ECONOMIC IMPORTANCE OF OLEORESIN (*DIPTEROCARPUS ALATUS*) TO FOREST-ADJACENT HOUSEHOLDS IN CAMBODIA

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ABSTRACT

The genus *Dipterocarpus* is the main source of marketable liquid oleoresin, which is important as a source of income for forest communities in Southeast Asia. However, deforestation and illegal as well as legal logging pose a threat to resin yielding species (*Dipterocarpus* spp.). There is still more to be learned about resin yield, harvest techniques, and the importance of resin to local livelihoods. This study quantifies yields from one of the most intensively tapped resin species, *Dipterocarpus alatus,* and estimates household incomes from resin extraction in Cambodia. A total of 43 resin tappers were interviewed and 100 resin trees were measured to examine factors affecting resin productivity. Forest-adjacent households were highly dependent on resin extraction for cash income. Households spent an average of 105 days annually on resin extraction. The mean annual household gross-income derived from liquid resin was USD 3,236. Solid resin contributed only a small part of household incomes except for the most remote and isolated village, Spong, in which solid resin contributed significantly to the gross-income. Resin trees yielded an average of 18 liters of oleoresin per year according to interview findings, and yield was positively correlated with the size and health of the tree, and with proximity to watercourses. Finally, yield was influenced by season and condition of the tapping-hole.

Keywords: *Dipterocarpaceae*, essential oil, extractivism, forest dependence, indigenous people, Kuy, NTFP, rainforest, *Shorea*, Southeast Asia

INTRODUCTION

The Dipterocarpaceae is one of the most important tree families in Southeast Asia. Trees belonging to this family form some of the most vast forest formations on earth, the dipterocarp forests (APPANAH & TURNBULL, 1998). Dipterocarps are dominant in the tropical timber markets, especially species of the genera *Dipterocarpus*, *Hopea*, *Shorea* and *Vatica*, which provide valuable hardwood. Less is known of the commercial importance of non-timber forest products (NTFPs), but dipterocarp resin is extracted for cash income by forest-adjacent communities (HEYWOOD *ET AL*., 2007) and is considered one of the most important NTFPs of forest-adjacent communities in Southeast Asia (ANKARFJÄRD & KEGL, 1998; EVANS *ET AL*., 2003; BAIRD, 2009; LUU & PINTO, 2007; BAIRD, 2010; LÆGAARD, 2010). The resin from dipterocarps can be classified into two categories: oleoresin (liquid resin) and solid resin. Liquid resin is extracted mostly from *Dipterocarpus* species in Laos, Thailand, Vietnam and Cambodia, with

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D. alatus being the main source (Luu & Pinto, 2007). In Malaysia liquid resin is collected mostly from *D. kerrii* (Evans *et al.*, 2003). Studies also show that resins from other species of the family Dipterocarpaceae, such as *Anisoptera thurifera* (Blanco) Blume, support the livelihoods of people in parts of the Philippines (Ella, 1996). Resin is used domestically for lighting and sealing boats, and commercially for paints, varnishes and perfume fixatives (Evans *et al.*, 2003).

Solid resin can be collected from the genera *Shorea*, *Hopea* and *Vatica*. Solid resin is less widely used and less economically important than oleoresin (Evans *et al.*, 2003; Luu & Pinto, 2007).

There is a long history of resin tapping in Cambodia by different ethnic groups (Evans *et al.*, 2003; Baird, 2009, 2010). Commercial tapping in the country has been done since the 1930s and supposedly earlier, but families have gathered resin from the trees for subsistence purposes for even longer (Evans *et al.*, 2003). Resin trees are protected according to the National Forestry Legislation (Law on Forestry, Ministry of Agriculture, Forestry and Fisheries 2002). However, widespread illegal and legal logging, conversion of forest land, and lack of law enforcement has led to the loss of thousands of resin trees across the country in the past decades (Community Peace-Building Network [CPN], 2014; Evans *et al.*, 2003). Resin trees can be legally cut down if villagers are given permission, want to sell them, or if trees are not being actively tapped (Evans *et al.*, 2003; Law on Forestry, Ministry of Agriculture, Forestry and Fisheries 2002). Thus, resin trees do not have strong legal protection and currently the most important resin-yielding species, e.g. *D. costatus* and *D. alatus,* are listed as Endangered on the IUCN red list (International Union for Conservation of Nature [IUCN], 1998).

Lowland forests were once the most common vegetation types in Cambodia, but are exposed to severe degradation and are highly threatened by deforestation (Baird, 2009; Theilade *et al.*, 2011). Cambodia's significant reserves of high-value forests present an important economic resource, the sustainable use of which would be of considerable benefit to the country and contribute to national development (World Bank, 2000; International Tropical Timber Organisation [ITTO], 2006). Nevertheless, studies show that forests in Cambodia are facing the fastest acceleration of tree cover loss in the world (World Resources Institute [WRI], 2015). Cambodia has a system of protected areas, but there is a clear lack of protection for lowland evergreen forests (Olsson & Emmett, 2007). More recently, Economic Land Concessions (ELCs) have been identified as the largest threat to forests in Cambodia, as well as having disastrous consequences for local communities (Strange *et al.*, 2007; Global Witness, 2013). ELCs are long-term leases for industrial agriculture, with rubber plantations being one of the most widespread industries within ELCs in the country (Global Witness, 2013). In the 1990s the government of Cambodia granted around 40 logging concessions covering more than 7 million ha, corresponding to 39% of Cambodia's land area (Global Witness, 2009). By 2013 an estimated 73% of Cambodia's arable land was leased for ELCs (Global Witness, 2015). According to Cambodia's Land Law from 2001 (cf. article 59), land concessions cannot exceed 10,000 ha (The Land Law, Ministry of Land Management, Urban Planning and Construction 2001), but there is a loophole in the system which is often utilized to get around the rule (Neef *et al.,* 2013). Furthermore, many ELCs have been granted on land that belongs to indigenous peoples, whose rights are specified in articles 23 and 24 of the Land Law. Often farmers and local communities are not considered as legal landholders, and frequently concessions are granted without consultations with the local people affected by the concessions. The initial impact on the livelihoods of local people has been substantial, with rice fields, cattle pastures, rivers and roads being lost to concessions (NEEF *ET AL.,* 2013). ELCs were found to have severe negative impacts on both household incomes and environmental incomes, e.g. from NTFP collection and sale (JIAO *ET AL.*, 2015). Furthermore, illegal logging is often related to ELC activities as illegal timber is laundered through the land concessions. Prey Lang lowland evergreen and semi-evergreen forests are characterised by a high density of commercial timber species, rich biological diversity and provision of NTFPs for forest-adjacent communities (MCKENNEY *ET AL.*, 2004). More than 250,000 people live in 340 villages within 10 km of Prey Lang and depend on the forest to sustain their livelihoods (OLSSON & EMMETT, 2007; THEILADE & SCHMIDT, 2011). Oleoresin constitutes the most significant source of cash income for the indigenous Kuy (HAYES *ET AL.*, 2015), yet this income has never been comprehensively quantified. To measure the impact of land grabbing on local welfare, it is necessary to understand the economic importance of natural resources to local economies. We use a case study of Prey Lang in central Cambodia to assess the importance of dipterocarp species for local household economies.

The overall aim of this study is to quantify the socio-economic value of *Dipterocarpus alatus* to local households through investigating 1) time spent on resin collection, 2) cash-income from resin extraction and associated costs, and 3) resin yield per tree, and tree and site characteristics affecting resin productivity.

STUDY AREA

Cambodia has a population of 15.2 million with 71% living in rural areas as of the year 2014 (National Institute of Statistics [NIS], 2015). The average household income was USD 135 per month (1.02/day/cap) in 2009 (NIS, 2010), and the rural national poverty line in 2006 was estimated as USD 0.44/day/cap (NIS, 2006).

Prey Lang is the largest lowland evergreen to semi-evergreen forest complex in Cambodia and probably in the entire Indo-Burma biodiversity hotspot (THEILADE *ET AL.*, 2011). The forest is located west of the Mekong River in the central plains of the country (OLSSON & EMMETT, 2007) (Fig. 1). Prey Lang forest complex covers 500,000 hectares, comprising a primeval area of 80,000–100,000 ha (THEILADE *ET AL.*, 2011). The Prey Lang is a mosaic of seven different forest types. The evergreen and semi-evergreen forests are the most biologically valuable, where large Dipterocarp species dominate the canopy (MCDONALD, 2004; THEILADE & SCHMIDT, 2011). A map of Cambodia's forest cover and the study area is shown in Figure 1.

METHODS

Data Collection

The data collection consisted of two parts. Firstly, we conducted semi-structured interviews with 43 resin tappers living in four forest-adjacent villages (Thmea, Phneak Roulek, Spong and Srae Veal) (Fig.1, Table 1). Secondly, we undertook species identification and recorded tree and site characteristics of 100 resin trees and their yields. The interview survey and field study were conducted during 8–15 December 2014. Since the month of December was not yet finished when the interviews took place, the data on resin extraction for December 2014 was an estimate based on what the interviewees had already collected in that particular month and what they expected to collect during the rest of the month. We selected villages based on 1) proximity to the forest over a forest type gradient (semi-evergreen to evergreen), and 2) known engagement in resin extraction. Field identifications and herbarium work was done by the late J. F. Maxwell, Chiang Mai University Biology Department Herbarium (CMUB).

The term "household" is used in this paper for a group of people, mostly relatives, who live in the same house and are economically interdependent. The term "tapping-event" refers to the situation where a resin tapper harvests resin from one tapping-hole in a tree.

We interviewed 43 people from four villages about oleoresin and solid resin extraction. Questions included time spent on resin extraction, amounts extracted, selling prices, associated costs, and species and number of trees the household owned and tapped. Details regarding seasonal variations in extraction yields and selling prices were also recorded. Wealth categories of the interviewees were assigned based on the roof style of their houses (palm leaves, corrugated iron, or fired-clay tiles). This is a common approach to specify wealth classes in Cambodia, and was applied in a previous study carried out in Prey Lang (LÆGAARD, 2010).

We recorded yield and tree characteristics for 100 resin trees in evergreen forest, mainly of the species *D. alatus* (Fig. 1). Trees were selected by following two resin tappers on a resin collection trip. Seventeen measurements and observations were recorded for each resin tree. These included resin yield, growth site (i.e., forest type), distance to watercourse, tree size (diameter at breast height [DBH]), height, crown width, health, and condition of the tapping-hole. The tapping-hole condition was assessed based on 1) extent of burn damage above the tapping-hole caused by repeated burns, and 2) fungal growth and rot inside the hole, and the tapping-hole was classified as being in a (1) good, (2) medium or (3) poor condition (abandoned or nearly so). With regard to the health condition of the tree, the following categories and indicators were used: (1) good condition (tree with no sign of diseases or broken branches); (2) medium condition (main parts of the crown healthy but larger branches broken, branches without leaves or leaves withering, or stem with rotting holes and/or bark stripped off); (3) poor condition (larger parts of crown dead). Measurements of height, crown width and health were in some cases difficult to conduct, due to dense surrounding vegetation.

RESULTS

The 43 interviewees extracted liquid resin from three different species of *Dipterocarpus* and solid resin from two species of *Shorea*. In Table 2 the species are listed according to frequency of mention in the interview survey, with *D. alatus*, *D. intricatus* and *D. costatus* being the most frequently mentioned species.

All interviewees collected liquid resin and 13% of them also collected solid resin. No one collected only solid resin. Eleven interviewees belonged to the lowest wealth class (roof of palm leaves), 29 belonged to the medium wealth class (roof of corrugated iron) and three interviewees belonged to the highest wealth class (roof of fired clay tiles). The lowest wealth class owned more resin trees (430 trees/household) than the two other wealth classes. The mean age of the interviewees was 45 years (SD = 11). Tapping oleoresin is a physically demanding job mostly done by men, while women mainly collected solid resin. Trees producing liquid resin were privately managed, whereas trees producing solid resin were considered common property.

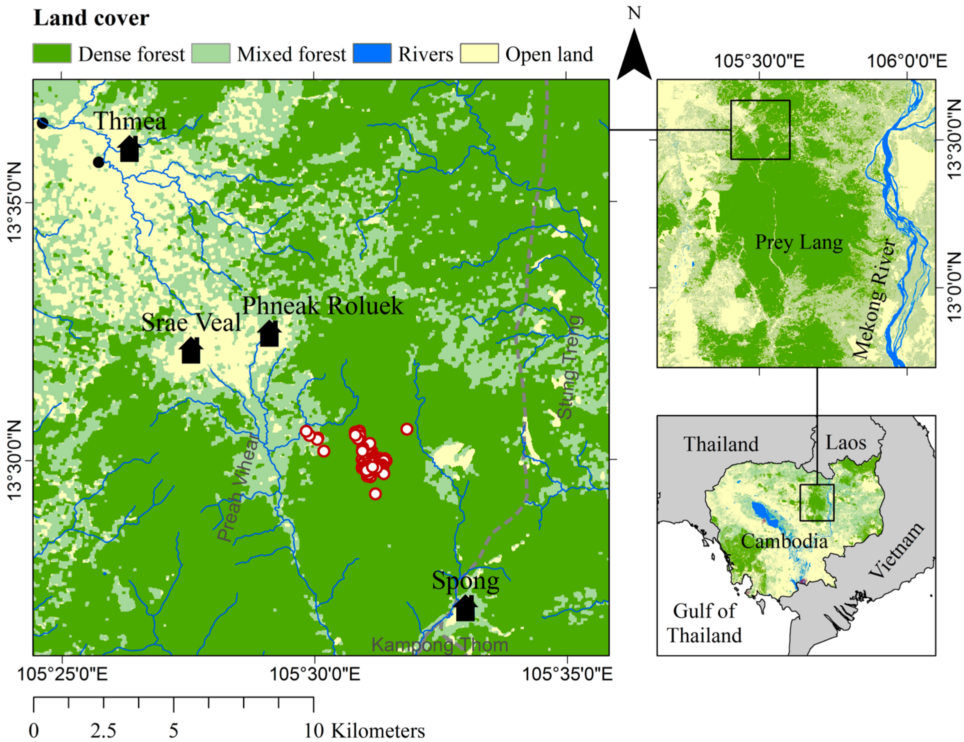

Figure 1. Map of study site with villages (black cottage icons) and locations of the resin trees (*Dipterocarpus alatus*) shown with white/red circles. Black dots indicate villages not included in the survey. (Data source: Open Development Cambodia, 2014).

Table 1. Demographic data on studied villages in Prey Lang. Population and household figures are extracted from CPN (2014).

Village	No. of Interviewees (*n*)	Gender distr. in study (F / M) (*n*)	Total population (*n*)	Total Households	Interviewed households (%)
Thmea	8	3 / 5	2,024	358	2.2
Phneak Roulek	12	5 / 7	578	94	12.8
Spong	13	1 / 12	803	163	8.0
Srae Veal	10	1 / 9	497	218	4.6
Total	**43**	**11 / 34**	**3,902**	**833**	**5.2**

Table 2. Resin tree species recorded in the interview survey. Results from two pilot interviews are included. Field identifications and herbarium work was done by the late J. F. Maxwell, at CMUB Herbarium, Thailand.

Scientific name	Khmer name	Liquid (L) or Solid (S)	No. of interviewees tapping resin from the species (*n*)
Dipterocarpus alatus Roxb. ex G. Don	Cheuteal	L	30 (67 %)
Dipterocarpus intricatus Dyer	Trach	L	16 (36 %)
Dipterocarpus costatus G. Don	Cheuteal Kreuh/ Cheuteal Bang Koye	L	15 (35 %)
Shorea guiso (Blanco) Blume	Chor chong	S	5 (10 %)
Shorea obtusa Wall	Pchuek Odorm	S	1 (2 %)

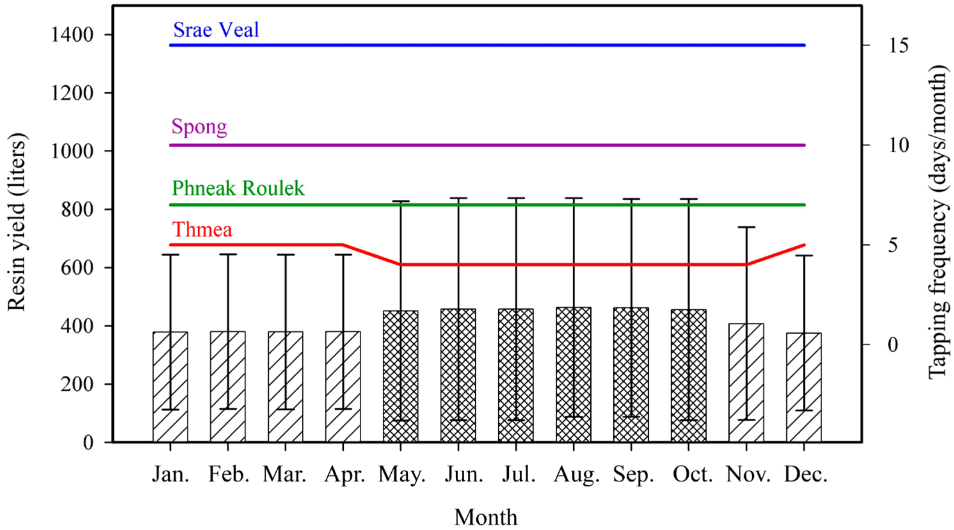

Figure 2. Yield of resin per household in 2014 (primary Y-axis columns with SD in bars) and tapping frequency (secondary Y-axis, thick lines) during dry season (November–April) and rainy season (May–October).

Labour Input, Resin Yields and Income

A mean of 105 tapping days (SD = 70) were spent per household per year (Table 3). Resin tappers spent on average 2.2 days (SD = 1.3) on a single collection trip and most resin tappers stayed overnight in the forest. An average of 12,530 tapping-events (SD = 5,124) were conducted per household per year with the highest labour input occurring in Srae Veal (Table 3). The households were tapping all year round and the tapping frequency was constant throughout the year. However, the resin yields were highest in the rainy season between May and October and resin tappers gathered 20% more resin in the rainy season than in the dry season (Fig. 2).

Table 3. Socio-economic results based on the interview survey. Standard deviations are shown in brackets.

Villages	Time-consumption per household (days/yr)	Gross-income per household (oleoresin) (USD/yr)	Selling price (oleoresin) (USD /*l*)	Gross-income per resin tree (oleoresin) (USD /yr)	Gross-income per household (solid resin) (USD /yr)	Costs per household (USD/yr)	Owned resin trees per household (*n*)	Tapping-events per household (events/yr)
Thmea	51 (28)	998 (437)	0.72 (0.12)	9 (4)	-	86 (48)	117 (39)	4,906
Phneak R.	74 (26)	3,092 (2,223)	0.68 (0.06)	12 (4)	26 (33)	116 (80)	275 (142)	11,267
Spong	116 (59)	4,557 (2,564)	0.60 (0.07)	12 (3)	840 (306)	271 (282)	748 (606)	15,738
Srae Veal	180 (87)	3,482 (2,131)	0.66 (0.11)	15 (5)	-	70 (105)	335 (288)	18,209
Average	**105 (70)**	**3,236 (2,386)**	**0.66 (0.09)**	**12 (4)**	**-**	**146 (186)**	**402 (432)**	**12,530 (5,124)**

The highest monthly yield was collected in August (463 liters/household, SD = 376), and the lowest in December (375 liters/household, SD = 266), figure 2. Furthermore, the highest monthly yields were collected in the remote village Spong and the lowest yields in Thmea (Fig. 3). Resin trees were tapped approximately 50 times per year which gave an average yield of 18 liters per tree per year (Fig. 4).

The average time spent per tapping-event, i.e., to clean the tapping-hole, burn it, and scoop the resin into a container, was 4.10 min. The burning usually lasted 1–2 min. It took an average of 3 min to walk from one tree to the next. Thus, over the course of 2.5 days 100 trees were tapped spending 4.45 hr walking and 7 hr tapping. In total, 12 working hours were spent on collecting 57 liters of liquid resin. At a price of USD 0.66/liter of resin (2014 prices) this is equivalent to about USD 3/hr of work.

Gross-Income from Oleoresin

The mean selling price for a 30-liter container across villages was USD 20 (SD = 7), corresponding to USD 0.66/liter (Table 3). The selling price was 50% higher in the rainy season (USD 24 per container (SD = 7), or USD 0.79/liter) than in the dry season (USD 16 (SD = 4) per container, or USD 0.58/liter). The monthly resin incomes of the households in each of the four villages are shown in Figure 5. The columns show average monthly income for all interviewees for every month of the year. A single resin tree contributed a cash income of 12 USD/yr (SD = 4). The highest incomes per tree were observed in Srae Veal with 15 USD/yr (SD = 5) on average (Fig. 4; Table 3). The monthly household income from oleoresin was 74% higher in the rainy season compared to the dry season (Fig. 5). The total annual household gross–income from resin extraction was USD 3,236 per household (SD = 2,386) (Table 3). The remote village Spong had the highest average annual household income of USD 4,557 (SD = 2,564). The seasonal income fluctuations followed the same pattern in all villages, with the rainy season (May–Oct) offering the highest income (Fig. 5).

The main costs were petrol used for transportation on motorbike to/from the forest and containers for resin storage. However, almost half (42%) of the interviewees walked to the resin trees and therefore did not have any transportation costs. The mean annual costs were USD 146 per household (SD = 186), with the highest costs occurring in Spong (USD 271/yr) (Table 3).

Gross-Income from Solid Resin

Trees producing solid resin were considered a common pool resource, and exposed to less systematic extraction. Six out of 43 interviewees collected solid resin; two interviewees from Phneak Roulek, and four from Spong. Solid resin was usually gathered from *Shorea* species, mostly from *S. guiso* (Table 2). Moreover, solid resin was mostly collected by women. Interviewees from Spong collected 600–2,400 kg solid resin annually (Table 3). The selling price for solid resin was 0.5 USD/kg throughout the year. Incomes from solid resin were important in Spong with annual gross-incomes ranging between USD 360 and 1,200 per household (Table 3).

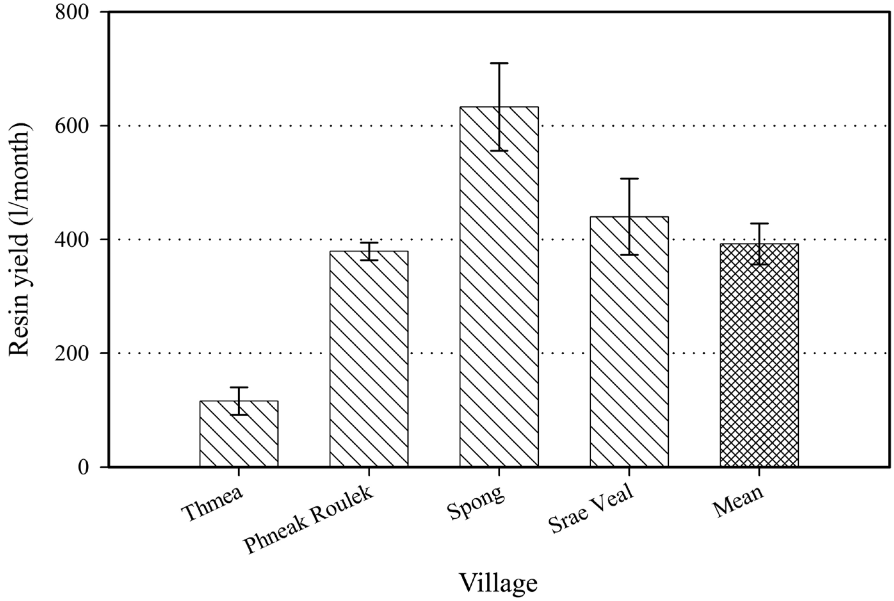

Figure 3. Monthly extracted resin yields per household (liters) with SD in bars in each village.

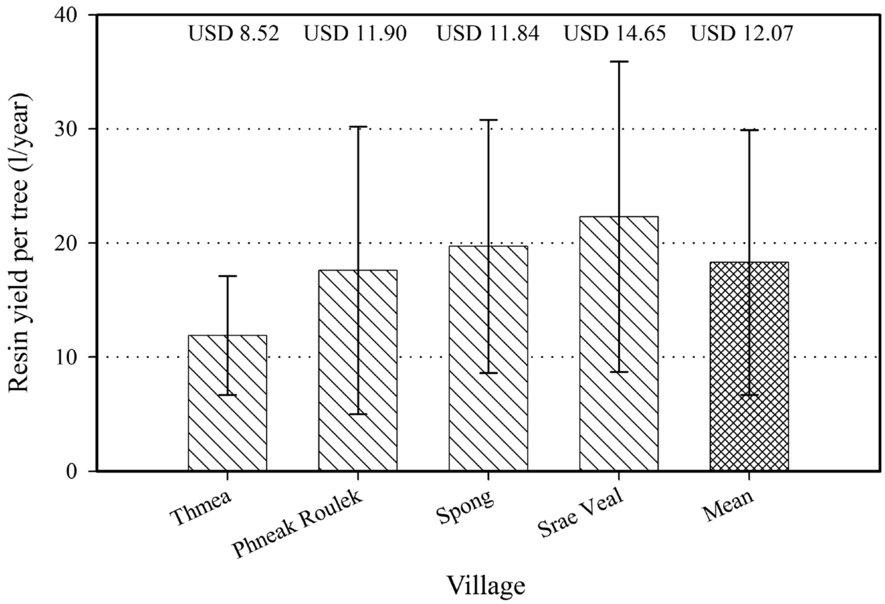

Figure 4. Annual extraction in liters per tree per household with SD in bars and annual resin-value per tree in each village.

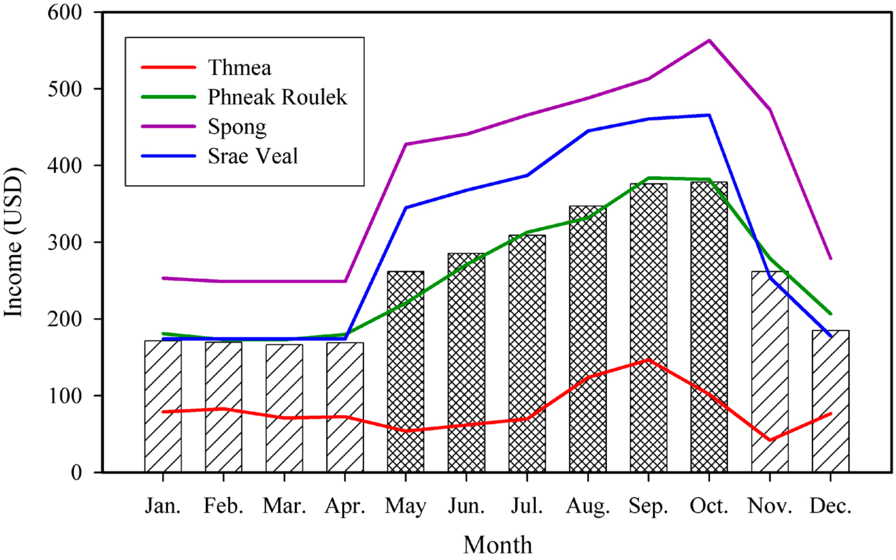

Figure 5. Mean monthly resin income per household in 2014 during dry season (November–April) and rainy season (May–October) in each village.

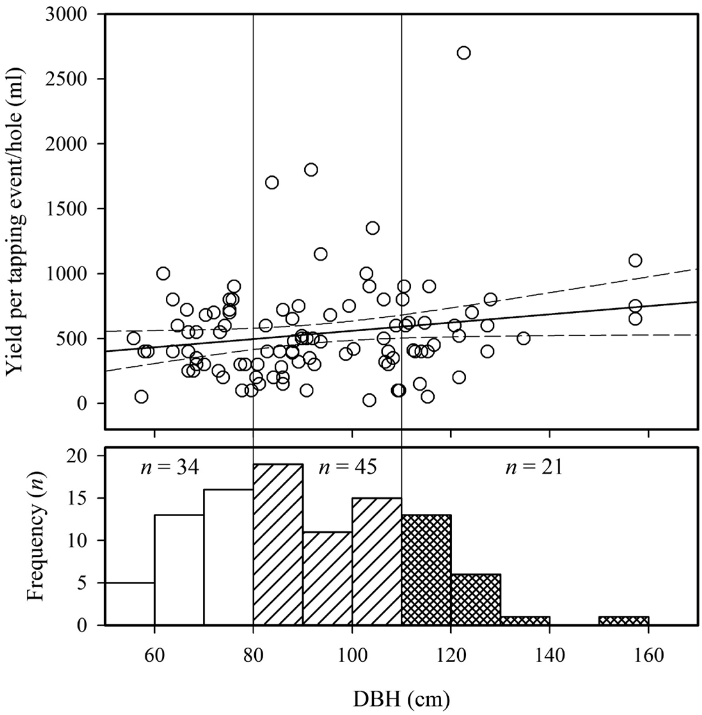

Figure 6. Resin yield per tapping-event (above) and DBH distribution of the 100 surveyed trees (below). The linear regression (unbroken line) is yield = 243.88 + 3.17 DBH ($R^2 = 0.04$). Dashed lines indicate 95% confidence ranges of the predicted yield.

Tree and Site Characteristics

All resin trees measured had a DBH > 50 cm, with a mean DBH of 91 cm (SD = 21). The most abundant size range was DBH = 80–89 with 18 trees (Fig. 6). According to the two resin tappers, resin trees were not tapped before they exceeded a DBH of 50 cm. In our analysis, we distinguish three DBH classes: small trees (DBH = 50–79 cm), medium sized trees (DBH = 80–109 cm), and large trees (DBH ≥ 110 cm) (Fig. 6). The yield per tapping-event across DBH values is shown in Figure 6. Small trees yielded a mean of 507 ml (SD = 242) per tapping-event, the medium sized trees 528 ml (SD = 393) and the large trees 614 ml (SD = 477). Hence, large trees yielded 21% more than small trees. Height of the tree and crown width did not correlate with resin yield but were in some cases difficult to measure due to dense surrounding vegetation.

The mean yield for resin trees located within 25 m from watercourses (8 resin trees) was 782 ml per tapping-event (SD = 447), while the mean yield for trees located farther away (92 trees) was 513 ml (SD = 365) on average. Thus, although the mean values are not significantly different based on this small sample size, it appeared that trees near watercourses yielded about 50% more resin than trees at greater distances from watercourses.

Health Condition of Trees

Trees recorded as being in a "good" condition had a mean resin yield of 605 ml (SD = 440) per tapping-event and trees in a "medium" or "poor" condition yielded 470 ml (SD = 246) on average. In agreement with this, there was a significant correlation between health condition and resin yield ($r = -0.225$, $p = 0.040$). Only one tree was registered as being in a "poor" condition (yield = 25 ml for one tapping-event), and the resin tapper was about to cease tapping this tree. There was no significant correlation between the health of the trees and the time (number of years) the trees had been exposed to tapping ($r = 0.106$, $p = 0.334$).

Tapping-Hole Condition

Twenty-seven of the 100 measured resin trees had more than one tapping-hole (active and abandoned), and five trees had more than one active tapping-hole. Trees with a single tapping-hole yielded 40% more resin (average 590 ml, SD = 413) per tapping-hole, than trees with two tapping-holes or more (average 424 ml, SD = 242). There was a significant correlation between the health of the tapping-hole and the yield per tapping-event ($r = -0.267$, $p = 0.006$). It should be noted that due to the applied classification rule (good = 1 and poor = 3) the coefficient of correlation is negative. The significant outcome may to some extent be an effect of tappers using known yield to assess the condition of the tapping-holes rather than the extent of damage by repeated burns and the maintenance of the hole. The health of the tapping-hole and the number of years the tapping-hole had been used was based on tappers' assessments and recollection (see Methods section). Tapping-holes recorded as being in a good condition yielded 46% more resin (636 ml, SD = 408) per tapping-event than tapping-holes in a medium or poor condition (437 ml, SD = 310). Only one tapping-hole was recorded as being in a poor condition (Fig. 7). The condition of the tapping-holes also correlated with the time (years) the trees had been tapped ($r = 0.3445$, $p = 0.0003$). On average, resin trees with tapping-holes in a good condition had been exposed to tapping for 7 years (SD = 4) and tapping-holes in a medium or poor condition had been exposed to tapping for 9 years (SD = 2). Figure 7 shows tapping-holes in a good (left) vs. poor condition (right).

Figure 7. Example of tapping-holes in a good condition (left) and poor condition (right) in *Dipterocarpus alatus*. Photos: Anne-Mette Hüls Dyrmose.

DISCUSSION

Previous studies have found that 80–90% of surveyed families in Mondulkiri and Stung Treng provinces in Cambodia owned resin trees (Evans *et al.*, 2003; Lægaard, 2010), and that resin collection was the most important contributor to rural livelihoods after rice-cultivation, because of its permanent market value (Appanah & Turnbull, 1998; Ankarfjärd & Kegl, 1998; Evans *et al.*, 2003; Lægaard, 2010; McKenney *et al.*, 2004). It should be noted that *D. alatus* trees are mostly considered to be inheritable private property in Cambodia, and the ownership of a tree is held by the first person who finds the tree and cuts a tapping-hole (Baird, 2009; Evans *et al.*, 2003). Yet studies in Ratanakiri Province document that *D. alatus* is sometimes managed as a common pool resource (Baird, 2009). In our study, only species producing solid resin, such as *S. guiso* and *S. obtusa,* were regarded as common property. Evans *et al.* (2003) concluded that if income from resin collection was to be lost, it is unlikely that other supplementary sources of income could replace resin collection. The supplementary sources were found mostly valuable to secure against fluctuations in the resin market.

The present study provides details regarding incomes, costs, labour input, and seasonal variation in yields and selling prices. It is one of the first studies to quantify resin yields per tree in such detail and relate yield to tree and site characteristics. Several factors can influence resin yield. These include: 1) environmental factors, 2) tree volume, 3) hydrological conditions, 4) health of tree, 5) genetic factors, 6) seasonal climate effects and, in particular, 7) anthropogenic exploitation (EVANS *ET AL*., 2003). This study indicates that yields are correlated with 1) tree size, 2) health of the tree, 3) condition of the tapping-hole and, 4) that yields are higher in the rainy season, which is in agreement with the findings of EVANS *ET AL*. (2003) and BAIRD (2009). According to EVANS *ET AL*. (2003) tappers report decline in yield already from the first time a tree is tapped; however, no long-term studies have been done to document whether the decline levels off or yields continue to decline until the tree is exhausted.

The present study shows that resin harvesting takes place regularly and all year round in the surveyed villages. According to comments from interviewees, shorter breaks from resin tapping can occur in the rainy season where households are busy with rice cultivation. The tapping frequency among the four villages was the same throughout the survey year, ranging between 4 and 15 "tapping-days" per month (Fig. 2). Similar tapping frequencies were found by BAIRD (2009), where the trees were tapped every 5–8 days, whereas 7.3 days was the average time between tappings in this study. According to findings by BAIRD (2009), tappers from Ratanakiri Province (Taveng District) only harvest resin in the period from October/December to May/June (6–9 months). The extra time that the trees are allowed to rest in Taveng District may help keep the trees healthy, although this has not been documented. An interviewee in the present study stated that he was harvesting his trees only three times per month, because longer times between tapping-events had a positive effect on the resin quality. Another interviewee argued the opposite, claiming that it is important to harvest resin on a continuous basis with short time between tappings, since otherwise the resin dries up and the yield decreases. Among the respondents in the study there was no general agreement on the appropriate time interval between tappings and its effects on resin quality and quantity. Moreover, it remains unclear how resting time influences health, survival and growth of resin trees, and what the optimal time between tappings should be (BAIRD, 2009). To determine this would require long-term studies.

Although the sample size was small, *D. alatus* trees near permanent watercourses (< 25 m) appeared to produce more resin than trees growing farther away. This was confirmed by interviewees who told us that resin trees near watercourses produced larger quantities and that they collected resin from these trees more frequently. In line with this, the majority of the interviewees commented that the quantity, the quality and selling prices were higher in the rainy season, which is also reflected in Figures 2 and 5. This was also the case in a study done in Laos, where tapping carried out in the rainy season resulted in higher yields (ANKARFJÄRD & KEGL, 1998). However, villagers in Ratanakiri Province did not tap in the rainy season or did so only occasionally, because the labour demand for rice cultivation was high in this season. Also, travelling can be restricted due to flooding and a large amount of rainwater can cause contamination of the resin (BAIRD, 2009). Nevertheless, the study by BAIRD (2009) confirmed that resin production by *D. alatus* was higher in the rainy season than in the dry season. However, no detailed quantification of resin yields from *D. alatus* was carried out.

According to resin tappers, the harvest technique may affect the health of the tree and thereby the yield. Trees might be burnt too severely in the attempt to provoke greater resin flow at each tapping-event. Too-frequent tapping, poor maintenance of the tapping-hole, and too many tapping-holes cut in each trunk may also reduce yield. Further studies are needed to investigate the impact of tapping techniques on resin yield and recommend best practices. Data on long-term exploitation are limited, but some reports based on interviews indicate that trees can be tapped for decades (ANKARFJÄRD & KEGL, 1998; EVANS *ET AL.*, 2003). In the present field study, 78 of the 100 measured trees had been tapped continuously for 10–12 years. A huge resin tree in Spong is claimed to have been tapped by at least three generations (~50 years) and is likely to be several hundred years old. Most of the recorded resin trees (88%) were tapped every 5th day by the tappers, giving an idea of the magnitude of a tree's "tapping life". There was great variation in the amount of resin tapped from each tapping-hole for the 100 sample trees. The average amount was 540 ml, but the observed range of yields was 25 ml to 2,700 ml per tapping-event. These recordings are in agreement with the findings of BAIRD (2009, 2010), who reported production of 500–1,500 ml per tapping-event. Both our study and BAIRD (2009, 2010) found higher yields per tapping-event than the mean yield estimated from the interview survey (375 ml per tapping-event).

A rough estimation is included below to give an idea of the economic importance of *D. alatus* to low-income households. Findings in this study indicate that an average *D. alatus* tree under private management is tapped 50 times per year (interview study), has 1.06 active tapping-holes (field study), and the price per liter is USD 0.66 (Table 3). Hence, the three DBH-classes (field study) will yield and earn as follows:

Small (50–79 cm):	27.0 liters/yr (17.8 USD/yr)
Medium (80–109 cm):	28.0 liters/yr (18.5 USD/yr)
Large (≥110 cm):	32.5 liters/yr (21.5 USD/yr)

A low-income household that owns 430 trees on average, where 34% are small trees, 45% are medium and, 21% are large trees (Fig. 6), would have a yearly gross-income of USD 8,123.

Previous studies from Laos estimated annual yield per tree to be around 22.5–31.0 liters/tree, based on both interview and field findings. However, the findings are based on data from the dry season when the production is low, and should therefore be interpreted as a minimum yield (ANKARFJÄRD & KEGL, 1998). In Mondulkiri Province the estimate was 30–40 liters/tree (EVANS *ET AL.*, 2003). The present study estimated a somewhat lower annual yield of 18 liters/tree based on the interview survey, but the field findings (27.0–32.5 liters/yr), are similar to those mentioned by ANKARFJÄRD & KEGL (1998).

Selling prices were highest in Thmea, which is the least remote village in terms of infrastructure and distance to markets, including provincial and district towns. The lowest selling prices were found in Spong, which is the most remote village. It is also the village with the highest number of trees per household, the highest labour input to resin extraction, and the highest gross-incomes from liquid and solid resin. It appears that the economic importance of species producing solid and liquid resin is highest in isolated, remote communities with few alternative cash income sources.

Resin tappers sell their products to traders or company representatives who set the prices, and the interviewees claimed that they were not aware of the factors causing the observed seasonal price fluctuations, except that resin quality possibly has an impact. This pattern is in agreement with EVANS *ET AL.* (2003), who found that resin tappers, especially in isolated villages, are trapped in a relationship with a single buyer, placing them in a weak bargaining position, which may partly explain why the lowest selling price was observed in Spong (0.60 USD/liter) (Table 3). The study in Laos by ANKARFJÄRD & KEGL (1998), shows that the price for resin increased five times from the tapper, going through the company representative to the exporting company. This might indicate possibilities for increasing tappers' share of the profits, but an analysis of the trade chain was beyond the scope of this study. However, one interviewee was actually trying to increase his earnings by selling the resin directly on a big market in Chhaeb District town in Preah Vihear Province, because this way he could get a much higher price than traders were willing to pay.

In spite of the lower selling prices in Spong, the annual gross-incomes were approximately 350% higher than in Thmea. Spong is surrounded by forest with a high abundance of large resin trees, and households in Spong owned more trees than households in Thmea. Overall, the 43 households in this study owned more trees than observed in previous studies. EVANS *ET AL*. (2003) reported an average of 77 resin trees/household, ranging between 52 and 135 trees/household in Mondulkiri Province, and BAIRD (2009) reported 40 trees/household where families heavily involved in resin tapping had up to 200 trees/household (Ratanakiri Province, Taveng District). Our study found that households owned 402 trees on average, ranging from 35 to 1,000 actively tapped trees per household or 35 to 2,200 trees per household when including young untapped trees and abandoned trees (Table 3).

Very little is known about solid resin collection and yields. According to APPANAH & TURNBULL (1998) a fully productive tree can yield approximately 50 kg of solid resin per year. Solid resin is mainly collected from *Shorea* trees and it appears to be relatively insignificant to local economies, although significant income from solid resin was documented in a remote village in the Mondulkiri Province (EVANS *ET AL*., 2003). The present study shows that solid resin generated household cash income ranging from USD 360 to 1,200 per year in the remote village Spong, reiterating the importance of solid resin to remote rural villages.

About 70% of Cambodia's population lives in rural areas (NIS, 2015), and the rural poverty line is USD 0.44/day/cap (NIS, 2006). A typical household in Cambodia consists of five members (UNITED NATIONS CHILDREN'S FUND [UNICEF], 2013) though fertility rates and household sizes are likely higher in the rural areas (JIAO *ET AL*., 2015). Based on gross-income estimates show in Table 3, a family of seven members earns USD 258 from resin per month, corresponding to a daily income of 1.2 USD/day/cap, which is enough to maintain the family above the poverty line. These results emphasize the importance of resin extraction to local economies and rural welfare.

Resin trees are often logged (illegally or legally) which is likely to have detrimental impact on rural livelihoods and lead to increased poverty among resin tapping communities (CPN, 2014). Enforced legislative and political action is urgently needed to help communities protect resin trees in Cambodia and the wider Southeast Asian peninsula. Tapping of resin trees provides a long-term, non-destructive way of using dipterocarp forests. Recent studies have shown that about 50% of the biomass in tropical forests is stored in "giant" trees with a DBH above 60 cm (SLIK *ET AL*., 2013). Hence, sustainable utilisation and maintenance of forest carbon stocks, which help mitigating climate change, go hand in hand with the ancient practice of resin tapping in Indochina.

CONCLUSIONS

This study provides detailed quantitative and qualitative findings on household-level resin incomes and yields in four forest-adjacent villages in Cambodia. Households spent an average of 105 tapping-days per year, equivalent to 12,530 tapping-events. Usually two people collected the resin together. The mean selling price was USD 0.66/liter. The selling prices were 50% higher in the rainy season compared with the dry season. The monthly household income from oleoresin was 74% higher in the rainy season, due to higher extracted amounts and prices. The average annual household gross-income from resin extraction was USD 3,236 per household. A single resin tree contributed a cash income of 12 USD/yr. The mean annual costs were USD 146 per household with the highest costs occurring in the most remote village Spong (USD 271/yr). Spong had the highest average annual household gross-income of USD 4,557, and was the only village with significant household incomes from solid resin ranging between USD 360 and 1,200/yr. Resin trees yielded an average of 18 liters of oleoresin per year, and yield was positively correlated with the size and health of the tree, health of tapping-hole and with proximity to watercourses. The rainy season offered the highest resin yield and income in all villages surveyed. The socio-economic importance of resin tapping reiterates the need for forest- and resin tree protection in order to secure local economies and welfare in forest-adjacent communities.

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