Effects of resin harvesting on the status of the *Agathis philippinensis* population in the Cleopatra's Needle Critical Habitat, the Philippines

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ABSTRACT

In Palawan, the Philippines, a biological hotspot was turned into a protected area, called Cleopatra's Needle Critical Habitat (CNCH). The most important goals of the CNCH are to conserve the rich endemic biodiversity and to maintain the culture of the *Batak*, a group of indigenous people who depend on forest resources for their livelihood. As resin extraction from *Agathis philippinensis* is a key component of the income of the *Batak* people, it is important to study the scope for sustainable exploitation of this species. This study focused on the effects of resin harvesting on the physical status and mortality of *A. philippinensis* trees in 15 subpopulations within the CNCH. These population characteristics were related to the intensity of resin harvest and the distance to communities. We found that the physical tree status deteriorated and the proportion of dead trees increased with harvest intensity and proximity to communities. These results indicate that overharvesting of the resource is taking place, which may lead to prolonged recruitment failure and population decline of *A. philippinensis* in the study area.

Keywords: *Agathis philippinensis*, *Batak*, bark removal, resin extraction, unsustainable harvest.

INTRODUCTION

In 2016, over 100 acres of original primary forest was designated as Cleopatra's Needle Critical Habitat (CNCH) in Palawan, Philippines. The CNCH is an evergreen forest characterized by abundant rainfall and very

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warm weather, these are the reasons why there are many different types of vegetation and animal species found. This tropical rainforest located in a mountainous region was identified, in a November 2013 study published in *Science,* as the world's fourth most "irreplaceable" area for unique and threatened wildlife. The CNCH contains 85% of Palawan's endemic and endangered plant and animal species. This unique blend of endemic species can be explained by the fact that the island was once connected to Borneo, resulting in a mix of influences from Sundaland and the Philippine Archipelago (Rainforest Trust 2013).

The CNCH also shelters the last tribe of hunter gatherers in the Philippines (FAO 2011; CS 2014). This indigenous people, called the *Batak*, live of NTFPs (Ticktin 2004; Ella 2008). The area around Cleopatra's Needle (the highest mountain in the CNCH area) is divided in seven *barangay* (smallest division in a municipality) of which four are home to a *Batak* tribal village. The other areas are used by the so-called lowlanders; people who live in the villages at the edge of the forest. The borders between these areas are not clearly defined and there is no regulation on who may enter or leave the forest.

Until the end of the nineteenth century the *Batak* were physically and culturally isolated from other human populations living in Palawan. Since then, the *Batak* and their biophysical surroundings were incorporated in the wider socio-ecological system of lowland Philippine society (Eder 1987). As a result, their community became market-entrenched due to the rampant exploitation of forest resources. Currently, most of the *Batak* income is obtained by selling NTFPs to the lowlanders. These NTFPs include honey, rattan (strong stems used to make baskets and other furniture), but mostly the resin from the *Agathis philippinensis* tree (local name: Almaciga) which accounts for 80% of their income (CS 2014). This indicates that the *Batak*, although participating in a wider socio-ecological system, are still highly dependent on the ecosystem services provided by the forest. However the health of this tropical forest ecosystem seems to be suffering, indicated by the declining number of *A. philippinensis* trees in the CNCH (Halos and Principe 1978; Ella and Domingo 2012; CS 2014). Other areas in the Philippines with *A. philippinensis* populations show similar trends, where unsustainable resin harvesting methods seem to be the main cause of this decrease (Westphal and Jansen 1989; Ella and Domingo 2012).

The extent in the decrease in population of the *A. philippinensis* population has been reduced in the CNCH and the cause(s) of this reduction is, is still unknown. Subsequently, it is unclear how the diminishing population of *A. philippinensis* is going to affect the *Batak.* To provide an insight on these issues, this study focuses on providing an overview of the state of degradation of the *A. philippinensis* population in the CNCH.

METHODOLOGY

This study was conducted in CNCH in Palawan, Philippines (Figure 1). For the data collection all *A. philippinensis* trees along 200x50 meter transects were sampled (including dead trees; Clark et al. 2014).

The selection procedure for the starting points of the transects were based on a random sampling design placed over a map of the CNCH area.

Figure 1. Map of the study area in Palawan, the Philippines circled in light green (Rainforest Trust 2013).

Of all the living *A. philippinensis* trees the diameter at breast height (DBH), the total surface area of bark removed and the overall physical status of the *A. philippinensis* trees were collected. A method of visually determining the physical status of a tree (Prooijen 2008) was used with the following categories, which were based on observations of diseased *A. Philippinensis* trees described by Halos and Principe (1978) and personal observations (Figure 2):

1. **Healthy**: the bark of the tree has a red-greyish colour and the crown is full.
2. **Early stage**: a dark brown discoloration of the bark around the basal area.
3. **Diseased**: the branches start shedding twigs and leaves and the density of the crown decreases. The tree stem is only hollow (in a state of decay) directly behind the harvested areas.
4. **Terminal**: the trunk is colonized by white ants/termites and the heartwood of the tree is rotting. Density of the crown is low.
5. **Death**: the trees collapse before they die because of (a combination of) rotten heartwood and storms.

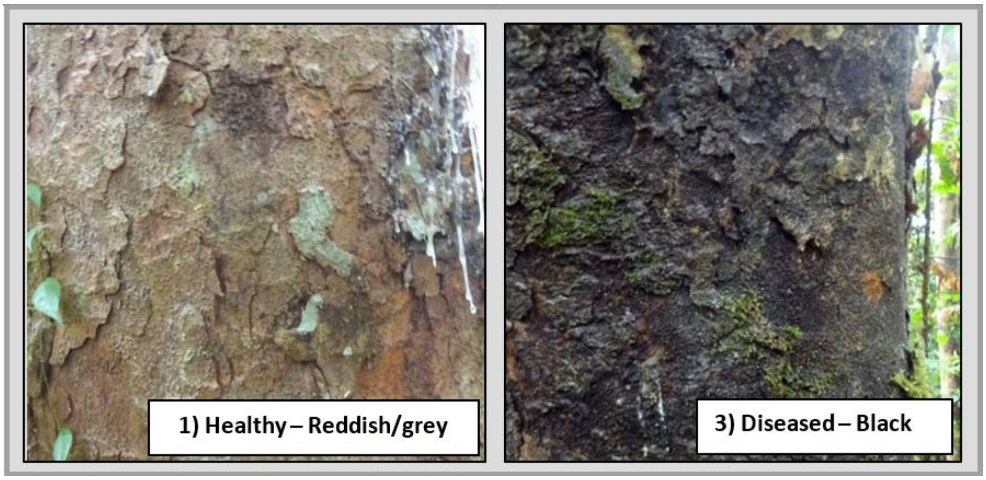

Figure 2. Example of a healthy bark (left) and the bark of a diseased tree (right).

The total surface area of bark removed for harvesting (in cm^2) was used to calculate the harvest intensity of each tree (1). The harvest intensity is the percentage of the bark below 250 cm that is harvested (Figure 3). The threshold of 250 cm was used as this was vertically the highest tree that was harvested.

(1). *Harvest Intensity = (surface of bark removed / (circumference x 250) x 100*

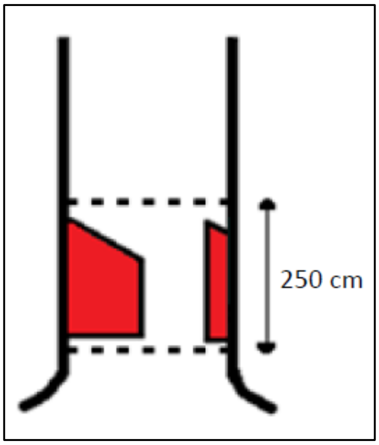

Figure 3. In red are the areas harvested for resin of the *A. philippinensis*. Harvest intensity is the percentage of the circumference *250 cm that was harvested.

The distance and the number of hours walking from each transect to the nearest village were determined. For each transect, the average DBH, physical status and harvest intensity was calculated and a dead/alive ratio of *A. philippinensis* was determined. This transect data only includes trees with a DBH higher than 40 cm, as this is the size from which resin collection of the *A. philippinensis* tree starts.

Sixteen local resin collectors from both the *Batak* villages and the “lowland” *barangays* were interviewed. Information was collected about their harvesting methods and how these changed over time. They were also asked to compare the state of degradation in the different areas compared to the past and if there were any changes in management measures. Finally, they provided an estimate of the degradation in areas where quantitative research was not conducted.

The transect data was imported into SPSS v. 20. All variables were normally distributed. Spearman Correlation tests were used to find correlations between (i) the harvest intensity and physical status, (ii) harvest intensity and ratio dead/alive and (iii) distance from nearest village and ratio dead/alive. An additional, summarizing, variable was created to indicate the state of degradation of *A. philippinensis* subpopulations in the CNCH. This variable was based on correlations and trends in the measured variables and was used to create a map with the degradation state of *A. philippinensis* in the CNCH. This degradation state ranges from no degradation, low degradation, and moderately degraded to heavily-degraded. The transect locations and their corresponding state of degradation suggests where the degradation transition lines are in the CNCH. To interpolate the state of degradation in areas that lack measurements, observations were made, and information about logging and degraded areas were obtained from resin collectors through interiew. These observations, including any noticeable changes in the harvest intensity, physical status, DBH and ratio dead/alive, were noted while hiking and provided a very general understanding of the state of degradation in areas where quantitative research was not conducted.

RESULTS

The six expeditions completed for this study, have resulted in fifteen transects during which 206 living and 50 dead *A. philippinensis* trees were sampled. 67 of the living trees were excluded from this analysis as their DBH was below 40 cm.

Transect Data

The strongest correlation occurred between the harvest intensity and the physical status (r=0.868, p=0.000) (Figure 4). A low harvest intensity (<10%) corresponded with trees that were healthy or at an early stage of deterioration, while a high harvest intensity (>30%) corresponded with trees that were between a diseased and terminal state.

There was a moderately positive relation between the harvest intensity and the ratio dead/alive (r=0.562, p=0.029; Figure 5). With increasing harvest intensity the number of dead trees per 10 living trees increased from approximately 1 dead tree per 10 living trees for a low harvest intensity (<10%) to 8 dead trees per 10 living trees for a high harvest intensity (>30%).

The distance from the nearest village and the ratio dead/alive showed a moderately strong negative correlation (r=-0.720, p=0.002; Figure 6). 2.5 hours walking from the nearest village one can find 8 dead trees per 10 living trees, while 6.5 hours away from the nearest village one can encounter 1 dead tree per 10 living trees.

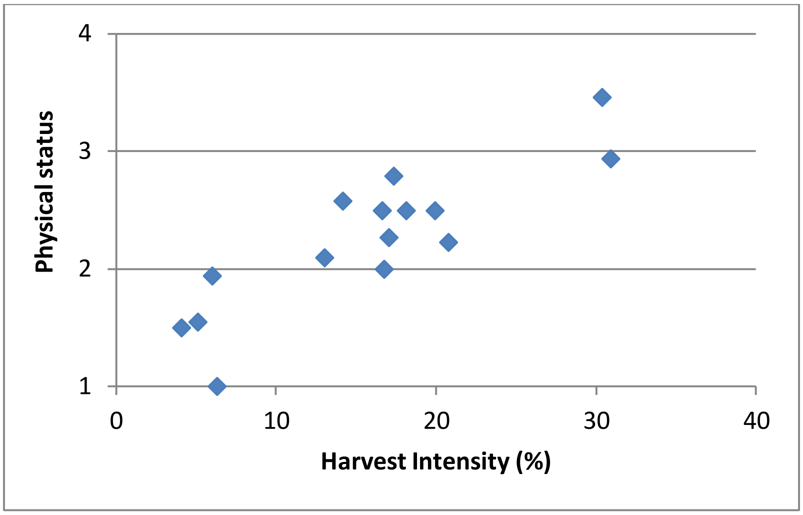

Figure 4. The relation between average harvest intensity and the average physical status of the transects (r=0.868, p=0.000). The physical status is 1=healthy to 4=terminal.

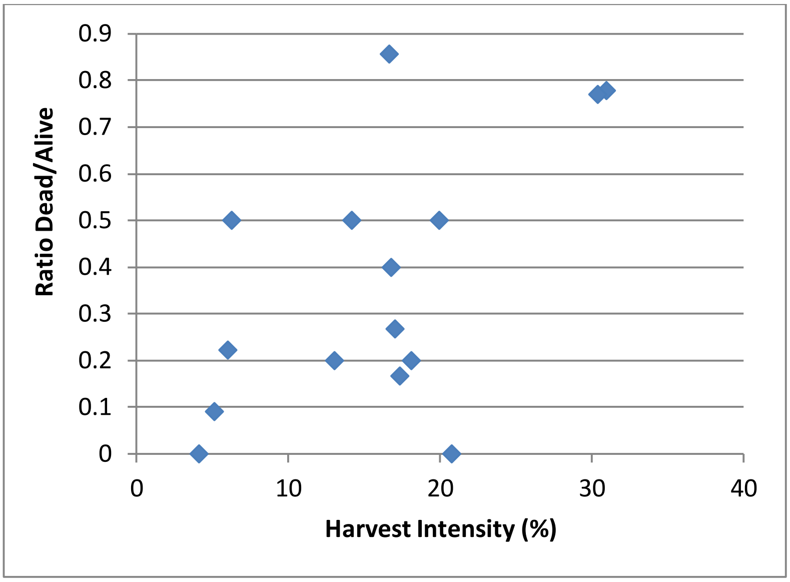

Figure 5. The relation between average harvest intensity and the ratio dead/alive of the transects (r=0.562, p=0.029).

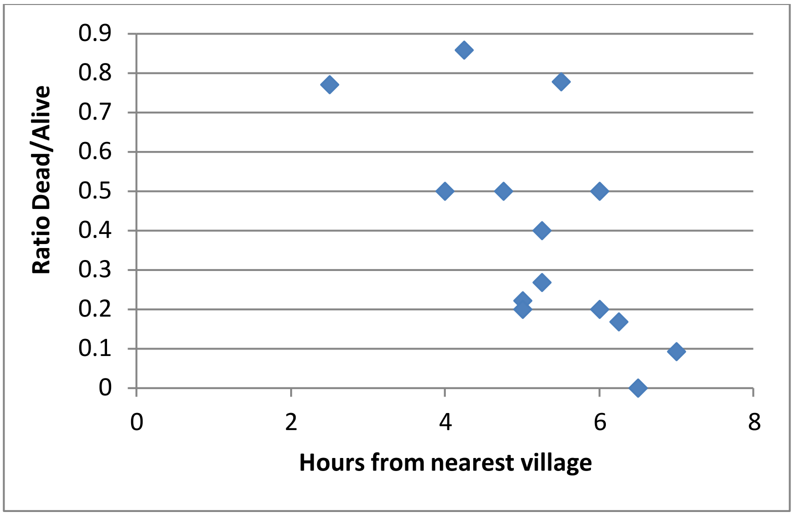

Figure 6. The relation between the distance from the nearest village and the ratio dead/alive of the transects (r=-0.720, p=0.002).

Degradation State

Relations between the four health variables (harvest intensity, DBH, physical status and ratio dead/alive) indicate a trend (Table 1 and 2). This trend shows that the *A. philippinensis* subpopulations in the CNCH are at different degradation levels (Table 1 and 2). The tables begin with subpopulations that have encountered *no degradation*. This indicates that they have a low harvest intensity (< 10%), exist out of a set of large trees (DBH > 100 cm) which are healthy (physical status < 2), and consist of less than 2.5 dead trees per 10 living trees (Table 1).

Table 1. Four states of transect degradation regarding *A. philippinensis* populations due to prolonged harvesting of resin. The states are based on variations in the average harvest intensity, average DBH, average physical status and ratio dead/alive of the fifteen transects in the CNCH.

State of population degradation	**Harvest intensity**	**DBH (cm)**	**Physical status**	**Ratio dead/alive**
No	< 10%	> 100	< 2	< 0.25
Low	10% - 25%	> 100	> 2	< 0.25
Moderate	> 25%	> 100	> 2	> 0.5
Heavy	10% - 25%	< 100	> 2	> 0.5

An *A. philippinensis* subpopulation with a *low degradation* was inflicted with a moderate harvest intensity (10% - 25%). This set of trees also contains large trees (DBH > 100 cm), but they are diseased or even terminal (physical status > 2). However, less than 2.5 dead trees can be found per 10 living trees. With a *moderate degradation* state, the harvest intensity is high (> 25%), most trees are large (DBH > 100 cm) and either diseased or terminal (physical status > 2). In addition, more than 5 dead trees per 10 living trees can be found.

If the state of a stand becomes heavily degraded the ratio dead/alive remains constant (Table 2). However, the harvest intensity, DBH and physical status have decreased. This last state of degradation contains subpopulations with a moderate harvest intensity (10% - 25%), a relatively small set of trees (DBH < 100 cm), that are diseased or terminal (physical status > 2) and comprise out of more than 5 dead trees per 10 living trees. No *A. philippinensis* subpopulations were encountered where no harvesting had occurred.

Table 2. State of degradation for all fifteen transects and the corresponding trends in the average harvest intensity, average DBH, average physical status and ratio dead/alive for *A. philippinensis* in CNCH.

Transect	**Average harvest intensity (%)**	**Average DBH (cm)**	**Average Physical status**	**Ratio dead/alive**	**State of degradation**
9	4.1	115	1.5	0.00	No
14	5.1	162	1.6	0.09	No
15	6.0	132	1.9	0.22	No
7	17.0	132	2.3	0.27	Low
8	17.4	148	2.8	0.17	Low
11	20.8	114	2.2	0.00	Low
12	18.1	105	2.5	0.20	Low
10	31.0	112	2.9	0.78	Moderate
13	30.4	120	3.5	0.77	Moderate
1	14.2	90	2.6	0.50	Heavy
2	16.6	71	2.5	0.86	Heavy
3	6.3	57	1.0	0.50	Heavy
4	13.0	54	2.1	0.20	Heavy
5	20.0	68	2.5	0.50	Heavy
6	16.8	66	2.0	0.40	Heavy

Based on the quantitative research, the interviews with the resin collectors and the significant correlation between the distance from the nearest village and the ratio dead/alive all areas of the CNCH could be assigned with one of the four states of degradation (Figure 7). The degradation is most intensive in the southern regions of the CNCH. Most of the areas are heavily degraded and some even logged. *A. philippinensis* becomes less degraded when the distance from the nearest village exceeds approximately 10 km. Moving further north after this transition line the state of degradation quickly decreases to a state of low degradation, because the areas that are moderately degraded comprise a relatively small surface area. Closer to Cleopatra’s Needle and especially north of this peak there is no degradation of *A. philippinensis* trees according to the resin collectors. It is probable that large parts of Langogan are still undisturbed. Closer to Marufinas there is some low to moderate degradation.

DISCUSSION

This study strongly suggests that the degradation of *A. philippinensis* in the CNCH has an anthropogenic cause. At all study sites, *A. philippinensis* subpopulations subjected to tapping (high harvesting intensities) had a worse physical status than subpopulations that were exempt from tapping (Figure 4). In addition, the number of dead trees per 10 living trees significantly decreases with proximity from the nearest villages (Figure 6). As all dead trees had collapsed due to tapping, these results demonstrate that the prolonged harvesting of a NTFP, in this case resin, can gradually affect the state of tree populations in a primary forest.

The effect of bark removal on the health of a tree is also evident in other studies. In these studies, however, the researcher often used growth as a derivative for the physical status. For example, in south-east Asia Dijkman (1951) found that the extraction of latex from *Hevea* trees resulted in a reduction of 50% in diameter increment. Kärkkäinen (1981) found that when resin yield was doubled in Scots pine the diameter increment dropped by 35%. Research done on the effect of debarking on *K. senegalensis* by Gaoue & Ticktin (2010) also resulted in reduced growth of individuals of all size classes. It is thought that the process of dying due to debarking is caused by dysfunction of the phloem (the innermost layer of the bark). Depending on the intensity of harvesting, the transfer of assimilates from the leaves to the roots decreases. This affects the health of the roots and, as a consequence, the overall health status of the tree (Guedje et al, 2007).

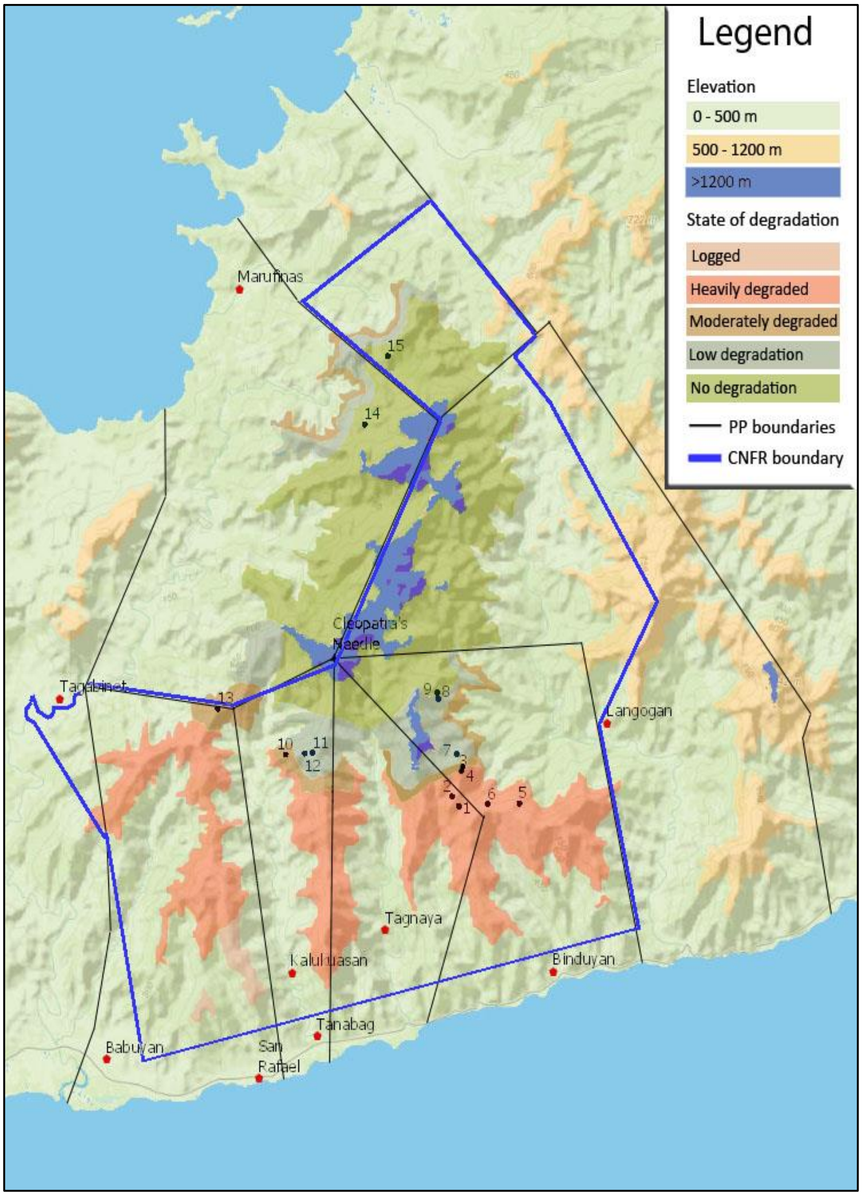

Figure 7. The occurrence and state of degradation of *A. philippinensis* in the CNCH. *A. philippinensis* trees occur between 500-1200 meter indicated by yellow. Inside the CNCH these areas are coloured indicating the state of degradation. The states of degradation are: (i) logged (light red), (ii) heavily degraded (red), (iii) moderately degraded (brown), (iv) low degradation (light blue) and (v) no degradation (green). The villages of resin collectors in the CNCH are indicated by red dots.

In addition to removing too much bark (overtapping), all tapped *A. philippinensis* trees in the CNCH had signs of cuts that extend past the bark to the sapwood portion of the tree, thereby penetrating the vascular cambium. This is called deep tapping and occurs widely in the CNCH due to the use of the machete. The machete reduces the precision and control of removing the bark so that the cambium is penetrated during harvesting. All of the interviewed resin collectors bring a machete as their main harvesting tool during the collecting trips. Based on the interview with the Chieftain of Kalukuasan the resin collectors previously used tapping knives for inflicting the cuts. These knives were more sustainable as they provide more precision and control. However, the *Batak* shifted to using the machete as the tapping knives became and continue to be too expensive for them to buy (400 peso or $9).

The use of the machete, however, is not the only reason why the tapped *A. philippinensis* trees had signs of deep tapping. The other cause is re-chipping where the accumulated resin that spreads out over the wound is removed and a new cut (about 3 cm of bark) is added above the first wound. With each consecutive re-chipping, however, the depth of the wound increases since not only the resin is removed but also an additional layer of bark. Subsequently, it becomes increasingly likely over time that the vascular cambium of a tree gets damaged if the first cut had not already reached this layer. The interviewed resin collectors believe that due to re-chipping a tapped tree is going to decline, as the process of wound closure is prohibited.

The effect of the depth of the wound on the physical status of *A. philippinensis* could not be determined during this study. This is because all samples that were tapped had signs of a damaged vascular cambium. Nevertheless, knowledge on the effect of the depth of a wound on *A. philippinensis* would be valuable when establishing a sustainable harvesting method. Literature on the depth of tapping wounds indicates that the impact of the depth of a wound is species-specific, and depends on the rate of wound closure (Ngubeni 2015). Based on the rate of wound closure a tree can be considered for bark harvesting. Some trees like *Prunus africana* and *Ocotea bullata* (Vermeulen 2009) show good wound regrowth, while in contrast *Burkea africana* and *Detarium microcarpum* showed poor or no bark regrowth (Delvaux 2009). Delvaux (2009) indicates that the ability to recover from tapping wounds in a relatively short time prevents large-scale insect attacks. The same study showed that leaving a thin layer of bark and the vascular cambium resulted in a wound recovery rate of 50% to 80%, whereas complete removal of the bark and cambium resulted in no or poor recovery (Delvaux 2009). According to Delvaux (2009), recovery from a wound therefore depends on the ability to preserve at least the vascular cambium after tapping.

Results coincide with that of Delvaux (2009) in that complete removal of the bark and cambium enables termites and potentially fungi and bacteria to infect the tree and thus the structure of the tree is weakened. In combination with strong winds, the trees snap where the stem is rotten. All of the sampled dead *A. philippinensis* trees died this way. Due to re-chipping of the bark the *A. philippinensis* trees do not get the chance to recover. More research is needed to determine whether *A. philippinensis* can recover when the vascular cambium is preserved during tapping.

The results suggest that the harvesting methods used by the resin collectors in the CNCH are not sustainable (Figure 7). About half of the areas where *A. philippinensis* trees thrive were either logged or heavily degraded. The worst conditions were observed in the southern regions of the CNCH. Here, the proximity of *A. philippinensis* subpopulations to the most populated villages in the area is the smallest, which results in the greatest pressure. The extent of the degradation in these regions is large enough to threaten *A. philippinensis* subpopulations with local extinction. This is because tapping decreases the chance for *A. philippinensis* trees to become reproductively viable. Bocxe et al. (2015) indicate that it is likely that an average *A. philippinensis* tree in the CNCH starts to produce cones from a DBH larger than 110 cm. Trees in the southern regions of the CNCH are, with an average of 68 cm, too small to assure the next generation of offspring. In addition, large *A. philippinensis* trees are becoming increasingly rare in the southern regions of the CNCH. As a result, resin collectors are already starting to target trees from a DBH smaller than 40 cm for resin collection thereby jeopardizing the long term survival of *A. philippinensis* in this area.

North of the heavily degraded areas a transition line separates the degraded from the undisturbed areas. The transition line ranges from 11 to 13 km to the nearest village. This range corresponds with the distance resin collectors can cover during a three day hiking trip. Resin collectors are reluctant to cross this transition line because that would require more resources and would induce higher risks. In addition, enough *A. philippinensis* trees that still provide resin, can be found within a one-day hike from their village. For now, these factors maintain the undisturbed state of *A. philippinensis* trees in the regions around and north of Cleopatra's Needle.

Subpopulations of *A. philippinensis* in between areas that are heavily degraded and undisturbed contain trees that have an average DBH close to or larger than 110 cm. This suggests that these *A. philippinensis* subpopulations comprise of trees that at least produce cones. However, studies have indicated that resin tapping can also affect cone fertility for resin producing trees like *Boswellia papyrifera* (Rijkers et al. 2006; Eshete et al. 2012) and *Khaya senegalensis* (Gaoue and Ticktin 2008). To understand the state of *A. philippinensis* in areas that are either low or moderately degraded, more research is needed on the effects of resin tapping on the cone production and fertility of *A. philippinensis*. The success of the nurseries that have been set up in the CNCH in 2015 suggest that fertility of the cones is not or barely affected by tapping.

Although the causes of utilizing unsustainable harvesting methods could not be proven during this study, the consequences of such methods can undoubtedly jeopardize the future of the local people. With the current decline of *A. philippinensis* trees, the resin collectors have to cover an increasingly large area to obtain enough resin in order to make it worthwhile. Not only does this increase the duration of the trips and the amount of supplies they need, but it also increases the chance of serious injuries. As a result, 35.7% of the surveyed resin collectors think that within 5 to 10 years it will not be feasible to collect resin from *A. philippinensis* trees in their region. Another 35.7% believe this will take up to 20 years. The remaining collectors think it will take more than 20 years to deplete the resin from *A. Philippinensis* trees in their region. All resin collectors agree, however, that it is only a matter of time. As a result, 80% of their current income and a specific way of living might disappear.

CONCLUSION

What the CNCH area needs, is what the CNCH stands for, that is: a protected natural area which stimulates the sustainable relationship of the *Batak* with their natural surroundings. Currently, however, this relationship is not sustainable. This is apparent by the decline of *A. philippinensis* trees in the area, on which the *Batak* depend for their income, by commercializing harvested resin. This unsustainable resource use is caused by removing too much bark in terms of surface area (overtapping) and depth (deep tapping). Using the wrong tapping tools is influential for the sustainability of resin harvesting. As a result, the population of *A. philippinensis* cannot reproduce, which creates an imminent local extinction, especially in the southern regions of the CNCH. The majority of the resin collectors in these regions indicate that resin extraction will lose its profitability within 20 years. As a consequence, it is likely that the main source of income for the *Batak* will disappear should the use of unsustainable harvesting methods endure.

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