 2008), with stem biomass calculated by multiplying stem volume with wood density (Brown and Lugo, 1984; Nogueira et al., 2007; Somogyi et al., 2007). In this case, biomass expansion factors are then applied to estimate biomass of branches and leaves (cf. Brown, 1997). Through allometric equations, above- and below-ground biomass in large stands can be estimated without the need to cut trees (Kira and Shidei, 1967; Kenzo et al., 2009). The obvious paradox here is that the equations must be based on destructive sampling of vegetation somewhere before they can be applied generally (Basuki et al., 2009; Chave et al., 2014).

Previously, we surmised that one important source of uncertainty in above-ground and below-ground carbon stock estimates for several land covers in Southeast Asia was the application of pre-existing allometric equations in locations differing from where they were determined (Ziegler et al., 2012; Yuen et al., 2013). In the prior works we did not report details regarding the sources of error related to the use of allometric equations in biomass assessments. Herein, we extend those analyses by reviewing studies reporting above- and below-ground allometric equations with the intention of (a) providing a summary of country-by-country allometric equations for the various land covers associated with major land use transitions in SE Asia; (b) discussing the limitations and uncertainties associated with the use of pre-existing allometric equations; and (c) identifying further directions for allometry research. The review is part of a larger effort to assess the effects of ongoing and projected land cover conversion on carbon stocks in the region (Fox et al., 2012, 2014; Ziegler et al., 2012; Yuen et al., 2013; Webb et al., 2014).