Forest Ecology and Management 304 (2013) 427–436

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Establishment of allometric models and estimation of biomass recovery of swidden cultivation fallows in mixed deciduous forests of the Bago Mountains, Myanmar

Nyein Chan [a,*], Shinya Takeda [a], Reiji Suzuki [b], Sota Yamamoto [c]

[a] Graduate School of Asian and African Area Studies, Kyoto University, Kyoto 606-8501, Japan
[b] Faculty of Bioenvironmental Science, Kyoto Gakuen University, Kyoto 621-8555, Japan
[c] Research Center for the Pacific Islands, Kagoshima University, Kagoshima 890-8580, Japan

ARTICLE INFO

Article history:
Received 2 April 2013
Received in revised form 18 May 2013
Accepted 20 May 2013
Available online 21 June 2013

Keywords:
Allometry
Biomass
Myanmar
REDD
Swidden cultivation
Teak

ABSTRACT

We established allometric models for fallow forests following swidden cultivation, to estimate biomass accurately in the fallows around a village in the Bago Mountains, Myanmar. By harvesting 160 individual trees from 53 species and 132 sample culms from four bamboo species, allometric equations were determined between tree/culm size variables, such as diameter at breast height (D130) and tree/culm height (H), and plant biomass components such as trunk/culm, branch, and leaf biomass in the fallows. The correlation coefficient for the allometric model for total above-ground tree biomass as a function of $D130^2H$ was high (0.956), although the value for leaf biomass was relatively low (0.626). In addition, best-fit allometric relationships for four bamboo species were established. All allometric models involving total above-ground biomass for all bamboo species had significantly high R^2 values: 0.817 for *G. nigrociliata*, 0.877 for *B. polymorpha*, 0.910 for *B. tulda*, and 0.963 for *D. strictus*. A comparison between the present models and previously reported equations for above-ground biomass for tropical forests revealed that our allometric models followed the general trend for biomass estimation, with substantial differences among forest types. In addition, our results suggest that when allometric models are developed using destructive sampling methods, either all mixed species combined or select dominant species can be used, although the optimal approach would include models with all species combined to estimate biomass accumulation for mixed-species forests. Using the best-fit allometric models for trees and bamboo, we estimated tree and bamboo biomass at the community level, supplemented by understory and vine biomass. Biomass accumulation in the study area generally increased with fallow age, with a large contribution of bamboo in the fallows. To estimate biomass of secondary forests accurately, especially fallow forests, relevant allometric relationships and the intensity of swidden cultivation must be considered.

1. Introduction

Swidden cultivation is the chief indigenous agricultural technique adopted in tropical areas and constitutes one of the most important land-use systems in the tropics (Karthik et al., 2009; Ramakrishnan, 1992). Today, this practice is considered a major driver of deforestation and forest degradation; up to 1991, it had accounted for 61% of overall tropical forest destruction on a global scale (Karthik et al., 2009).

Secondary forests following swidden cultivation have been considered instrumental to future agreements to reduce emissions from deforestation and forest degradation in developing countries (REDD) under the United Nations framework convention on climate change (UNFCCC). To estimate the effects of carbon sequestration and to evaluate the baseline carbon storage for individual nations under a REDD scheme (Kenzo et al., 2009a), accurate methods for estimating above-ground biomass in fallow forests are required. Although allometric relationships have been used to estimate biomass and carbon stock in forest ecosystems, few relationships have been developed for fallow forests, especially in tropical seasonal forests.

One appropriate approach for accurately estimating biomass is to develop allometric relationships for the biomass of plant-part components and plant parameters such as diameter (Brown, 1997; Kenzo et al., 2009a, 2009b) and height (Kenzo et al., 2009a). The accuracy of estimations using such equations is usually high, even when many tree species co-exist within the same forest stand (Yamakura et al., 1986; Kenzo et al., 2009a).

Most previous studies of fallow forests have focused primarily on the recovery of species richness and species composition

* Corresponding author. Tel.: +81 90 6556 2384.
E-mail address: nchan08@gmail.com (N. Chan).

0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.05.038

(Karthik et al., 2009) as well as fallow succession and factors affecting fallow recovery (*ibid*), with very few studies of biomass in fallows (Ramakrishnan, 1992; Fukushima et al., 2007). Several sets of allometric models have been developed to estimate above-ground biomass in primary forests (Rai and Proctor, 1986; Yamakura et al., 1986; Basuki et al., 2009), early successional forests (Hashimoto et al., 2004; Kenzo et al., 2009a), mixed secondary forests (Ketterings et al., 2001), and logged forests (Kenzo et al., 2009b). However, the equations developed for different forest types can vary substantially, and it is important to select the allometric relationships most appropriate for a target forest to accurately estimate forest biomass (Basuki et al., 2009; Kenzo et al., 2009a, 2009b). Brown (1997) recommended that local biomass regression equations should be developed to accurately estimate biomass. Allometric relationships for above-ground plant biomass of swidden cultivation fallows have rarely been reported, particularly for teak-bearing forests. Furthermore, the site- and species-specific dependencies of allometric equations pose a challenge, given the labor-intensive nature of measuring tree weights in forests (Komiyama et al., 2008) and the presence of multiple species (Brown, 1997).

In Myanmar, the area of closed forests has decreased at an alarming rate because of the rapid increases in open forests between 2007 and 2010 (FAO, 2011). The Bago Mountains is home to natural teak, but the area of closed forest is rapidly decreasing due to over-exploitation of wood and forest products as well as agricultural expansion (Tin Min Maung and Yamamoto, 2008), including swidden cultivation. Similar to other tropical countries, Myanmar has discouraged swidden cultivation practices because of their negative impacts on environmental conservation. Understanding how fallow forests recover, mainly with regard to biomass, is essential to the restoration and conservation of tropical forests and to sustainable livelihoods for local people. To this end, site-specific models must be developed for estimating the above-ground biomass in forests of mixed species. These models could be used for future research and to provide information for potential conservation agreements in Myanmar and other tropical countries with fallow forests under similar conditions.

In the present study, we established allometric relationships between plant-part biomass and plant parameters such as diameter and height for the estimation of biomass in swidden cultivation fallows. In addition, we estimated the extent of above-ground biomass recovery in fallow forests of the study region.

2. Materials and methods

2.1. Study site

This study was conducted in swidden cultivation fallows around a Karen village (S village) in the Bago Mountains of Myanmar (18°51′–18°54′N, 95°51′–95°54′E; approximately 250–450 m above mean sea level; Fig. 1). The major forest type in this study area is mixed deciduous, with teak and other commercial broadleaf tree species being dominant. The average annual rainfall is about 1900 mm, and the mean annual temperature is about 27 °C (measured at the Taungoo weather station located about 60 km east of the study village) with the distinct rainy season (May–October) and dry season (November–April). The soil type in the study area is classified as Ultisols (Suzuki et al., 2009). Data were collected for this study from January to February 2011 and from November 2011 to January 2012.

In this study area, the Karen people largely depend on traditional swidden cultivation for their livelihood. They slash and burn the above-ground vegetation in the selected site, cultivate their crops for only one year, and then move to another site for the subsequent year. In some cases, the villagers cut some big trees at higher point (>0.3 m) above the ground, or sometimes keep them as relict emergents. Uprooting the trees and bamboo is the rare case in this study area.

2.2. Methods

In total, 31 sample plots were established in 1- to 30-year-old-fallows using a nested sampling design, with three control plots in old forests near the village (Fig. 2). Fallow forests were chronosequentially chosen for this study based on interviews with local people regarding land use and the ages of fallow forests. Suzuki et al. (2007) have analyzed the land-cover changes in swidden-cultivated area using Landsat imagery since 1990. These original datasets, combined with interviewing the local people, were applied to verify the ages of old swidden cultivation fallows (10–20 years). Fallows older than 20 years were identified only based on interviews with village elders and patriarchs. According to these interviews, the older forests were considered taboo-like and were therefore preserved.

After determining the distribution of fallows, we randomly established sample plots to represent fallow vegetation in the study area. Old fallows (aged 20, 25, and 30 years) were difficult to find because farmers had opened the swidden fields on a 12- to 18-year rotation, primarily in bamboo-dominated areas. Therefore, the sample plots in the old fallows had to be established close to the outskirts of the village territory, which is adjacent to a natural forest, because the villagers tended to open fields within 3 km of the village repeatedly. According to interview with local people, most of the 1- to 15-year-old fallows were frequently opened more than 3 times, and also cultivated at least two times even in the fallows of older ages than 15 years.

In the old forests, which have been preserved by the villagers based on their beliefs, plots measuring 30 × 30 m were established to conduct an inventory of trees and bamboo. Understory biomass was surveyed in five subplots of 1 × 1 m. In the fallows, trees and bamboo were surveyed in 10 × 10 m plots. For trees, the diameter at breast height (D130; measured at 1.3 m above ground), bole height, and total tree height (*H*) were measured. The minimum diameter measured in most surveys of closed forests is typically ⩾10 cm. However, because this study was conducted in fallows that also belonged to forests with trees of small stature, all trees with a diameter ⩾1 cm were inventoried both in fallows and in old forests. For bamboo, the number of culms in each diameter class (⩽1 cm, 1–2 cm, 2–3 cm, etc.) and clump heights were measured. Specimens collected from each tree species were identified at the Forest Research Institute, Yezin, Myanmar.

To establish allometric relationships for the estimation of tree and bamboo biomass, destructive sampling was conducted. Vines were removed as much as possible from the 10 × 10 m plots in the fallows. To ensure the suitable selection of trees for harvest from multi-species stands, an individual tree with an average D130 was harvested for each species in every sample plot in the fallows. The trees were cut at 0.3 m above ground level. In total, 160 individual trees (9 individuals in 1-year-old fallows, 29 in 5, 27 in 10, 29 in 15, 18 in 20, 26 in 25, and 22 in 30 respectively) were harvested. The trees were divided into leaves, branches, and main trunks on site. Each trunk was cut into meter-long logs, and the diameters at each end were measured and recorded. The total fresh weight of each tree component was measured using portable hanging digital and spring scales. After measuring the fresh weights, representative samples of each tree component were measured to obtain sample fresh weights. For the analysis of trunk biomass, an approximately 4-cm-thick slice of wood was taken from the bottom of each of the meter-long logs and weighed. Representative samples of about 300 g of branches and leaves were