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Authors: Chan, Nyein, and Takeda, Shinya

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The Transition Away From Swidden Agriculture and Trends in Biomass Accumulation in Fallow Forests

Case Studies in the Southern Chin Hills of Myanmar

Nyein Chan* and Shinya Takeda

** Corresponding author:* nchan08@gmail.com

Graduate School of Asian and African Area Studies, Kyoto University, Sakyo-ku, Yoshida Honmachi, Research Building No. 2, Kyoto 606-8501, Japan

Swidden farmers are rapidly transitioning to other types of land use. This study was conducted in 2 villages (T village and P village) in southern Chin State, Myanmar. The number of swidden-cultivating households decreased by 50% in T village over 2003–2013, and varied over 2004–2013 in P village; 21% and 13% of the total population in T and P villages, respectively, have out-migrated for employment. In addition, the introduction of terrace farming, development of animal husbandry, marketing of non-timber forest products, and other activities that generate cash income have reduced dependency on swidden agriculture. Remittances from out-migrated family members also contribute significantly to household incomes. As a result, the area devoted to swidden agriculture has decreased. By establishing site-specific allometries and applying best-fit allometry coefficients, total aboveground biomass was estimated for both villages. Generally, the aboveground biomass increased with the age of the fallow. Out-migration, insufficient crop productivity, and the development of alternative income sources resulted in the decrease in swidden agriculture in the areas studied. Further biomass regrowth can be expected in both villages in the future.

Keywords: *Aboveground biomass; swidden-cultivated fallows; upland agriculture; Chin State; Myanmar*

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Introduction

Swidden agriculture, also called shifting or slash-and-burn cultivation, is rapidly being reduced in area and replaced by other types of land use (Mertz 2009; van Vliet et al 2013). In many frontier areas, swidden cultivation is still important, especially where agricultural intensification is difficult or where the multifunctionality of land use has been preserved as a strategy to align with changing ecological, economic, and political situations (van Vliet et al 2012, 2013). Researchers have identified a number of drivers of the change in swidden agriculture in Southeast Asia, including political and economic pressures as well as economic opportunities and incentives (Cramb et al 2009; Fox et al 2009; van Vliet et al 2012, 2013; Castella et al 2013; Vu et al 2013).

Although an understanding of swidden agriculture is fundamental for addressing development needs in rural areas (van Vliet et al 2013), the spatial and demographic dimensions of swidden agriculture are largely unknown, partly because of the nature of the systems, but also because there is little political interest in swidden-dependent people (Mertz 2009; Schmidt-Vogt et al 2009; van Vliet et al 2013). After reviewing trends in the Reduced Emissions from Deforestation and Forest Degradation (REDD) program and swidden cultivation, Mertz (2009) reported that the understanding of the impact of swidden cultivation on REDD was limited. Obviously, if this information is unavailable, planners and policy-makers will not have a sound basis on which to make decisions about land use and development in the poorest regions of their countries (van Vliet et al 2013).

Schmidt-Vogt et al (2009) attempted to quantify the extent of swidden cultivation in Southeast Asia and were able, within limits, to tabulate information on the extent of swidden cultivation on a country-by-country basis. However, there was still a surprising lack of conclusive data on the extent of these systems. In Myanmar, the available figures related to swidden agriculture are extremely variable (Schmidt-Vogt et al 2009), and little information regarding biomass in swidden-cultivated fallows has been reported. There, swidden agriculture is mainly practiced by ethnic groups in mountainous regions such as the Bago Mountains, the Chin Hills, the Shan Hills, and the northern part of the country (Collins et al 1991; Schmidt-Vogt et al 2009; FD 2011). In Myanmar, as in other tropical countries, swidden cultivation has given way to other land uses because of population pressure and restrictions on land use (MOF 2005; FD 2011).

In Myanmar's REDD+ road map (UN-REDD Programme 2013), the area under swidden systems operated by ethnic groups was considered one of the pilot regions. However, few studies of swidden cultivation that contribute to REDD+ have been conducted. Chan et al (2013) reported the recovery of aboveground biomass (AGB) in fallow forests after swidden cultivation in the mixed deciduous forest of the Bago Mountains. According to Peters and Neuenschwander (1988) and Ramakrishnan (1992), the extent of biomass regrowth after swidden cultivation differed based on factors including preburn vegetation, degree of disturbance, completeness of the burn, cultivation pattern (monoculture or polyculture) and kind of crop, extent of weeding, ability of preburn vegetation to survive the fire, proximity of the local seed source, dispersal patterns and regeneration strategies (eg resprouting, seed bank, and suckers/rhizomes), and other environmental factors (eg soil substrate, topography, slope, aspect, and climatic variation). Cramb et al (2009) reported that the growing differences within and between swidden communities in the course of economic transformation can marginalize some groups and make them worse off.

In Myanmar, there are more than 100 ethnic groups (DoP 2014), of which 1.5 to 2 million rural dwellers are either directly or indirectly involved in swidden agriculture (FD 2011). Chin State, considered the poorest region in Myanmar (UNFPA 2010; UNDP-Myanmar 2011, 2013; Stephan 2013), is home to more than 50 ethnic groups, and is much more diverse than the other regions of the country. The Chin people largely practice traditional swidden in a mountainous region (Keyes 1995; Martin 2002). Their staple foods are rice, maize, and millet; in the southern parts of Chin State, staple foods are primarily rice and maize. Because of the high ethnic diversity, traditional practices differ slightly under different local conditions.

The transition from swidden agriculture has occurred in this area mainly because of government policy (Takahashi 2007; Thein 2012). In 1964, terrace farming was introduced with the technical support of government agencies and national and international nongovernmental organizations (NGOs). Therefore, there are numerous swiddens and rice terraces in the Chin Hills (Takahashi 2007). The market for non-timber forest products (NTFPs) such as medicinal plants and orchids has recently been developed in the southern part of Chin State (Thein 2012; Win et al 2012). Working abroad has also become an alternative livelihood for residents of the state (Takahashi 2007; UNFPA 2010; UNDP-Myanmar 2011; Win et al 2012). Under these conditions, in which residents have been transitioning from swidden to other land uses in southern Chin State, it is critical to know the rate of biomass accumulation in subtropical hill evergreen forests, and to understand how biomass recovers in areas experiencing a reduction in swidden agriculture so that possible future agreements, such as REDD+, can be initiated.

There have been very few studies related to swidden agriculture in Chin State. Previous reports have mainly considered the livelihoods (Win et al 2012), socioeconomic conditions (Takahashi 2007; Stephan 2013), and traditions and customs of the Chin people (Martin 2002). Some studies (Ward 1958; Tanaka 2005; Fujikawa et al 2012) have reported on plant distribution in Natma Taung National Park in the southern part of Chin State. In this study, 2 major ethnic groups, the Zotung (primarily a maize-eating group) and Matu (a rice-eating group), were selected to reflect the majority of the differences in the forms of swidden agriculture practiced among the different ethnic groups in the region, and to assess the accumulation of biomass in their fallow forests.

Study area

This study was conducted in 2 villages (anonymized as T and P villages) in southern Chin State (Figure 1). T village is 25 km from the town of Matupi. It was established at its current location in 1957, and is inhabited by people of the Zotung ethnic group. Their staple food has historically been maize but has recently changed to rice. The total village territory is about 2657 ha. There were 523 people and 88 households in T village in 2013. The villagers ensure that forests remain conserved within 1 km of the village, as well as in a headwater mountain region. P village is only 5 km from Matupi and is inhabited by Matu people. P village was established in 1910, but was moved to its current location in 1963. This was originally a rice-eating community. It is 2461 ha in area, with 194.2 ha of newly conserved forest. In 2013, there were 982 people and 184 households in P village. In both villages, the villagers are trying to maintain trees along streams. Both ethnic groups are categorized as part of the Chin majority but have separate languages.

This area contains subtropical evergreen forest (Ward 1958) dominated by *Quercus*, *Lithocarpus*, and *Castanopsis* species. Secondary forests regenerated in swidden-cultivated areas are found between 600 and 1200 m above sea level (Fujikawa et al 2012). No natural growth of bamboo was observed in the fallows of either village, but some households planted bamboo close to the home or in the conserved forest zone for use by the household. According to the local agricultural and meteorological station, the soil around this area is a Fluvisol. The average annual precipitation is about 1454 mm, and the average annual temperature is about 21°C.

In both villages, the major livelihood activity is swidden agriculture, under a traditional collective land use system (Mang 2013). The cropping period is 1 year in both villages, but with 9 fallow years in T village and 7–8 fallow years in P village. The cultivable land within each

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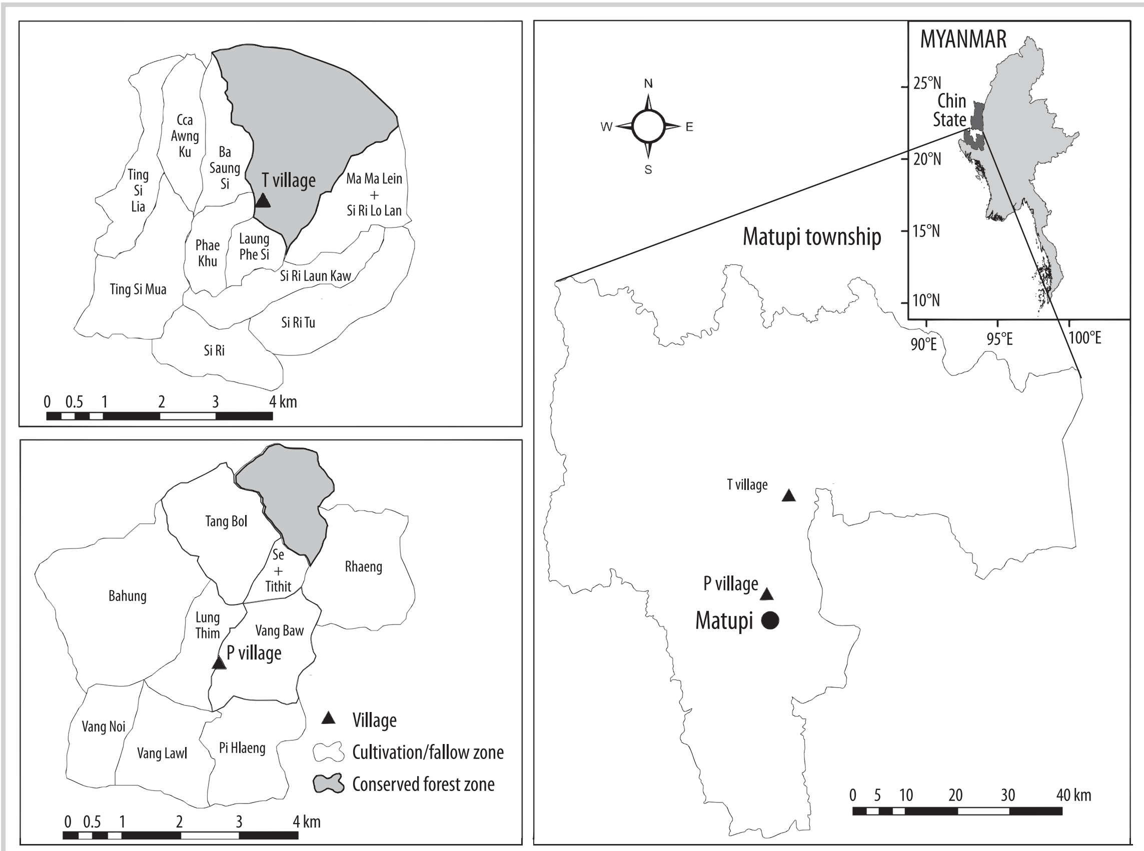
FIGURE 1 The study sites in Matupi Township, southern Chin State, Myanmar. (Map by authors)



village is subdivided into several zones, which are clusters of cultivated plots. There are 10 and 9 zones for swidden cultivation in T and P villages, respectively (Figure 1). In each zone, the villagers practice swidden cultivation according to the following customary rules, which exist separately from official farming regulations (Oberndorf 2012; Pyidaungsu Hluttaw 2012a, 2012b).

1. The individual that opened the plot is the usufruct holder of that plot.
2. Only the person who previously opened a plot can open it again.
3. The plot holder can rent the plot out for a short term or give it to relatives if unable to use it.
4. Usually, the youngest son inherits plots from his parents. In exceptional circumstances, the parents can decide to give plots to someone else.
5. If any villager wants to farm or garden in a plot owned by another person, he or she can ask that person to sell the usufruct.
6. If a villager sells his or her plot, he or she needs to open a new one.
7. At the time of zone selection for the coming year, all villagers who want to open their previous plots must meet and select a suitable zone.
8. The plot registration fee is 1000–1500 Myanmar kyats (MMK) per annum (about US$ 1–1.5). An individual is assigned by a consensus of the villagers to collect the fees and spend the money for the welfare of the village.

Adhering to these rules, the swiddeners in each village collectively choose a suitable cultivation zone for the coming year, usually during August and September. In T village, it is the oldest fallow zone; in P village, it is the zone with the largest vegetation (mainly tree) biomass, based on a visual observation. According to the villagers, vegetation recovery is different in each zone in P village, and thus some zones have to be left fallow for longer periods.

Swiddeners then slash the vegetation in their individual plots in December, dry the slashed biomass for 1 or 2 months, and burn it before the onset of the rains. After burning, they work collectively to fence the whole zone to protect against wild animals as well as their domesticated gaurs. (Gaurs require salt in their diet and may enter the burned fields before the fence is completed.) After fencing, the swiddeners burn the leftover debris and construct a hut. The planting of crops starts in the beginning of March for maize and in the third week of March for rice. Weeding is conducted twice for maize and 3 or 4 times for rice. Rice harvesting takes place from October to November, and maize harvesting in October.

Since 1997, a market for elephant foot yam (*Amorphophallus* spp.) has been established. The local people (mainly swiddeners) collected wild yams from the natural forests, and they became rare there after 2003 because of overexploitation. Therefore, the swiddeners started to cultivate the yam in old fallows that had been abandoned because of the decrease in the number of swiddeners. The environmental conditions are favorable to the cultivation of elephant foot yam.

Methods

Data collection

To explore the transformation of swidden agriculture, land-registration records were accessed, and a semistructured questionnaire survey was conducted in the villages. Village population data for 2013 were based on a 2007 household census by the immigration department of Matupi Township, and supplemented with updated information from the village headmen. In both villages, meetings were held with the village headman and members of the village administrative organization (in the case of P village, pastors and some patriarchs were included) to obtain general information about swidden agriculture, terrace farming, and the history of village development. Following a chronosequence approach, the vegetation conditions in the fallows were assessed to establish sample plots for biomass surveys and to select households for interviews. For some sample plots, 2 households were engaged. Altogether, 26 households (30% of the total) in T village and 13 households (7% of the total) in P village were interviewed.

A total of 33 sample plots (22 in T village and 11 in P village) were randomly established using the chronosequence approach. In T village, 4 sample plots were established using a nested sampling design in each of the 1-, 3-, 5-, 7-, and 9-year-old fallow zones, and 2 plots were established in the conserved forest zone near the village. In P village, small trees (height [H] < 1.3 m) and shrubs were sparsely distributed in fallow zones up to 7 years old; it was very difficult to make tree measurements and establish sample plots in those zones. Such slow vegetation regrowth was likely due to the frequent land use in P village, where fewer cultivation zones were available than in T village. Therefore, 3 sample plots were randomly established in each 8- and 10-year-old fallow zone, and 5 plots were established in the 14-year-old fallow zone, which was designated as conserved forest according to the villagers, although this was not (yet) apparent when setting the plot. Plots measuring 30×30 m were established in the conserved forest zones, and 10×10-m plots were established in fallow zones to conduct the tree inventory.

In the sample plots, the biomass of small vegetation, including small trees, shrubs, herbs, and vines, was included as understory biomass, even though they were not under the tree canopy, especially in young fallows. In some fallows, especially the young ones, the understory vegetation (mainly *Chromolaena odorata*) was higher than 1.3 m. Therefore, the understory vegetation was divided into 2 categories. High understory ($H > 1.3$ m) was surveyed in 5×5 m subplots, mostly in 1-year-old fallow zones because of the vigorous growth of *C. odorata,* and short understory ($H \leq 1.3$ m) was surveyed in 5 subplots of 1×1 m in both fallow and conserved forest zones.

To accurately estimate tree biomass, site-specific allometries were established by destructive sampling of 99 trees. Sample trees were harvested by selecting the average diameter at breast height (D130) for each species in every sample plot in the fallows of T village, to ensure the suitable selection of trees for harvesting from a multispecies stand. The trees were cut at 0.3 m above ground level and divided on site into 3 components: leaves, branches, and main trunks. Each trunk was cut into meter-long pieces, and the diameters at each end were measured and recorded. The total fresh weight of each component was measured by portable hanging digital scales. After the fresh weights had been measured and recorded, samples of each tree component were taken and measured to obtain the sample fresh weights. For trunk biomass analysis, an approximately 4-cm-thick slice of wood was cut from the bottom part of meter-long logs and weighed. Representative samples of about 300 g were also taken from the branches and leaves of each sample tree. All of these fresh samples were oven dried at the Forest Research Institute in Yezin until a constant weight was achieved. The wood density of each sample tree was calculated by dividing the oven-dry weight (g) by the green volume (cm^3) of the sample discs from the bottom of each meter-long log.

A destructive method was also used to estimate the understory biomass. A fresh sample of about 300 g was taken from each sample plot, and the oven-dry weight was measured for further analysis.

Changes in the extent of swidden agriculture

From the land records and interviews, the changes in the area of swidden agriculture zones over a complete rotation were analyzed. In T village, the number of households engaged in swidden was only available from 2003–2004 to 2012–2013. Therefore, the total area of swidden cultivation was calculated by multiplying the number of households and the average plot size obtained from the interviews. In P village, the number of households engaged in swidden cultivation and the total swidden area opened by each household were available. In this study, the changes in the extent of swidden

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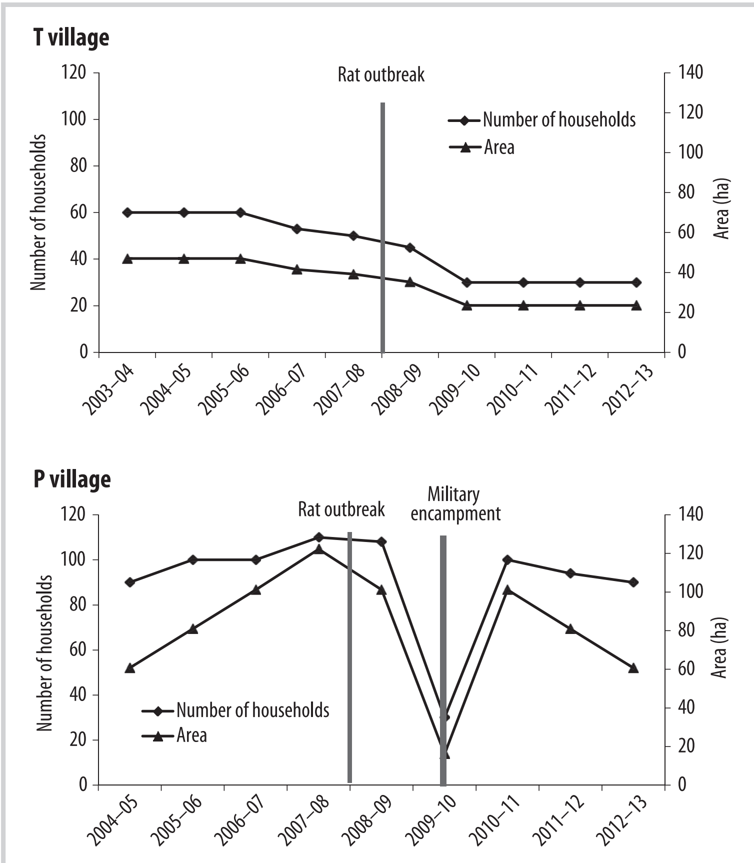
FIGURE 2 Changes in the land area under swidden agriculture and the number of swiddener households. (Data source: village administration offices)



agriculture were analyzed within the territory of each village.

Allometries, biomass estimation, and biomass recovery trends

Using the 99 sampled trees, which belonged to 52 species, with a D130 range of 1.6–17.8 cm and H range of 1.58–8.52 m, allometries for the AGB estimation were established by a regression analysis of measurable tree parameters (D130 and total tree H) and tree biomass components (trunk, branch, leaf, and total AGB). The correlation coefficient (R^2 value), standard error (SE), and average deviation (%) were used to select the best-fit allometry to estimate total tree AGB in the subsequent analysis.

Using the best-fit allometry, the total AGB of individual trees in each plot was estimated. At the plot level, the total AGB of trees was supplemented by understory biomass.

The biomass recovery trend in both villages was also analyzed by regression as a function of total AGB against fallow age. By extrapolation of the resulting functions, the period required for the accumulation of total AGB in fallow forests in each village to attain the AGB accumulated in conserved forest (which seems to be older than 100 years old according to village patriarchs) was estimated.

Results and discussion

Decrease in swidden agriculture

Swidden agriculture gradually decreased in both villages because of the decreasing number of swidden cultivators and a shift toward alternative livelihood activities.

Decreasing number of swidden cultivators: Figure 2 depicts the changes in the number of households engaged in swidden agriculture and changes in the area under swidden cultivation in both villages. In T village, the number of households engaged in swidden agriculture fell from 60 in 2003–2004 to 30 in 2012–2013. In P village, the number of households engaged in swidden agriculture varied over time. The number of households has decreased since 2008–2009, with a marked decrease in 2009–2010, during which time a military camp occupied land near the village. Only 30 households opened swidden sites in a limited fallow area (16.19 ha) of village territory. Other households opened sites in another village's

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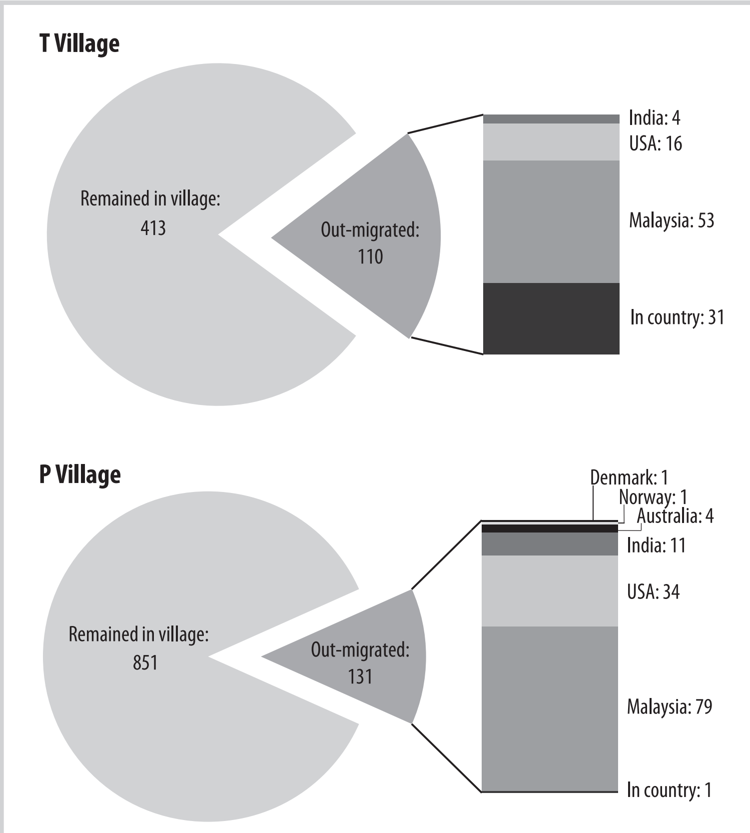
FIGURE 3 Village migration patterns.



territory, following negotiations with the military, but these were not counted in the analysis.

Residents of both villages, primarily young people, out-migrated in search of work (Figure 3)—21% in T village and 13% in P village—to other countries including India, Malaysia, and the United States, or to places within Myanmar. Out-migration for better job opportunities has been observed elsewhere in Chin State. Takahashi (2007) reported a Malay connection with the Chin people in the northern part of the state, including swidden cultivators. UNFPA (2010) reported that there were 159,000 migrants from Chin State in 2001, but the Department of Population (DoP 2015) reported that 51,545 people from Chin State were living abroad.

One of the major drivers of migration has been insufficient agricultural production (Takahashi 2007; UNDP-Myanmar 2011, 2013; Win et al 2012). Thein (2012) also reported that the survival of families in this area depended mainly on remittances from migrant workers. Cramb et al (2009) and Schmook et al (2013) reported the types of out-migration related to demographic changes in Southeast Asia. As in the villages studied here, insufficient agricultural production, failure of crop production due to harsh climatic conditions in some years, the peripheral effects of a forest rat outbreak in 2008 (CHRO 2008), and the low level of socioeconomic development in the region due to difficulties in communication caused by the rugged terrain were the major factors for out-migration. With out-migration, the number of swidden cultivators in the studied villages is decreasing.

Shift to alternative income sources: Although the majority of households were still engaged in swidden cultivation in 2013, a number were turning to nonshifting cultivation on old fallows. Table 1 shows land uses and crop production volumes in the study villages in 2013, based on data from the household interviews.

Terrace farming was introduced by a government program in the 1960s (Thein 2012). A marked development of terraced fields occurred during 2001–2010 with assistance from United Nations agencies, national and international NGOs, and governmental organizations. This has decreased dependency on swidden agriculture and, in T village, triggered a switch from maize to rice as the staple food. Rice productivity was higher in P village, because rice produced from terrace farming was included.

Food production was insufficient for subsistence, and village livelihoods depended on nonfarming income sources as well (Takahashi 2007). Cash-earning activities are summarized in Table 2. Remittances from out-migrant

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TABLE 1 Land use and crop production, 2013.[a)]

Land use (number of households)	T village		P village	
	Number	%	Number	%
Swidden cultivation	22	85	11	85
Terrace farming	7	27	7	54
Gardening in old fallows	12	46	11	85
Production of major crops (kg ha^{-1})	Number		Number	
Rice	542.5		2017.9	
Maize seed	546.5		no data	
Sesame	35.3		no data	

a) Notes on crop production data: The kg value was derived from a local measure called the basket, which is equivalent to just under 21 kg of rice, 25 kg of maize seed, or 41 kg of sesame. The rice production figure for P village includes the yield from terrace farming. In this table, only major crops from swidden cultivation and terrace farming are mentioned. Household in P village did not seem to produce maize seed or sesame.

family members accounted for about 32% of household cash income in T village and 40% in P village. Animal husbandry, formerly part of the subsistence system, provided 45% of the total cash income generated in T village and 32% of the income of P village, with 50% of this animal husbandry income contributed by gaur (*Bos gaurus*) in both villages. The Chin Hills are a natural habitat for gaur (FAO 2000; Duckworth et al 2008; Shisode et al 2009; Tanaka et al 2011). Gaurs are essential to the customs of the local people; they are used as marriage gifts and as sacrificial animals in various ceremonies (Duckworth et al 2008; Shisode et al 2009). A gaur husbandry project was initiated in Chin State in 2007 as a local development initiative.

As NTFPs, *wa-u* (*Amorphophallus* spp, commonly known as elephant foot yam) and firewood were collected, not only from the gardens of residents but also from natural forests. *Wa-u* was collected mainly in T village and occasionally in P village. Earlier, it was cultivated for home consumption as part of a mixed crop in swidden farming. It has recently been cultivated as a cash crop in southern Chin State (Win et al 2012). The increasing demand for *wa-u* from China and Japan has led to a move away from subsistence cultivation toward a semicommercialized system. The swiddeners have started to grow *wa-u* in gardens in their old fallows. *Wa-u* is a perennial plant that produces many bulbils (Hetterscheid and Ittenbach 1996; Chua et al 2010), and thus a single planting can yield many years of harvests. *Wa-u* cultivation accounted for about

TABLE 2 Average income generated per household from activities other than crop raising, 2013, in Myanmar kyats (US$ 1 ≈ MMK 980).[a)]

	Price per unit	T village	P village
Number of individuals per household		6	8
Remittances from out-migrant family members		1,250,000	1,500,000
Animal husbandry			
Gaur	350,000 per head	603,000	423,000
Buffalo	330,000 per head	330,000	No data
Pig	136,000 per head	237,000	290,000
Chicken	7000 per head	35,000	No data
Collection of NTFPs[a]			
Wa-u	4000 per *viss*	210,000	No data
Firewood	40,000 per *kyi*	No data	99,000
Home business	Not applicable	180,000	222,000
Land rental	Not applicable	350,000	150,000
Wage labor			
For farming	Not applicable	519,000	No data
For other purposes	Not applicable	180,000	414,000
Vegetable farming	Varies	No data	610,000

a) *Wa-u* is the local name for elephant yam or elephant foot yam (*Amorphophallus* spp, family Araceae); dry sliced *wa-u* is exported to Japan and China. The *kyi* is a local measurement unit for firewood (1 *kyi* = 2.04 m^3). The *viss* is also a local measurement unit for mass/weight (1 *viss* = 1.63 kg).

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TABLE 3 Best-fit allometric relationships between tree component biomass and dimensional variables ($y = ax^b$).

y	x	*n*	a (± SE)	b (± SE)	$R^{2a)}$	Adjusted R^2	SE	Average deviation (%)
Total biomass (kg)	D130 (cm)	99	0.105 (± 0.012)	2.256 (± 0.075)	0.904	0.903	0.367	7.00
Trunk biomass (kg)	$D130^2H$ (cm^2m)	99	0.059 (± 0.008)	0.843 (± 0.028)	0.902	0.901	0.370	7.04
Branch biomass (kg)	$D130^2H$ (cm^2m)	98	0.008 (± 0.002)	0.904 (± 0.059)	0.708	0.704	0.769	51.11
Leaf biomass (kg)	D130 (cm)	99	0.011 (± 0.003)	2.025 (± 0.162)	0.617	0.613	0.797	44.08

a) R^2 values are all significant at a 95% confidence interval.

5% of the total average cash income in T village. Firewood collection is usually for home consumption, but in P village, it is also a cash-earning activity that accounted for about 16% of total average cash income.

Other cash-income-generating activities, such as traditional costume weaving, small-scale retail sales, temporary land rental, farm labor for wages, and other tasks such as hauling freight, also contributed to household income. P village's greater access and proximity to Matupi town made cash cropping of vegetables an option there.

Thus, the transition from swidden farming to cash-generating activities occurred both outside the village (labor migration) and inside the village (eg animal husbandry, NTFP gathering, and vegetable farming for sale to local markets).

Changes in the extent of swidden-cultivated land: The changes in land area devoted to swidden are shown in Figure 2. In T village, the swidden area has gradually decreased since 2005–2006, probably because of out-migration. The year 2009–2010 was the peak of out-migration within the analyzed period, because of the peripheral effects of a rat outbreak that occurred in 2008 and seriously damaged crops. The outbreak occurred at the time of harvest, and only a 10th of the usual amount could be harvested. Therefore, most of the young people migrated to work in other parts of Myanmar or abroad. Similar effects were encountered in P village. However, food security was not markedly affected by the rat outbreak, because extensive terraced farming was already established in this village, and it was close to town, so there were other livelihood options such as vegetable farming. In addition, the proportion of the population currently residing in the village rather than out-migrating was higher compared to that in T village (Figure 3), but smaller in terms of swidden-practicing families.

Allometries, biomass estimation, and biomass recovery trends

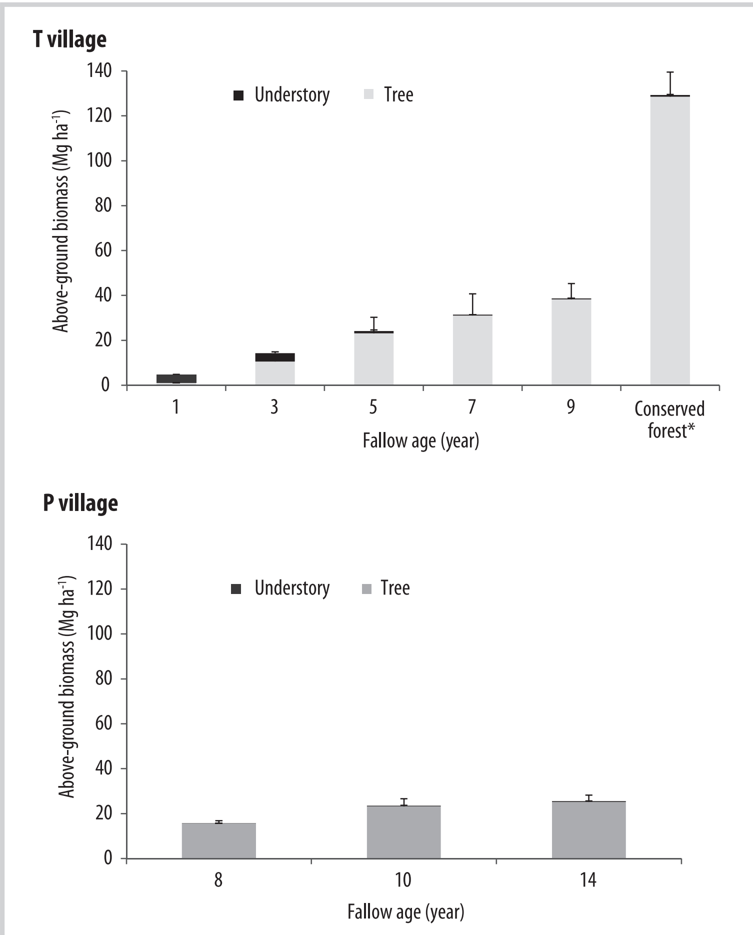
Allometries for AGB estimation at individual tree level: The allometries used to estimate the AGB of individual trees are described in Table 3. The most useful predictor of total tree AGB and leaf biomass was D130, which had the highest R^2 values (0.904 for total AGB and 0.617 for leaf biomass). The best-fitting parameter for trunk and branch biomass estimation was $D130^2H$ (0.902 for trunk biomass and 0.708 for branch biomass).

Regarding establishment of allometries for biomass estimation, many studies have considered the various predictive parameters used to estimate total AGB. Most previous studies (Brown 1997; Ketterings et al 2001; Hashimoto et al 2004; Basuki et al 2009; Lima et al 2012) have recommended D130 as the best parameter for estimating the biomass of each tree component. Kenzo et al (2009) showed that diameter at ground level provided a more accurate estimation than D130 and H. $D130^2H$ was reported to be the best predictor of total AGB by Ogawa et al (1965); Kenzo et al (2009); and Chan et al (2013). Lima et al (2012) reported that a model with 2 tree variables (D130 and H) gave a better correlation with tree biomass than a model with only 1 variable. However, in this study, D130 produced the best fit to estimate the total tree AGB for the analysis. The results showed that leaf biomass was not strongly related to the total H of the tree, which was probably because of the stunted tree growth on rugged mountains (Whitmore and Burnham 1984).

Biomass estimation at plot level in swidden-cultivated fallows: The contribution of tree biomass to total AGB was significant in both villages. The understory biomass markedly contributed to total AGB in younger fallows (Figure 4). In T village, the understory biomass accumulated 3.74 (± 0.127) Mg ha^{-1} (79% of total AGB) in 1-year-old fallows, but this decreased to 0.39 (± 0.048) Mg ha^{-1} (1%) in 9-year-old fallows. The tree biomass accumulation accounted for 1.01 (± 0.035) Mg ha^{-1} (21%) in 1-year-old fallows, but this increased to 38.26 (± 7.085) Mg ha^{-1} (99%) in 9-year-old fallows. In P village, the contribution of understory biomass was very small at 0.18 (± 0.045) Mg ha^{-1} (1% of total AGB) in 8-year-old fallows and 0.37 (± 0.100) Mg ha^{-1} (1% of total AGB) in 14-year-old fallows. The tree biomass contributed 15.52 (± 1.272) and 25.17 (± 3.040) Mg ha^{-1} in 8- and 14-year-old fallows, respectively.

Average AGBs of 4.24 (± 0.263), 14.24 (± 1.703), 24.13 (± 6.928), 31.43 (± 9.644), and 38.65 (± 7.118) Mg ha^{-1} were estimated in 1-, 3-, 5-, 7-, and 9-year-old fallows of T

FIGURE 4 Average biomass accumulation in swidden-cultivated fallows. *Conserved forest seemed to be more than 100 years old according to village patriarchs.



village (Figure 4), whereas average AGBs of 15.70 (± 1.251), 23.52 (± 3.421), and 25.54 (± 3.092) Mg ha^{-1} were estimated in 8-, 10-, and 14-year-old fallows of P village (Figure 4). The average total AGB of conserved forest in T village was 129.32 (± 11.150) Mg ha^{-1}.

Thus, biomass regrowth was much more rapid in T village than in P village, probably because there was 1 more zone in T village than in P village. Field observations confirmed the slow regrowth of vegetation in swidden-cultivated fallows of P village and the limited amount of regeneration sources in both villages, due to traditional collective swidden practices, which left little regeneration material in large areas. Sprouting and coppice regeneration were the major regeneration strategies. In P village, the villagers chopped off the branches and left the trunks, from which new shoots emerged to produce pollards. A similar method was also used in T village; the number of pollards produced there was higher. Therefore, although the traditional practices were similar, the earlier land use history and the condition of the remaining vegetation had an effect on regrowth during fallow. Ramakrishnan (1992) reported that fallow regrowth during the early secondary succession varied depending on earlier land use history, such as swidden cycle length, preexisting vegetation, and cropping procedures.

The total accumulated AGB in both villages was lower than that reported for swidden-cultivated fallows in the Bago Mountains, Myanmar (Chan et al 2013), which is likely because of the difference in forest types. The total AGB accumulation in 7-year-old fallows in this study (31.43 Mg ha^{-1}) was almost equivalent to that (31.31 Mg ha^{-1}) of 5-year-old fallows in the Bago Mountains (Chan et al 2013). However, Ramakrishnan (1992) reported a total AGB of 2330 g m^{-2} (23.3 Mg ha^{-1}) in Meghalaya, which is similar to the biomass accumulation in 5-year-old fallows in T village. A total AGB of 5750 g m^{-2} (57.5 Mg ha^{-1}) accumulated in 10-year-old fallows in Meghalaya (Ramakrishnan 1992) and 47.1 Mg ha^{-1} in the Bago Mountains of Myanmar (Chan et al 2013), but only 23.52 Mg ha^{-1} in the 10-year-old fallows of P village. Therefore, it was clear that the biomass regrowth in P village was slower than that not only in T village but also in neighboring study sites in northeastern India and central Myanmar.

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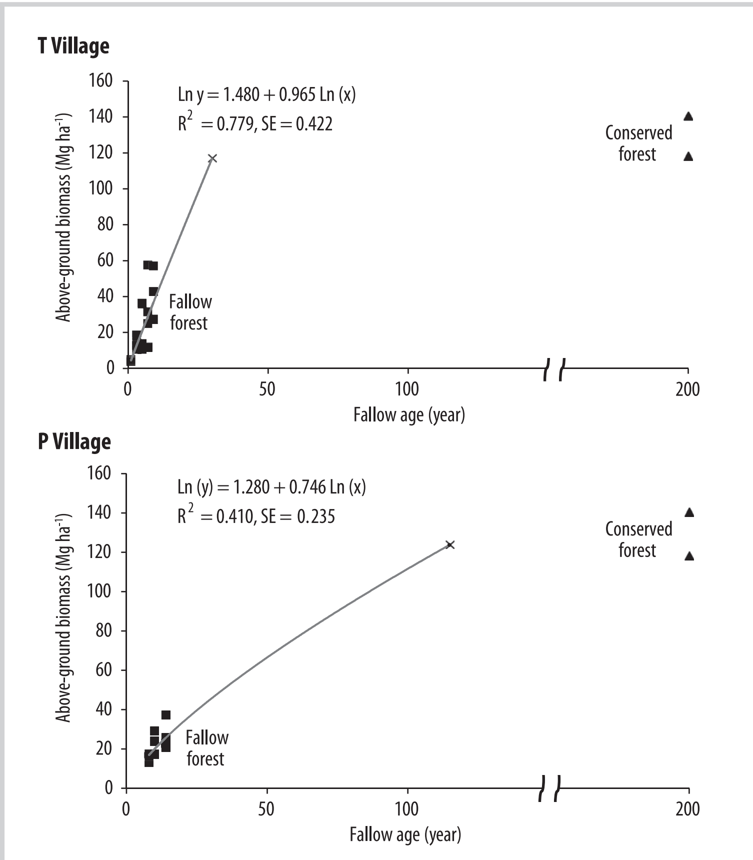
FIGURE 5 Biomass recovery trends.



Biomass recovery trends: In a review, Delang and Li (2013) reported 2 patterns relating AGB accumulation to fallow age. In the first pattern, AGB increased with fallow age (Uhl 1987; Read and Lawrence 2003; Fukushima et al 2007; Chan et al 2013). However, total AGB has also been shown to initially increase, but then remain constant (Saldarriaga et al 1988; Van Do et al 2010).

The biomass recovery trends of T and P villages are shown in Figure 5. The total AGB accumulation is shown in the form of a saturation curve, with rapid initial biomass accumulation followed by slower regrowth. This supports the conclusion of Uhl (1987) that the biomass accumulation rate is likely to decline after 10 years of fallow, with the linear relationship disappearing. Read and Lawrence (2003) used a linear regression to fit the relationship between the biomass of fallow stands and fallow age over a 25-year period. Gehring et al (2005) showed the logarithmic allometry fitted to the curve of total AGB against time after abandonment. Chan et al (2013) reported that power regression provided a good fit to the relationship between total AGB and fallow age. Uhl (1987) suggested that the biomass accumulation was not linear with respect to time. The analyses in both villages provided a good fit for the power regression (Figure 5). A better correlation between AGB accumulation and fallow age was observed in T village than in P village.

Generally, the total AGB accumulation in swidden-cultivated fallows increased with the fallow age. The average total AGB in the conserved forests of T village was 129.32 (± 11.15) Mg ha^{-1}. The biomass accumulation of swidden-cultivated fallows in T village was equivalent to about 30% of the accumulated biomass in conserved forests after 9 years of regeneration, but the corresponding figure was only about 20% in P village after 14 years. When extrapolating the fitting equations in each village beyond the time span, biomass would theoretically accumulate to 100% of the biomass level accumulated in the conserved forests after 30 years of regeneration in T village, and after 115 years of regeneration in P village. A review of previous studies suggested that 65 years of regeneration in swidden-cultivated fallows in the Bago Mountains, Myanmar, would likely attain an AGB of 156.6 Mg ha^{-1} (Chan et al 2013). After 60 years of regeneration in northwestern Vietnam, 80% of the AGB in old forests was hypothetically recovered (Van Do et al 2010). In the southern Yucatan region of Mexico, recovery to the prelogged state was estimated to take 65–120 years (Read and Lawrence 2003).

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Thus, total biomass accumulation increased with fallow age in both villages. In association with the transition away from swidden agriculture, further biomass accumulation can be expected in both villages.

Conclusions

The migration of local residents, especially younger people, for employment opportunities has resulted in a decrease in the number of swidden cultivators, and consequently in the area devoted to swidden agriculture. The period of 2009–2010 was the peak of out-migration, because of crop failure due to a rat outbreak in southern Chin State. Overall, 21 and 13% of the population of T and P villages, respectively, migrated for employment inside or outside Myanmar.

The insufficient productivity of swidden farming and the development of alternative income sources, especially animal husbandry and sale of NTFPs, as well as terrace farming (introduced through a government program), are the major factors that have weakened dependency on swidden agriculture in both villages. Remittances sent by out-migrant family members also contributed substantially to household incomes in both villages.

To accurately estimate AGB accumulation in the fallow forests, site-specific allometries were established. D130 was identified as the best parameter for estimating AGB accumulation. In addition, the regression of total AGB against fallow age made it possible to easily estimate biomass accumulation when the fallow age was known.

The AGB accumulation in the fallow forests was estimated using the best-fit allometries. In T village, an AGB of 4.24 Mg ha^{-1} accumulated in 1-year-old fallows, and AGB increased to 38.65 Mg ha^{-1} in 9-year-old fallows. In P village, an AGB of 15.70 Mg ha^{-1} accumulated in 8-year-old fallows, and AGB increased to 25.54 Mg ha^{-1} in 14-year-old fallows. In general, AGB accumulation increased with fallow age. A power regression provided a good fit for the relationship between AGB and fallow age in both villages. In T village, the equivalent of 30% of the biomass level in conserved forests would theoretically be attained after 9 years of regeneration. In P village, the corresponding figure was 20% after 14 years of regeneration. Therefore, biomass regrowth was clearly slower in P village than in T village.

The decline in swidden cultivation, due to out-migration and the development of alternative livelihood activities, led to an increase in fallow forests, as well as to a lengthening of the fallow period in some abandoned fallows. Accordingly, a further increase in biomass is likely in the villages studied here in the future.

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