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Estimating the aboveground biomass in an old secondary forest on limestone in the Moluccas, Indonesia: Comparing locally developed versus existing allometric models

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ABSTRACT

Deforestation and forest degradation are widespread in Indonesia and pose serious threats to biodiversity and other ecosystem services. The Indonesian government is implementing several Reduction of Emissions from Deforestation and Forest Degradation (REDD+) initiatives to help support the conservation of tropical forests, but the eastern part of Indonesia has yet to be included in this effort. Tropical forests growing on limestone are a prominent feature of that region, but little is known about their ecology and management, and only limited research has been conducted on biomass and the associated carbon storage capacity of these secondary forests. Here, we estimate the aboveground tree biomass (AGB) in an old secondary forest on limestone in Seram, the Moluccas, East Indonesia. We destructively sampled all aboveground vegetation in 0.04 ha forest and developed a local allometric model (n = 25; diameter-range of 10.4–41.7 cm). We tested and compared the performance of our locally developed model with existing local models and a recent pantropical model (Chave et al., 2014) at our site. Total AGB in the 1-ha forest plot was estimated at 177 Mg ha^{-1}, of which 141 Mg ha^{-1} (80%) was allocated in trees $\geqslant$10 cm diameter at breast height (dbh), 33 Mg ha^{-1} (19%) in trees <10 cm dbh and 2 Mg ha^{-1} (1%) in lianas and non-woody vegetation. Both our locally developed and the pantropical model estimated the biomass of harvested trees accurately (local model: bias = 0.1%, CV = 15.5%; pantropical model: bias = −7.7%, CV = 17.7%), while other local models had much lower performance (bias = −57.1 to −7.3%, CV = 59.2 to 75.8%). At plot-level, the AGB estimate of the pantropical model approached the estimate of our local model, while other local models considerably underestimated actual AGB. Together, our findings confirm that trees <10 cm dbh can store a large fraction of total AGB in secondary forests, and highlight the robustness of generic models. These results provide further guidance for accurate assessments of forest carbon stocks in Indonesia and more generally for REDD+ initiatives.

1. Introduction

Deforestation and forest degradation rates in continental and insular Southeast Asia are alarming (FAO, 2010; Miettinen et al., 2011). In Indonesia, in particular, over 6 Mha of primary forests were lost from 2000 to 2012 (Margono et al., 2014), with tremendous consequences for biodiversity and other ecosystem services (Sodhi et al., 2004; de Bruyn et al., 2014).

One approach to conservation and mitigation of environmental degradation is to develop payments and markets for environmental services. The Reduction of Emissions from Deforestation and Forest Degradation (REDD+) was proposed as a mechanism to provide financial incentives to developing countries to reduce emissions from forest loss and promote forest conservation, sustainable forest management and the enhancement of forest

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carbon stocks (Angelsen et al., 2009). A major technical challenge for REDD+ is the estimation of these carbon emissions at regional or national levels.

Aware of this situation, the Indonesian government has been among the first to implement a national forest carbon initiative (Indonesian REDD+ Task Force, 2012), but the eastern part of the country has yet to get involved. At the request of the local government of the Moluccas in eastern Indonesia, a feasibility research and development program on land zoning, land-use planning and ecosystem services assessment was carried out on one of the largest islands of the region, Seram. It included research on biomass stocks, biodiversity management and maintenance of ecosystem services through community participation in and around a large conservation area: the Manusela National Park (MNP) in the Central Moluccas regency (Kabupaten Maluku Tengah).

One unique feature of the MNP is the large limestone massif, spanning from sea level up to 3000 m.a.s.l. Limestone karsts cover an area of around 400,000 km^2 in Southeast Asia, mostly concentrated in Indonesia (145,000 km^2; Clements et al., 2006). Forests on limestone tend to be water-stressed because they grow on seasonally water-depleted soil (Crowther, 1983; Whitmore, 1984). They are also known for their high levels of endemism and species diversity (Clements et al., 2006). Their ecology and management, however, are poorly known, consisting of a few studies in Peninsular Malaysia (Crowther, 1987, 1982) and Sarawak (Proctor et al., 1983) in Malaysia; and Sumatra (Laumonier, 1997), Western New Guinea (Takeuchi, 2003; Johns et al., 2007) and the Moluccas (Edwards et al., 1990; Ranlund, 2011; Stas, 2014) in Indonesia, with limited research on secondary forests and biomass stocks. Like elsewhere in Indonesia, lowland limestone forests in the Moluccas are under high pressure of agrarian changes, and proper understanding of secondary succession is crucial for future landscape management and restoration.

Biomass and associated carbon estimates are highly sensitive to the choice of a particular allometric equation (Chave et al., 2004; Van Breugel et al., 2011). Many biomass equations have been developed locally for Indonesian forests, with most studies focusing on Kalimantan and Sumatra (see Anitha et al., 2015); the eastern Indonesian region, including Sulawesi, the Moluccas, Nusa Tenggara and Western New Guinea, is seriously understudied (Anitha et al., 2015). While local allometric models perform generally well for a given site or forest type, they are laborious to develop and potentially give significant errors in biomass estimations when applied elsewhere (Chave et al., 2005). Generic models were shown to outperform local models in Indonesia (Rutishauser et al., 2013), but have not been thoroughly tested in secondary forests. Here, we destructively sampled all aboveground vegetation in 0.04 ha forest and developed a local allometric model to estimate the aboveground biomass (AGB) of trees in an old secondary forest on limestone in Seram, the Moluccas. We compared the performance of our locally developed model with a selection of existing local models (Kenzo et al., 2009; Ketterings et al., 2001) and the most recent pantropical model (Chave et al., 2014) at our site. The implications of these results for carbon accounting initiatives are discussed.

2. Material and methods

2.1. Site description

Seram island in the Moluccas, East Indonesia, covers an area of about 18,000 km^2. Seram's lowlands have a perhumid tropical climate and mean annual temperatures at sea level vary between 25° and 30 °C. In the northern coastal lowlands around Wahai, annual precipitation is between 2000 and 2500 mm, with a weak or no dry season (Fontanel and Chantefort, 1978). The "drier" season is from May to October, when monthly rainfall seldom exceeds 100 mm (Edwards, 1993). The central part is characterized by large outcrops of massive limestone (circa 5% of Seram's land area), ranging from the coast up to the mountains. The vegetation on these karsts is largely protected in the Manusela National Park (MNP), the largest conservation area in the Moluccas, which represents approximately 10% of Seram (1860 km^2).

Data were collected in a lowland forest (circa 70 m.a.s.l.) on soils developed on limestone, situated in the northern part of Seram near the village of Masihulan and outside the MNP, in 2011 (Fig. 1). Structure and floristics of this forest are described in Stas (2014). Information from local people was used to retrieve the disturbance history and forest usage at the study site. The forest experienced a natural fire in 1982, but its magnitude and duration and the exact locations of burned sites remain unclear; apparently, some large standing trees survived the fire. Local people, and possibly also a logging company, extracted some timber in the area in the 1990s, but probably not from the study plot. The natural fire is considered as the main disturbance and this forest can be best classified as "post-fire secondary forest", or more broadly as "post-catastrophic secondary forest", following the definition of Chokkalingam and de Jong (2001): "Forests regenerating largely through natural processes after significant reduction in the original forest vegetation due to a catastrophic natural disturbance or succession of such disturbances, and displaying a major difference in forest structure and/or canopy species composition with respect to nearby primary forests on similar sites".

2.2. Data collection

2.2.1. Non-destructive measurements

All living stems $\geqslant$10 cm diameter at breast height (dbh; i.e. diameter at 130 cm from ground level or 30 cm above buttresses) were tagged and their dbh measured in a 1-ha plot (100 × 100 m in horizontal projection). The plot was divided into subplots of 10 × 10 m to facilitate measurement. Tree heights were measured with a Haga altimeter. Botanical samples were collected and local names recorded. Species identification was further conducted in the herbarium of Bogor, Java, Indonesia, in 2011. The taxonomy was recently updated using The Plant List (2013). Palms were not sampled.

2.2.2. Destructive sampling

After completing the non-destructive measurements, four subplots of 10 × 10 m each (in total 0.04 ha) were selected within the 1-ha plot for destructive sampling, aiming at representing the mosaics of different successional stages of the vegetation in the secondary forest plot. A total of 25 trees $\geqslant$10 cm dbh were cut down, in the range of 10.4–41.7 cm dbh, 10.3–23.6 m height and 0.320–0.730 g cm^{-3} wood density (see Appendix A for a tree-by-tree description). Four of the five most abundant species in the 1-ha plot (for trees $\geqslant$10 cm dbh), i.e. *Decaspermum bracteatum* (Myrtaceae; 24%), *Hancea penangensis* (Euphorbiaceae; 20%), *Meliosma pinnata* (Sabiaceae; 7%) and *Elaeocarpus serratus* (Elaeocarpaceae; 6%) were present in the destructive sampling.

In the selected subplots, all aboveground vegetation was cut down, as close to the ground as possible. Heights of harvested trees $\geqslant$10 cm dbh were measured with a measuring tape after felling. Vegetation was separated into trees $\geqslant$10 cm dbh, trees <10 cm dbh, lianas, epiphytes, mosses and herbs. As water content varies among compartments, trees (comprised of trees, treelets and shrubs) were further divided into leaves, twigs, branches and stems, and lianas into leaves and stems (hereafter referred to as "compartments"). The non-woody vegetation, i.e. epiphytes, mosses and herbs, was not further divided.