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Underground Biomass Accumulation of Two Economically Important Non-Timber Forest Products Is Influenced by Ecological Settings and Swiddeners' Management in the Bago Mountains, Myanmar


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Contents

စီးပွားရေးအတွက်အရေးပါသော သစ်တောထွက်ပစ္စည်း(၂)မျိုး၏ မြေအောက်ဇီဝဒြပ်ထု စုဆောင်းမှုအပေါ် ဂေဟစံနစ်ဖွဲ့စည်းပုံနှင့်တောင်ယာစိုက်ပျိုးသူများစီမံခန့်ခွဲမှုတို့၏ လွှမ်းမိုးပုံကိုလေ့လာခြင်း

ဒေါက်တာအိ၊ ဦးစီးအရာရှိ၊ လေ့ကျင့်ရေးနှင့်သုတေသနဖွံ့ဖြိုးရေးဌာန
နှင့်
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စာတမ်းအကျဉ်း

ရွက်ပြတ်ရောနှောတောများ၏ အမျိုးစုံလင်သော အပင်တို့သည် လူတို့အတွက် သစ်သာမက လောင်စာ၊ အစားအစာ၊ ဆေးဝါးစသည့် သစ်မဟုတ်သည့် သစ်တောထွက်ပစ္စည်း များကိုလည်း ထောက်ပံ့ပေးပါသည်။ သစ်တောထွက်ပစ္စည်းများ၏ ရေရှည်တည်တံ့မှုနှင့် စီးပွားရေး တန်ဖိုးများကို များစွာလေ့လာထားပြီးဖြစ်သော်လည်း ယင်းလေ့လာမှုအများစုသည် မြေပေါ်အပင်ပိုင်း ထုတ်ယူမှု များ ဖြစ်၍ မြေအောက်အပင်ပိုင်းထုတ်ယူမှုလေ့လာခြင်းကို တွေ့ရှိရခဲပါသည်။ အဘယ့်ကြောင့် ဆိုသော် မြေအောက်ထဲရှိအပင်ပိုင်းများကို တူးဖော်လေ့လာရန် အခက်အခဲများရှိခြင်း၊ သစ်နှင့် နှိုင်းယှဉ်လျှင် စီးပွားရေးတန်ဖိုးလျော့နည်းသဖြင့် သစ်တောစီမံအုပ်ချုပ်မှုတွင် ထည့်သွင်းစဉ်းစားမှု နည်းပါးခြင်း တို့ကြောင့်ဖြစ်ပါသည်။ ယခုသုတေသနစာတမ်းတွင် တောင်ယာစိုက်ပျိုးရေးဖြင့် အသက်မွေးလျက် သစ်တောများအပေါ်မှီတင်းနေထိုင်သည့် ဒေသခံကရင်လူမျိုးများ ဝင်ငွေရရှိရေး အတွက်ထုတ်ယူသော *Rauvolfia serpentina* (ဘုမ္မရာဇာ) နှင့် *Amorphophallus bulbifer* (ဝဥ/ဖျံဥ)တို့၏ တောင်ယာ စိုက်ပျိုးမြေ၊ ဖုန်းဆိုးတောနှင့် တောကျန်များတွင် သဘာဝအလျောက် ပျံ့နှံ့ပေါက်ရောက်ပုံ၊ မြေပေါ်အပင်ပိုင်းအရွယ်အစားနှင့် မြေအောက်ရှိ အမြစ်/ဥ ဇီဝဒြပ်ထု စုဆောင်းရရှိမှု ဆက်စပ်ပုံတို့ကို လေ့လာခဲ့ပါသည်။ ခန့်မှန်းတွက်ချက်ရရှိသည့် ဇီဝဒြပ်ထုပမာဏ များနှင့် ဒေသခံတောင်ယာလုပ်ကိုင်သူ များ၏ ဘုမ္မရာဇာမြစ်နှင့်ဝဥထုတ်ယူပုံအလေ့အထများအရ တောင်ယာကွက်များတွင် ရာနှုန်းပြည့် အလင်းပွင့်သဖြင့် ဘုမ္မရာဇာကြီးထွားမှုကို ပိုမိုကောင်းမွန် စေကြောင်း၊ ခြုံနွယ်ပေါင်းထူထပ်သော ဖုန်းဆိုးတောနုအဆင့်၌ ဘုမ္မရာဇာနှင့်ဝဥအပင်များ မြေအောက်ဇီဝဒြပ်ထု စုဆောင်းရန် အခွင့်အလမ်း ရရှိစေပြီး သက်လတ်ဖုန်းဆိုးတောနှင့် တောအို များတွင် ပြန်လည်ထုတ်ယူခြင်းဖြင့် အလှည့်ကျ ထုတ်ယူသော စနစ်ကိုဖြစ်ပေါ်စေကြောင်း၊ ထုတ်ယူပုံအလေ့အထများအရ အပင်မျိုးဆက်နိုင်ရန် ဘုမ္မရာဇာ အမြစ်အစိတ်အပိုင်းနှင့် ဝဥ အသီးလုံးများ တောထဲတွင် ကျန်ရစ်စေကြောင်း တွေ့ရှိခဲ့ရပါသည်။ ၎င်းအပင်များသည် တောမီးရှို့စိုက်ပျိုးသည့် တောင်ယာစနစ်ကျင့်သုံးသောနေရာတွင် လိုက်လျောညီထွေစွာ ရှင်သန် ပေါက်ရောက်နိုင်ပြီး ဖုန်းဆိုးတောအခြေအနေအလိုက် ထုတ်ယူပုံ နည်းစနစ်ကြောင့် ဆက်လက် ရှင်သန်နေသော ဝင်ငွေအကျိုးပြု သစ်တောထွက် ပစ္စည်းများဖြစ်ကြောင်း လေ့လာသိရှိခဲ့ရပါသည်။

Underground Biomass Accumulation of Two Economically Important Non-Timber Forest Products Is Influenced by Ecological Settings and Swiddeners' Management in the Bago Mountains, Myanmar

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Abstract

Diverse tree species, understory bamboos, shrubs, and herbs in mixed deciduous forests (MDFs) provide timber and also non-timber forest products (NTFPs) in terms of fuel, food, and medicinal plants. Sustainability and the economic value of NTFPs have been studied mainly for the aboveground vegetative components of plants. However, such important knowledge of the underground parts of the plants is limited because of difficulties observing them and lesser consideration of the lower value of NTFPs, compared with timber, in forest management. We established allometric models to predict the root and corm biomasses of *Rauvolfia serpentina* and *Amorphophallus bulbifer* in relation to their aboveground, vegetative parts. Estimated underground biomasses of the two species were compared among three habitat types: a swidden field, a fallow forest after cultivation, and a ridge forest that was not subjected to swidden agriculture. The length of the longest leaf of each individual plant explained the accumulation of the underground biomass of *R. serpentina* ($R^2 = 0.64$, $P < 0.001$) in a positive, linear relationship, and stem diameter at ground level did the same for *A. bulbifer* ($R^2 = 0.92$, $P < 0.001$). The largest biomass accumulation of *R. serpentina* was found in swidden fields because of its light demanding nature, which was supported by a significant, negative correlation between canopy cover and leaf length (Pearson's correlation $= -0.612$, $P < 0.05$). Because *A. bulbifer* was cut during weeding time, we could not measure its biomass accumulation in swidden fields; however its occurrence in swidden fields was confirmed by farmers and field observations. No difference in the biomass accumulation of *A. bulbifer* was observed between the fallow and ridge forests. The promising growth of both species in the same year that a fire occurred during swidden cultivation suggests that the underground regeneration source provides advantages related to the harvesting of NTFPs and allows them to co-exist with slashing and burning in a swidden system, as well as surface fires in an MDF. Establishment of the two species in fallow vegetation was possibly facilitated by ecological and anthropogenic factors such as the reproductive bulbils of *A. bulbifer* and the broken root fragments of *R. serpentina* left after the harvest, as well as the dormancy period of these species during the dry season. This study revealed the cultivation potential of NTFPs that are suitable for community and agroforest plantations using a swidden system in an MDF that experiences fires.

Keywords: *Amorphophallus bulbifer,* Fire-prone environment, Mixed deciduous forest, *Rauvolfia serpentina*, Swidden fallow

Underground Biomass Accumulation of Two Economically Important Non-Timber Forest Products is Influenced by Ecological Settings and Swiddeners' Management in the Bago Mountains, Myanmar

1. Introduction

Swiddening, also known as slash-and-burn cultivation, is a common practice of subsistence agriculture for forest dwellers in hilly regions. In the Bago Mountains in Myanmar, the Karen people have lived on swidden agriculture since before British colonial times (Bryant, 1994b). The Bago Mountains are a range of undulating hills covered with mixed deciduous forests (MDFs) that are characterized by valuable tree species such as teak (*Tectona grandis*), *Xylia xylocarpa*, and *Pterocarpus macrocarpus* (Blasco et al., 1996; Bullock et al., 2009), and they have experienced a long history of teak forest management since the time of the British colonial government. Because vegetation is diverse in terms of tree species, as well as understory bamboos, shrubs, and herbs (Whitmore, 1984), MDFs provide non-timber forest products (NTFPs) in the form of fuel, food, and medicinal plants that aid the subsistence of swidden communities. In line with the recent, growing influence of the cash economy, the Karen people have come to rely on harvesting NTFPs, such as *Rauvolfia serpentina* (Apocynaceae) and *Amorphophallus bulbifer* (Araceae) that grow with other forest floor species in swidden fields and surrounding forests, for cash income.

Rauvolfia serpentina (bonma-yaza in Burmese), which is known as Sarpagandha in Ayurvedic medicine, is a prominent medicinal plant from which alkaloid contents are extracted from its roots to treat hypertension (Soe et al., 2004; Monachino, 1954; Sheldon et al., 1997). Increasing demand and the overexploitation and loss of *R. serpentina* habitats after excessive deforestation resulted in its resource exhaustion in wild populations, for example, those in India, Java, and Indonesia (Cai et al., 2009; Dey and De, 2010; Sheldon et al., 1997), and the species has been included in the Convention on International Trade in Endangered Species of Wild Fauna and Flora Appendix II since 1990 (Sheldon et al., 1997). *Amorphophallus bulbifer* (wa-u in Burmese), commonly known as konjac, is famous for the glucomannan in its corms, which is valued as a low-calorie, high-fiber food, and used as a straight-chain polymeric material (Wang et al., 2011).

Because of the increasing demand for medicinal and herbal species, forest degradation, and the conversion of forests into other land uses, source of NTFPs have decreased worldwide (Shackleton et al., 2011). It may not be possible to prevent the overexploitation and extinction of plant resources unless NTFPs and land use systems are included in forest management strategies. Formulations of management interventions to sustainably use plant resources critically require the evaluation of NTFP extraction by local people. In Myanmar, underground NTFPs are less studied because of the difficulties associated with directly measuring their harvestable parts, compared with their aboveground vegetative parts, and because NTFPs extracted from undergrowth have a comparatively smaller biomass and lower value than timber products and they are less considered in forest management. However, forest management in Myanmar has focused recently on local livelihoods and biodiversity conservation by encouraging agroforestry and community forestry in degraded secondary forests near human settlements. Logging has also been suspended for at least a decade in the Bago Mountains to accelerate forest rehabilitation, and, thus, NTFPs have become prominent because of their productive value in the forests in this area. Furthermore, the demand for NTFPs seems to have been increased by current political changes of the country, which has resulted in increased economic investments and trade from foreign countries. A lack of information on small plants with economic value in swidden systems may lead to less recognition of the importance of local resource management, as well as the cultivation potential of marketable plant species in community-based agroforestry programs.

2. Objectives

The objectives of this study were (i) to understand the botanical characteristics and swiddeners' harvest practices of *R. serpentina* and *A. bulbifer*; (ii) to estimate and compare their underground biomasses among swidden fields, fallow forests, and ridge forests; and (iii) to analyze the influences of both ecological and anthropogenic factors on their biomass accumulation to improve the sustainable management of NTFPs in an MDF.

3. Materials and methods

3.1. Study site

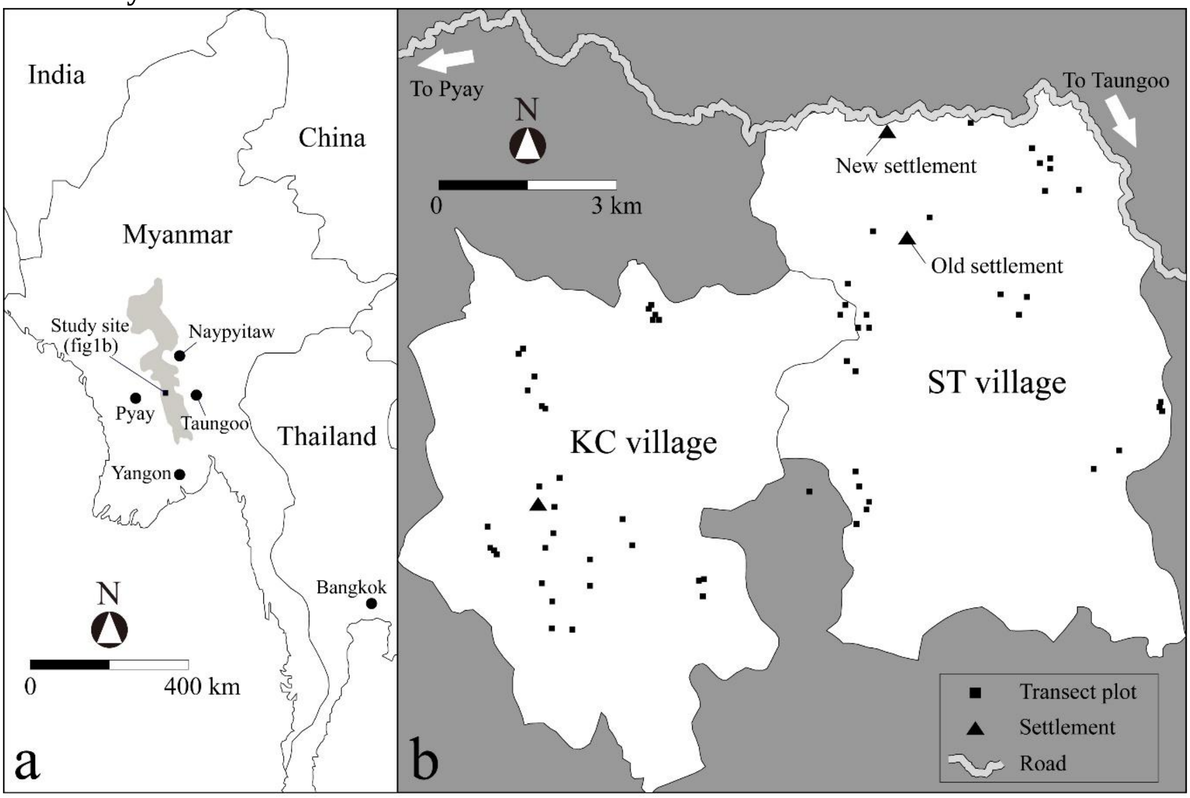


Fig. 1 (a) Location of the Bago Mountains indicated in gray in the map of Myanmar (b) Areas in white indicate the two Karen areas inside reserved forests.

The Bago Mountains (Fig. 1a), located between N 16°50'34" and 19°29'34", E 94°41'19" and 97°13'27", comprise undulating hills with average elevation of 600 m. They experience distinct rainy and dry seasons from May to October and November to April, respectively, because of the tropical monsoon climate. The mean annual temperature is 26 °C, and the mean annual rainfall is 2,300 mm, with variations along the mountain range running from north to south. Forest vegetation, which is typical of tropical monsoon forests (Bullock et al., 2009; Whitmore, 1984), is supplied with rainwater during the monsoon, and it is seasonally deciduous during the dry season, while surface fires and swidden burning occur annually. Secondary forests at the study site are the mixed deciduous type and are dominated by tree species of *T. grandis*, *X. xylocarpa*, *P. macrocarpus*, *Dalbergia* spp., and *Dipterocarpus* spp., which are associated with a large proportion, approximately 30% of the basal area density, of bamboos (Thein et al., 2007). The Bago Mountains are regarded as home to *T. grandis*, and the forests here have been managed for more than one century to produce timber, which is an important part of Myanmar's economy. Reserved forests (Fig. 1b), which are divided into compartments, are the fundamental management units of the forest territory, and they were formed at the time of forest management by the British colonial government. Human access for tree felling and logging is prohibited in reserved forests (Bryant, 1994a).The Karen people, who live in these hills, were recognized by the colonial government as participating in the formation of teak plantations using an agroforestry system that was based on traditional Karen swiddening (Bryant, 1994b; Maung and Yamamoto, 2008; Win and Kumazaki, 1998). Therefore, they have been regarded as indigenous swiddeners with a long history of residence in the study area. During the British colonial period, some of the reserved forest area, approximately 4,000 to 6,000 ha, was granted to each community for customary land use (the Karen area), and it was placed under forest management by the government to support the local livelihoods of swiddeners. Local swiddeners subsist on traditional swidden cultivation and forest products within the designated Karen area. For swidden agriculture, farmers slash and burn secondary forests, preferably vegetation comprising a mixture of trees and bamboos (Chan et al., 2013), to prepare well-burnt fields enriched with ashes. They cultivate crops, including upland rice (*Oryza sativa*), cotton (*Gossypium hirsutum*), sesames (*Sesamum indicum*), chilis (*Capsicum frutescens*), and vegetables, for 1 year and repeat the same process at a different place the following year. After cultivation, swidden fields are abandoned as fallows during a vegetation recovery period as long as 12 to 18 years (Chan et al., 2013; Fukushima et al., 2007); however, some fallows that are easily accessible (in terms of distance) are opened frequently, thereby reducing the length of the fallow period to approximately 8 years (Chan et al., 2013). Connections to lowland areas have been improved within the last few decades, and, currently, the cash economy has become important for local livelihoods, for example, people sell cash crops and forest products to middlemen and buy household commodities from peddlers.

We studied two Karen areas, the KC and ST villages (Fig. 1b), where the people conduct traditional swidden agriculture. The settlement in the ST village was relocated to the roadside by the government one decade ago because of civil unrest in the eastern part of the Bago region. However, ST villagers are still conducting swidden agriculture around the old settlement, which is far from the new settlement. The landscape of the study site is characterized by swidden fields, fallow forests on slopes, remnant forests, and conservation forests, which have cultural importance, on ridges between the swidden fields.

3.2. Allometric model establishment

An allometric model was established by simple linear regression based on the assumption that the aboveground plant growth of *R. serpentina* and *A. bulbife*r is related to the masses of their roots and corms. A regression analysis is used commonly to predict the response variable, especially for estimating plant biomass and finding the relationship between the measurements of plant parts by establishing allometric models (Budiman, 2012; Chamberlain et al., 2013; Li et al., 2008). In this study, to predict the dependent variable (the fresh weights of roots or corms), the explanatory variables of stem diameter at ground level, stem height, and the length of the longest leaf were tested in a simple linear regression analysis, using 69 individual plant samples each of *R. serpentina* and *A. bulbifer*. A natural log transformation was applied to the measured variables to meet a normal distribution assumption in the linear regression analysis. For each species, the best-fit model was validated by the correlation coefficient and used to estimate underground biomass.

3.3. Vegetation survey

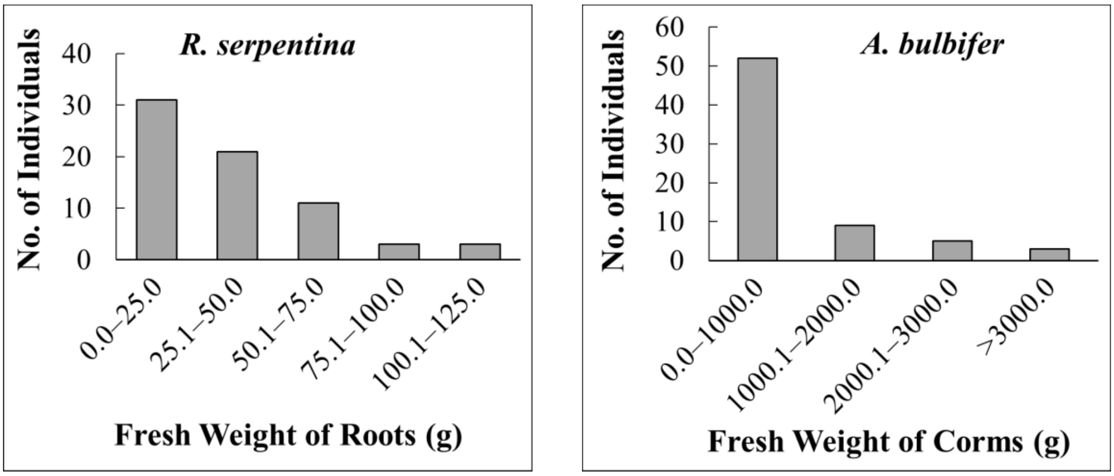
The explanatory variables and the density of plants were measured by transect surveys. We established plots where target plants occur in swidden valleys, slopes, and ridges, as well as in fallow forests and ridge forests in each of the two Karen areas (Fig. 1b). A total of 61 transects, 4 m × 100 m each, were surveyed by allocating 10 plots in each of the swidden valleys, slopes, and ridges, 16 plots in the fallow forests, and 15 plots in the ridge forests. The primary purpose of the transect survey was to analyze plant occurrence and microhabitat conditions in different forests and cultivation zones. However, the occurrences of both species did not overlap completely in the forest plots; therefore, we increased the number of plots to cover the occurrence of each species in the fallow and ridge forests. Two sub-plots, 1 m × 1 m each, were positioned at the highest or lowest density spots of the target species in the two halves of each transect to measure the percent cover, total height, and canopy cover. The species on the forest floor and in the canopy layer of these plots were also recorded. During the transect survey, harvest practices and local knowledge of plant occurrence were also ascertained by interviewing farmers at each swidden field or hut.

4. Results

4.1. Botanical characteristics and harvest practices of R. serpentina and A. bulbifer

Rauvolfia serpentina and *A. bulbifer* are distributed naturally throughout mixed deciduous and open forests, but they are not cultivated currently in the Bago Mountains. All the root and corm supplies of these species come from the wild, particularly swidden plots and secondary forests.

Based on the 69 samples of *R. serpentina*, including juvenile plants that constituted nearly one-half of the samples (Fig. 2a), its average height was 10.7 (±7.61) cm (Table 1), with the highest plant being 32.0 cm. *Rauvolfia serpentina* became established during the early rainy season, from May to June, and it started flowering and fruiting from June to August (Fig. 3). The plant has dark green leaves in a whorl, and many flowers in a cyme with a white to pink color (Fig. 4a), which grow and produce green drupes that become dark purple to black when they ripen. Its leaf color changes gradually to pale yellow, and the plant finally sheds its leaves in the beginning of the dry season. The plant cannot be found in the forests from December to April, when farmers clear and burn vegetation at new swidden plots (Fig. 3). When the monsoon rain starts in early May, the plant sprouts from its root stock and starts appearing in the fields. During the rainy season when a new sprout grows,



(a) (b)

farmers find *R. serpentina* plants in their crop fields during weeding and in secondary forests near their swidden fields. Farmers mentioned that they randomly find few or many sources of *R. serpentina* when they rotate their swidden fields every year to fallows, which are used as a common resource by villagers without individual ownership.

Fig. 2 Distribution of roots and corms in each size category for (a) *R. serpentina* and (b) *A. bulbifer* in the allometric regression analysis.

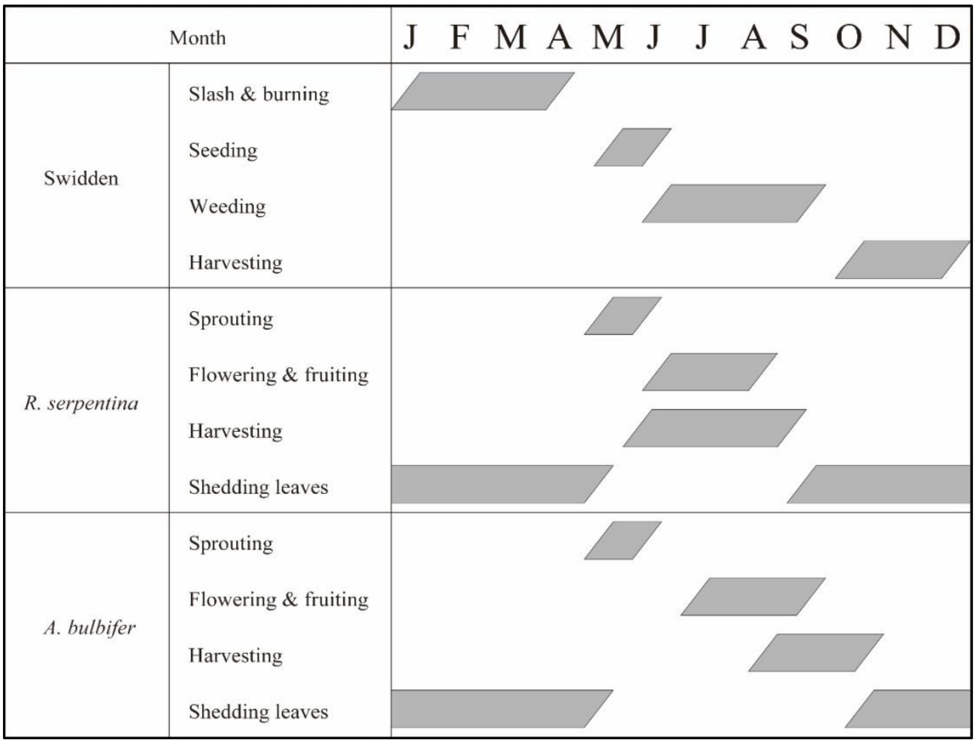


Fig. 3 Swidden calendar and phenology of *R. serpentina* and *A. bulbifer* within a year.

Table 1 Descriptive statistics of the dependent and predictor variables of *R. serpentina* and *A. bulbifer* plant samples in the allometric model establishment. SD = standard deviation.

	R. serpentina Mean (±SD), n = 69	*A. bulbifer* Mean (±SD), n = 69
Stem diameter at ground level (cm)	0.4 (±0.23)	3.1 (±1.74)
Stem height (cm)	10.7 (±7.61)	89.0 (±36.93)
Length of the longest leaf (cm)	20.0 (±8.05)	55.4 (±24.84)
Root length/corm diameter (cm)	40.0 (±18.13)	14.9 (±6.89)
Fresh root weight/ fresh corm weight (g)	34.3 (±30.21)	733.7 (±1071.52)
Number of bulbils on the leaflets of plants	-	16.0 (±19.31)

The roots of *R. serpentina* are easily broken, and the entire roots, which are as long as 40.0 (±18.13) cm (Table 1) and taper to their base as shown in Fig. 4c, are difficult to excavate. However, the length of the roots is not important for selling products, but their weight is measured for NTFP products. Therefore, collectors never mind broken roots, and they do not try hard to excavate complete roots, which is exhausting and time-consuming. When swidden fields are weeded, farmers collect *R. serpentina* roots using agricultural tools, such as a scooper and knife (Fig. 4b), if the use of such tools will not disturb cultivated upland rice, sesame, and cotton. Usually, farmers keep *R. serpentina* in swidden fields when they find it during weeding and have no chance to collect it, but they cut its aboveground parts if it is likely to disturb cultivated crops. Farmers recognize that *R. serpentina* will re-establish itself during the current rainy season or certainly during the following rainy season, even if they cut its aboveground parts, because the woody stock of the roots remains underground. They realize that the remaining roots will develop and become NTFP resources in the following years. Thus, some farmers are conscious of swidden fields with high stocks of *R. serpentina* during the cropping season, and they often search for places to collect the roots during the subsequent fallow stages.

When buyers come in the beginning of June, farmers start collecting *R. serpentina*, and the collection season ends in 2 months because the available resource becomes scarce and the remaining plants shed their leaves and are difficult to find. At the end of the collection season, only sporadic individual plants remain, rather than a high density of plants in a spot that is usually discovered during the early rainy season. Under these circumstances, farmers' interests shift to the collection of *A. bulbifer* during the late rainy season because searching for and excavating a small amount of *R. serpentina* that is distributed in a large space is inefficient.

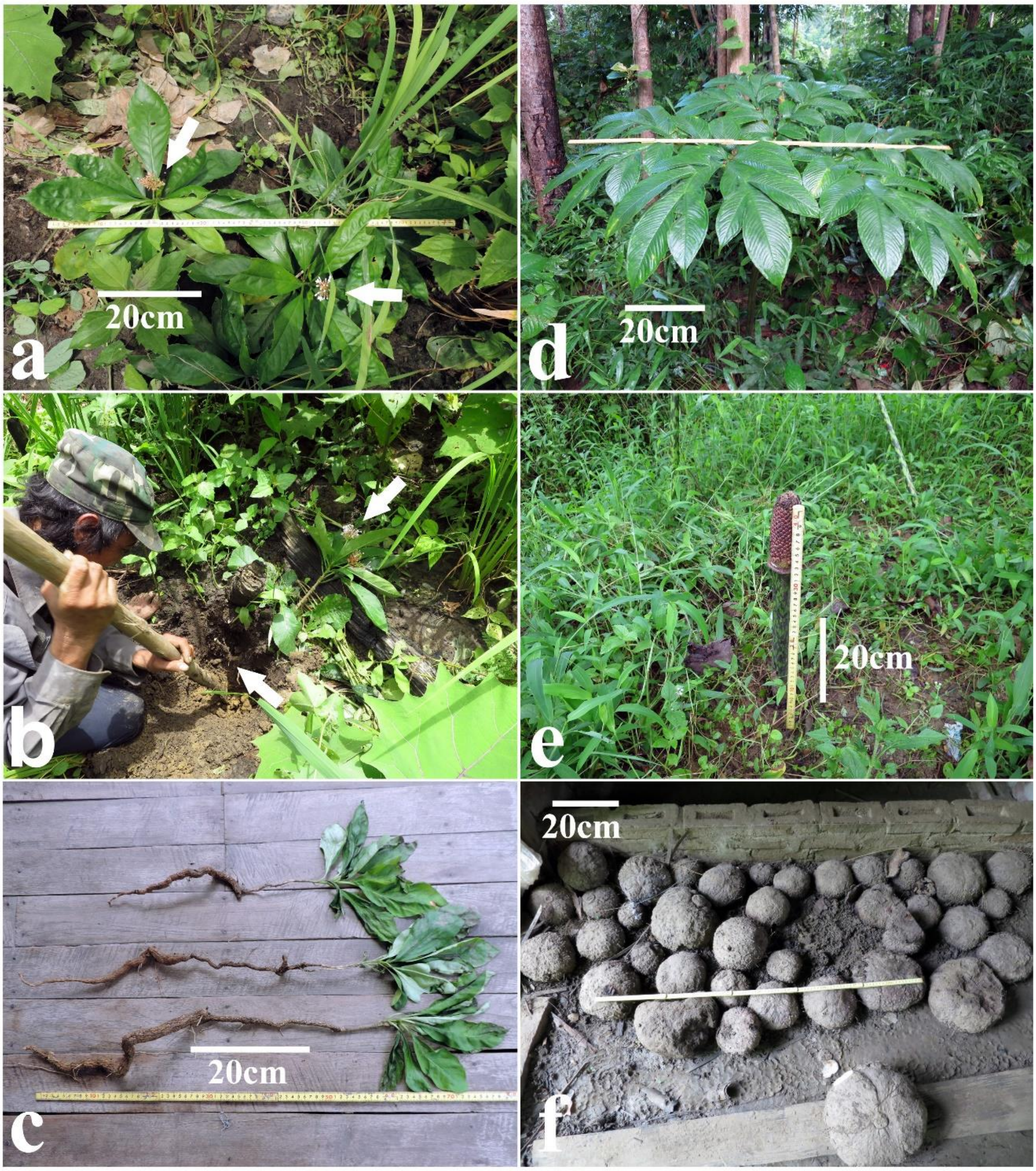


Fig. 4 (a) *R. serpentina* in a swidden field; (b) a swidden farmer excavating the roots of *R. serpentina*; (c) *R. serpentina* roots after harvest; (d) *A. bulbifer* in a fallow forest; (e) an *A. bulbifer* plant at the fruiting stage; (f) marketable *A. bulbifer* corms in various sizes. Arrows in white indicate the aboveground and underground parts of *R. serpentina*.

Gathering *A. bulbifer* corms starts just after the peak *R. serpentina* season (Fig. 3). The seasonality and annual growth characteristics of *A. bulbifer* are similar to those of *R. serpentina* (Fig. 3); however, its flowering and fruiting (Fig. 4e) are not annual, but alternate during a reproductive phase that occurs within 3 to 5 years after maturity, although it varies with species and environmental conditions such as light intensity. The corms of *A. bulbifer* remain as an underground stock during the dry season after the aboveground part has disappeared.

According to the local people, there are marketable and unmarketable species of *Amorphophallus*, the former of which has bulbils on its leaflets (*A. bulbifer*) (Fig. 4d), while the latter lacks bulbils (*A. napalensis*). Color variation in reddish and whitish corms was observed among the collected corms of *A. bulbifer*. The reddish corms are in greater demand than the white ones, although both are marketable. There were several bulbils on the leaflets of *A. bulbifer* (Table 1), ranging from one to 80 among the 69 plant samples, at different vegetative phases because mature plants have considerably more bulbils than juvenile plants that regenerated recently from bulbils or seeds. During the next growing season, new plants can become established from bulbils that have dropped to the ground. Stems with whitish green or dark purple stripes were found to be as high as 174.0 cm, and they had an average height of 89.0 (±36.93) cm (Table 1). Because its shade will considerably affect swidden crops, farmers usually cut the stem of *A. bulbifer* when weeding swidden fields.

Collecting *A. bulbifer* corms is easier than collecting *R. serpentina* corms because they can be excavated at shallow depths using a knife. The weights of collected corms (Fig. 4f) were measured, and the minimum size of a single marketable corm was approximately 1 kg. Corms were collected from various plant stages, ranging from juveniles to the flowering stage, which have different sized corms (Fig. 2b), with the heaviest being 4.8 kg. Farmers also have local knowledge regarding the best time, the late rainy season, to collect large *A. bulbifer* corms. Similar to *R. serpentina*, farmers are aware that *A. bulbifer* in swidden fields can be obtained in future harvests in fallow forests, although they cut its stem to prevent its shade from interfering with cultivated crops, without collecting it in the current swidden field. Mostly, farmers do not collect *A. bulbifer* in swidden fields because excavating a corm as large as 1 kg will damage other cultivated crops. Thus, they search mainly for the plants in secondary forests (Fig. 4d) near their swidden fields because they can frequently access fallow and ridge forests while staying and working in their swidden fields. However, people do not enter young fallows, such as 1- to 4-year-old fallow forests, because of dense scrub comprising *Chromolaena odorata*, *Thysanolaena maxima*, and creepers, which make it difficult to find and excavate *R. serpentina* and *A. bulbifer*. Swidden farmers are aware of the habitats of these species in forests, as well as the medicinal value of *R. serpentina* through knowledge obtained from prior generations; however, the current generation does not use these species for medicine or food, but only gathers them to sell.

Sales of these species were introduced by lowland people who come to buy plant products to trade in urban areas. Collection of the two products started in the ST village approximately within the last 15 years, while it started approximately 7 years ago in the KC village. Despite people collecting NTFPs annually, *R. serpentina* and *A. bulbifer* plants obviously occurred in swidden fields, fallow forests, and ridge forests.

4.2. Allometric model

In a simple linear regression analysis, a positive relationship was observed between underground biomass and each of the aboveground vegetative components (Table 2). With the highest coefficient of determination, the length of the longest leaf explained the accumulation of the underground biomass of *R. serpentina* (R^2 = 0.64, P<0.001), and stem diameter did the same for *A. bulbifer* (R^2 = 0.92, P<0.001) (Fig. 5). Accordingly, the following allometric equations were used to predict the root and corm masses, which comprise the underground biomass of these species:

Equation (i) for *R. serpentina* $\log RW = -3.19 + 2.10 \log LL$

Equation (ii) for *A. bulbifer* $\log CW = -2.50 + 2.47 \log SD$

where RW = root weight; LL = the length of the longest leaf; CW = corm weight; and SD = stem diameter at ground level

The results of the linear regression are consistent with the local knowledge of swidden farmers who mentioned that large *R. serpentina* roots come mainly from well-grown plants with vigorous leaves, regardless of plant height, and that huge *A. bulbifer* corms can usually be collected from plants exhibiting vigorous stem growth, as evidenced by stem diameter.

Table 2 Linear relationships of underground biomass to the length of the longest leaf (LL), stem diameter at ground level (SD), and stem height (SH) of *R. serpentina* and *A. bulbifer*.

Dependent variables	Explanatory variables (n = 69)	R^2 value	Standard error of the estimate
Root biomass of *R. serpentina* (g)	LL (cm)	0.64***	0.92
	SD (mm)	0.60***	0.98
	SH (cm)	0.32***	1.26
Corm biomass of *A. bulbifer* (g)	LL (cm)	0.75***	0.81
	SD (mm)	0.92***	0.47
	SH (cm)	0.66***	0.97

*** Significant

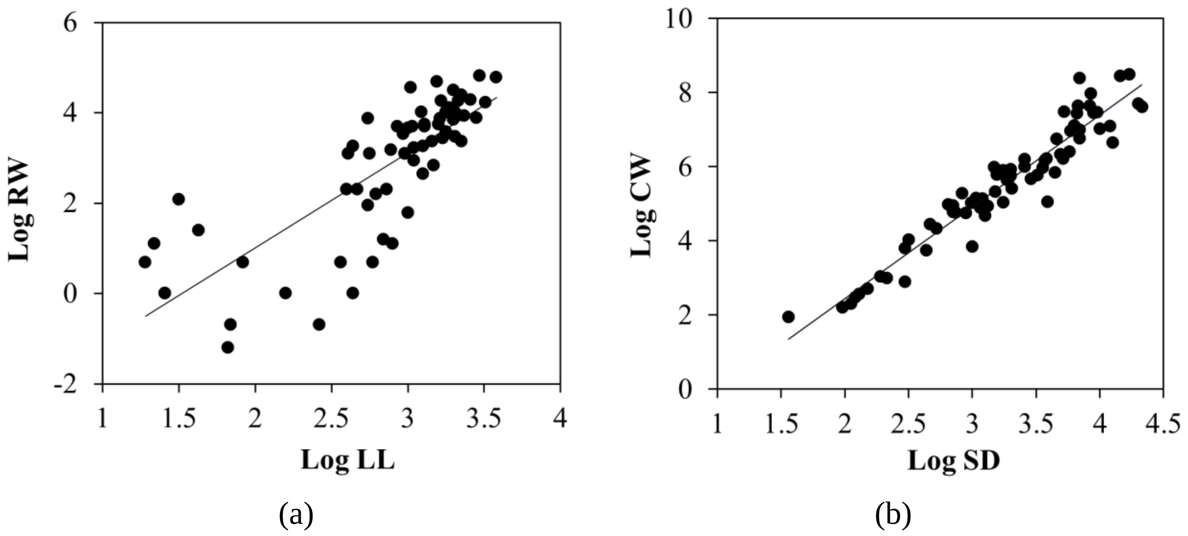
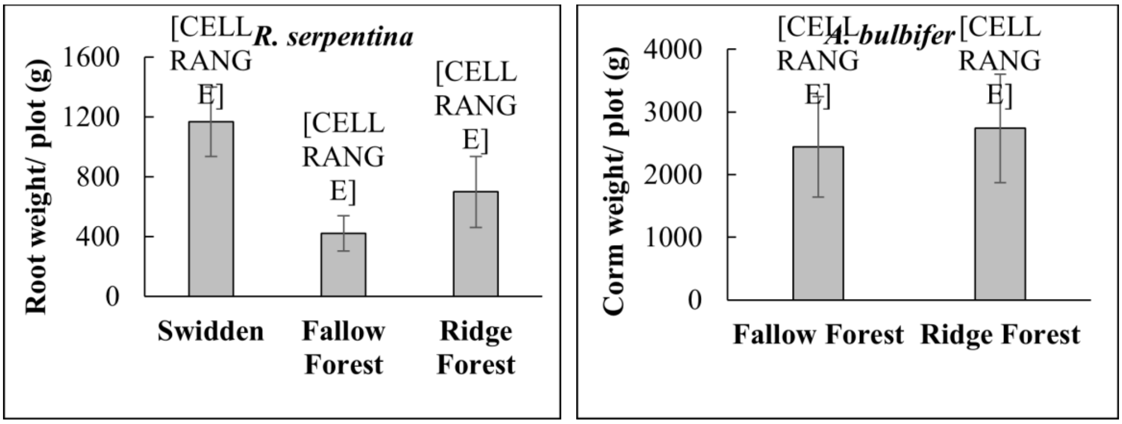


Fig. 5 Linear regression at the logarithmic scale between (a) the length of the longest leaf (LL) and the fresh weight of roots (RW) of *R. serpentina* (n=69, R^2=0.64) and (b) stem diameter at ground level (SD) and the fresh weight of corms (CW) of *A. bulbifer* (n=69, R^2=0.92).

4.3. Underground biomass accumulation among different habitats

The root biomass accumulation of *R. serpentina* was highest in swidden fields (Fig. 6a) followed by ridge forest and fallow forest habitats (Kruskal–Wallis test, χ^2 =17.249, P<0.05). In fallow forests and ridge forests, canopy species comprised mainly bamboos and tree species such as *Mitragyna* spp., *Dalbergia* spp., and *Albizia* spp., as well as *T. grandis*. The moderate correlation between the canopy cover and leaf length of *R. serpentina* (Pearson's correlation = −0.612, P<0.05) indicated that canopy openness in swidden fields positively affected plant growth.

Fig. 6 Estimations and comparisons of the underground biomass accumulation of (a) *R.*



(a) (b)

serpentina and (b) *A. bulbifer* among different habitats (lowercase letters indicate significant differences).

The height of *A. bulbifer* can reach 2 m or more; therefore, farmers usually cut these plants when weeding swidden fields so their shade does not interfere with other crops. The very small number of *A. bulbifer* individuals found in swidden fields did not allow a valid analysis of its biomass accumulation and density, although its occurrence was confirmed by farmers and field observations. There were no significant differences between *A. bulbifer* biomass in fallow forests and ridge forests (Mann–Whitney test, Mann–Whitney U = 440.000, P>0.05) (Fig. 6b). In addition, no correlation was observed between stem diameter and canopy cover for this species. Among the plots in fallow forests and ridge forests, canopy cover varied from 15% to 90% and 25% to 95%, respectively, similarly comprising bamboos, shrubs, and trees.

5. Discussion

5.1. Differences in underground biomass accumulation between swidden fields and forests

The morphology of *R. serpentina* is the same as that described by botanical studies in its distribution regions (Dey and De, 2010; Soe et al., 2004; Monachino, 1954). *Rauvolfia serpentina* is a light-demanding species that occurs naturally in open and deciduous forests under partially shady conditions (Dey and De, 2010; Sheldon et al., 1997). A difference in leaf length (a predictor variable) between the swidden and forest plots was expected based on the better growth performance of *R. serpentina* at the swidden sites, because of the more open canopy and higher light intensity in swidden fields, compared with forests (Cai et al., 2009). However, variations in the response of *A. bulbifer* growth to canopy cover in fallow and ridge forests were not significant, probably because of similar habitat conditions according to the canopy cover range, which was similar between these forests.

The petiole color, leaflet shape, and flowering season of *A. bulbifer* in this study are similar to those in hilly regions of India (Chakpram et al., 2014; Jaleel et al., 2012). *Amorphophallus* species generally prefer shaded conditions, but their growth may not be explained simply by canopy cover alone in this study, because it also varies with the age of the mother corm (Budiman, 2012; Santosa et al., 2006).

5.2. *Rauvolfia serpentina* and *A. bulbifer* establishment in fallow vegetation

People have conducted wild harvests of NTFPs from *R. serpentina* and *A. bulbifer* based solely on their local knowledge. For example, the mother corm of *Amorphophallus* species has a dormancy period during winter or the dry season, after which a new corm grows during the rainy season, which subsequently reaches the mother corm stage (Zhang et al., 2010). In this regard, local knowledge of the best harvest time was consistent with the dormancy and growing period of this species.

Old fallow forests and ridge forests remaining between swidden fields seem to be sites that villagers visit frequently to collect NTFPs. Early herbaceous fallow stages are almost impenetrable, and human and domestic animals do not enter fallows because very young fallow vegetation is dominated by densely growing weeds, mainly *C. odorata*, in MDFs (Chan et al., 2013; Fukushima et al., 2007; Schmidt-Vogt, 1999). The herbaceous fallow stage will last for approximately 3 years, which may allow *R. serpentina* and *A. bulbifer* to adapt to dense, weedy conditions by retaining their root and corm stocks as undisturbed, underground NTFP sources. During these years, people cannot enter very dense fallow vegetation to collect *R. serpentina* and *A. bulbifer*; consequently, these species may have a chance to restore their underground biomass. During the later fallow stages, tree growth facilitates weed control (Rerkasem et al., 2009), which provides a favorable habitat for the aboveground growth of *R. serpentina* and *A. bulbifer*.

During this process, both ecological and anthropogenic factors support the establishment of these species in fallow vegetation. Mother corms of *A. bulbifer* are collected from individual plants as NTFPs; however, the aboveground parts of mature plants are left in the field. The availability of reproductive bulbils that have dropped to the ground is supposed to be an important facilitator for sustaining the growth of this species. In addition to the bulbils on the leaflets of *A. bulbifer*, many seeds are also available during the reproductive phase, an alternate maturity stage of mother corms, and their germination rate is almost 100% (Zhang et al., 2010). In the case of *R. serpentina*, human harvest practices play a more important role because the remaining part of the root is broken at the time of harvest, which considerably supports the availability of root biomass a few years later. This phenomenon was also found to occur during the harvesting of other medicinal plant species, for example, goldenseal (*Hydrastis canadensis*) and black cohosh (*Actaea racemosa*) exhibit interwoven clonal growth, in which the remaining root fragments are thought to contribute to vegetative recovery (Chamberlain et al., 2013). Furthermore, *R. serpentina* flowers and fruits annually (Dey and De, 2010), and the plants that farmers keep in swidden fields that are not harvested can probably provide a seed source for germination during the subsequent fallow stages in the following years. People often collect *R. serpentina* and *A. bulbifer* at the later stages of fallowing. Even though fallow forests may suffer from harvest pressure, there will be a cycle of opening new swidden plots, in which the site will reach the herbaceous fallow stage after 1 year of cultivation; thus, it will be excluded from NTFP harvest pressure for several years. As discussed by Ticktin (2004), seasonal timing, harvest-specific practices, land use context, and environmental conditions, in combination, affect the tolerance of *R. serpentina* and *A. bulbifer* to harvesting in MDFs.

5.3. *Rauvolfia serpentina* and *A. bulbifer* are valued as NTFPs in a swidden system

NTFPs from *R. serpentina* and *A. bulbifer* have lower monetary values than timber, and they are rarely considered in agroforestry and community forestry plantation programs that cultivate only woody species. Unit prices (obtained by personal communication with local buyers and villagers) in the study villages are approximately 1.2 and 0.1 United States dollars (USD) for 1 kg of *R. serpentina* and *A. bulbifer*, respectively, from which a person can obtain a maximum of 50 USD for both products within a harvest season, whereas the daily labor wage for a person is approximately 2.5 USD. The prices of these products can increase up to five to 10 times in lowland markets after drying the products and sending them to city markets. Compared with the price of teak timber, 210 to 840 USD for 1 Mg (equivalent to 500 to 2,000 USD for 1 m^3) (Keogh, 2008), *R. serpentina* and *A. bulbifer* have very little monetary value. However, these products are available annually to swidden farmers in an accessible form, whereas planted teak, for instance, will take as long as 40 years to reach a marketable size. Thus, fallow vegetation will not be able to provide a good source of timber; however, it can be managed for valuable sources of NTFPs by local swiddeners, thereby generating cash incomes when livelihoods that are dependent on agroforestry systems cannot be secured by subsistence agriculture (Maung and Yamamoto, 2008).

In fact, in the swidden system, annually-opened cultivation plots comprise only 2% to 3% of the total Karen area that is subjected to swidden land use (personal communication); thus, most of the area comprises fallow forests and ridge forests. Based on the underground biomass estimates of *R. serpentina* and *A. bulbifer* in the swidden and forest plots, NTFP resources stored in these forests were estimated roughly as 100 Mg for *R. serpentina* and over 400 Mg for *A. bulbifer*, while *R. serpentina* resources in swidden fields can be approximately 3 Mg. The role of forest regrowth in traditional swidden systems, which provide a diversity of plant species that are valuable for local livelihoods (Durno et al., 2007; Rerkasem et al., 2009), was also distinct in this study, as it included the local use of forest resources for NTFPs during the implementation of timber plantation programs. Adaptation to slashing and burning, as well as shady conditions, in the annual growth cycle of these species further supports the possibility of their cultivation in community and agroforest plantations to generate alternative cash incomes from NTFPs in vast areas of MDFs.

6. Conclusions

Rauvolfia serpentina and *A. bulbifer* co-exist with slashing and burning in swidden systems, as well as seasonal dryness, in an MDF in the Bago Mountains owing to both ecological and anthropogenic factors. Slashing and burning associated with swidden systems create a suitable environment, with high light intensity under the opened canopy, for *R. serpentina*. Densely growing herbaceous vegetation at the early fallow stages prevents swiddeners' harvest activities and enhances biomass recovery of *R. serpentina* and *A. bulbifer*. The broken root fragments of *R. serpentina* and the reproductive bulbils of *A. bulbifer* leaves left after the harvest in swidden fields and forests facilitate the establishment of the next generation of these plants. Harvest pressure on these two NTFPs in the wild can be lessened by cultivating them, since there have been some cases of *R. serpentina* cultivation in the tropics (Dey and De, 2010; Sheldon et al., 1997), as well as the establishment of a plantation of *Amorphophallus* species in the Chin State of Myanmar (Chan and Takeda, 2016).

The swidden environment, with a long fallow period, in the Bago Mountains is one of the few and important habitats for *R. serpentina* and *A. bulbifer*. However, the regional trend of the decline of swidden systems throughout mainland Southeast Asia (Rerkasem et al., 2009) may also occur in the Bago Mountains, Myanmar, because of the increase in permanent agriculture and community forestry. Permanent agricultural production of commercial crops, such as sesames and beans, has been developing in the foothills of the Bago Mountains for more than 20 years. When the market for *R. serpentina* started in the lowlands, most of its production came from frontier forests in the foothills. Nevertheless, the market and production area gradually shifted to upland areas 15 years ago, probably because of plant resource scarcity and habitat changes in frontier forests.

Community forestry also began very recently (in 2014) in the upland area of the Bago Mountains following the allocation of plots to households in user groups that plant trees, particularly teak, for timber production. Because it takes a long time for teak to reach a marketable size, undergrowth NTFPs, such as *R. serpentina* and *A. bulbifer*, can be incorporated into an agroforestry system to generate a periodic cash income prior to timber harvests. Further investigations of the survival traits and reproductive strategies of these species are important for determining the appropriate conservation measures for these valuable plants in swidden fallows and MDFs.

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