Saving Almaciga (*Agathis philippinensis*): means of cultural preservation and species rehabilitation in Palawan, Philippines

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ABSTRACT

Agathis philippinensis Warb. (Almaciga) is a coniferous tree that forms a dominant component of upland primary forest in Palawan, Philippines. Almagica is valued for its high-quality timber and for its resin, which is used in the manufacture of varnish and linoleum. The species is categorized as "vulnerable" by the IUCN due to illegal logging, destructive methods of resin tapping, and land-use change. In Palawan, collection of Almagica resin provides up to 80% of income for indigenous communities and other inhabitants living in close proximity to the forests. A recent study into the effect of resin harvesting suggested that the resource is being collected unsustainably, leaving trees highly susceptible to outbreaks of pests and diseases, reproductive failure and death of trees, increasing the risk of local extinctions. Thus, the economic livelihood and future of indigenous peoples who depend on Almaciga resin is uncertain. This study aimed to provide protocols on propagation, reforestation, and sustainable management of *A. philippinensis*. This knowledge can be used to rehabilitate depleted populations of Almaciga. Between July and December 2016, three nurseries were established across two indigenous communities in the Cleopatra's Needle Mountain range, Palawan, where more than 10,000 seeds were collected and sown in seedbeds. These seeds generated more than 6,000 seedlings that were propagated, nursed and monitored throughout the study. Information on the collection of cones, seeds and seedlings, propagation and nursery management, identification and mitigation of pests and diseases, and environmental requirements for growth and survival were documented. The propagated seedlings were used to reforest declining populations of this species, thereby ensuring the future livelihood of the indigenous communities is preserved through conservation of Almagica populations.

Keywords: Threatened species, resin collection, conifer, nursery propagation, reforestation, aboriginal, sustainable forest management, rainforest tree.

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INTRODUCTION

Agathis philippinensis Warb. (Almaciga) is a species of conifer native to the Philippines and Indonesia. It is a large tree reaching up to 60 meters height, 300 centimeters in diameter and occurs in upland forests at altitudes between 250 to 2,200 meters. It occurs in the Babuyan Islands, from Northern Luzon to Palawan and Mindanao (Ella and Domingo 2011). Almaciga yields high quality resin, also known as Manila copal that is used as raw material for varnish, lacquer, paper paint driers, linoleum, and ink, among others (Brown 1921; Saminao and Ella 2014). Manila copal is considered an important dollar earner among the country's non-timber forest products. In the Philippines, Palawan is the largest producer of Almaciga resin (Razal 2013). Collection of resin is an important source of income for indigenous peoples (IPs) and other rural communities, along with collection of cashew and seaweed (Goloubinoff et al. Undated). Due to the current high market demand of resin however, the number of collectors has increased, including non-IPs, and many practice unsustainable tapping methods leading to decline in resin yield and quality and, at worst, the death of trees due to pests and disease (Vermeer et al. 2017) and other factors that remain to be determined. Almaciga timber is also of high quality and excellent for paneling; it commands a high price in the world market. Logging of Almaciga is currently banned by the Philippine government (Mittelman et al. 1997; Ella and Domingo 2011) but illegal logging still occurs. Sustained pressure from logging and resin collection has contributed to declining populations of *A. philippinensis* in the Philippines. If these malpractices continue, Almaciga is prone to local extinction, affecting the livelihood of communities depending on it. Although little is known of the ecology of this particular species, studies have shown that closely related *Agathis* species, throughout their natural distribution, contribute greatly to the maintenance and balance of soils and nutrient cycling, plant-water relations, forest succession and many other related ecological relationships (Steward and Beveridge 2010; Bieleski 1959). Finally, with climate change as a global concern, recurrence of natural calamities like typhoons and forest fires will have impacts on forest ecosystems, particularly vulnerable and threatened species like Almaciga (Razal 2013), and thus it is important we understand more about these ecologically and economically important plants.

The Cleopatra's Needle Mountain Range (CNMR) in Puerto Princesa, Palawan, is inhabited by three indigenous communities being their ancestral territory. The largest remaining population of Batak tribe inhabits the inner forests of CNMR. The Tagbanua and Cuyunon tribes inhabit the marginal civilized areas in close proximities of the CNMR, together with several other migrant populations from Visayan groups. Almaciga resin collection serves as the main livelihood for these communities. For the Batak tribe, the Almaciga tree has remarkable value as a big portion of their income revolves around this tree, providing roughly 80% of the tribe's total income (Jose unpublished data). The tree provides several benefits, including providing traditional medicine, fire starter, firewood, torches, and paste and caulking substance, coloring agents for artifacts, smudge against mosquitoes and ritual incense and accessories, among others. For the Batak tribe, ownership of individual trees is passed down from generation to generation. However, overharvesting is evident due to an influx of resin collectors from areas where the trees have vanished; this threatens the remaining population of the species in the CNMR. The trees eventually become weak due to over-tapping of resin and will collapse in the near future if no action is taken to restore the health of trees. This means that the traditional livelihood and thus the future for the tribes and locals depending on Almagica is very uncertain.

Promisingly, the Centre for Sustainability received grants from the Flagship Species Fund of Fauna and Flora International and the Philippine Tropical Forest Conservation Foundation. This flagship species project aimed to rehabilitate the population of Almaciga in CNMR and conduct research on the biology and ecology of the species. Furthermore, the project aimed to raise awareness within the communities on the species' conservation status, understand the links between the overharvesting of resin and the collapse of the trees and reduction in fertility of seeds, and develop sustainable management plans for the species. The goal of the project was to generate 10,000 seedlings in local nurseries, to be planted in the surroundings of the Cleopatra's Needle Critical Habitat. Efforts and strategies were developed to equip the communities with the capacity of understanding biology and ecology, sustainable use and rehabilitation of Almaciga trees, to save it from local extinction in the future. As part of this wider project goal, this study focused on providing protocols on propagation, nursery, reforestation and management of *A. philippinensis* in the forest of CNMR. Specifically, the study aimed to:

1. Test various methods of cone, seed and seedling collection;
2. Germinate seeds for use in reforestation of declining populations;
3. Monitor growth and survival of seedlings in the nursery;
4. Identify, manage and mitigate pests and diseases of seedlings in the nursery;
5. Identify pressures and approaches to address unsustainable resin harvesting.

METHODS

There were five major activities initiated in each nursery. Experimental treatments of seed propagation were performed for comparison purposes, considering that these activities were the first of its kind for any Almaciga nurseries in the country. The study was conducted between July and October, 2015.

Establishment of Nurseries

We aimed to establish nurseries in areas where Almaciga are naturally occurs since it is assumed that these areas are most suitable for seed propagation and growth of seedlings. However, after the reconnaissance survey done in the area this turned out to be impractical considering slopes, distance to the community and the difficulties in the monitoring, research timeframe, workload and budget. Therefore, three nurseries were established in more accessible areas, each in a distinct location differing in altitude and topography for purposes of comparison (Figure 1). The first nursery was established in the lowland area of Bgy. Binduyan, with an elevation of ≈1 meter above sea level (masl). The second nursery was constructed at the edge of the forest at a higher elevation (Pulang Bato, ≈100 masl, Bgy. Tanabag) while the third nursery was established at an elevation of ≈200 masl (Lipso, Bgy. Tanabag) where Almaciga trees naturally occur. A nursery in high montane elevation (1000+ masl), although desired, was not established. However, the three nurseries are sufficient to provide baseline data on Almaciga propagation, and nursery related requirements and studies.

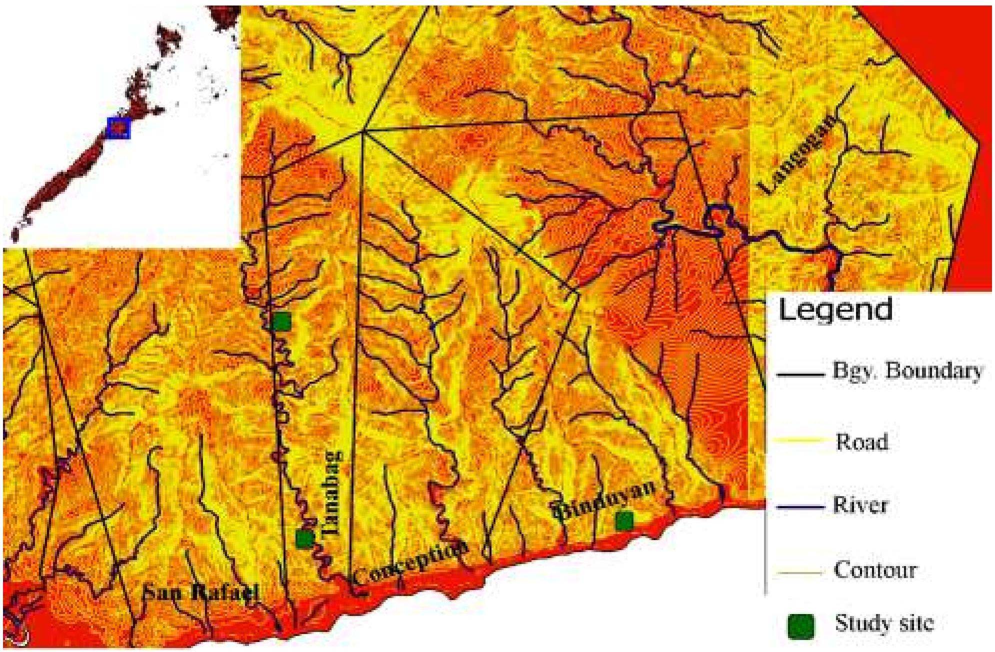

Figure 1. Map of Palawan (inset), CNMR and the nursery sites (green quadrangles). Nursery 1 – Binduyan; nursery 2 – lower Tanabag; and nursery 3 – upper Tanabag, Puerto Princesa City.

Cone and Seedling Collections

Preliminary consultations with local nursery experts and operators were performed to acquire information on nursery protocols prior to the actual surveys. Most of these experts and Almaciga nursery operators were propagating Almaciga seedlings collected from the wild; none had attempted collection of cones and seeds. In order to provide insights and options for cone/seed collection, field surveys were initiated in areas where Almaciga trees are located in the CNMR. Mother trees were identified for the presence of cones and seeds. These trees are found on top of high ridges with deep slopes in the forest, making the collection of fallen matured cones, seeds and/or seedlings for propagation and nursery very difficult. Fallen rotting cones, cones attacked by ants and termites and other signs of animal-eaten seeds, were observed. Moreover, wild seedlings are scarce in all of the surveyed areas. Based on these *in-situ* situations, three methods of cone collection were trialed. First, trapping of cones and/or seeds from pre-identified mother trees was undertaken by deploying a series of net traps, covering a total of 225 square meters (m^2) surrounding a mother tree, which were monitored for two months. Net traps were deployed and monitored in one mother tree, in the montane forest area of Bgy. Tanabag. Secondly, wildlings that were < 12 cm in height and below 5 mm diameter, that were encountered in the surveyed sites were collected and transplanted into seedling pots in the nurseries. Lastly, groups of local Batak tree climbers were employed during expeditions for cone collection.

Treatments of Cones and Seeds, Experimental Seedbeds and Seed Pot Transplanting

Considering the limited knowledge on propagation and nursery of the species and related germination data in wild populations, three methods of handling cones and seeds were trialed. In spite of our knowledge gap on the biology of the species, we tried to evaluate its seed viability. Seeds having distinguishable cotyledons inside the seed coat were separated from seeds without obvious cotyledons. Seventy-six seeds with cotyledons and 124 without obvious cotyledons were sown in a seedbed as preliminary trial. The rest of the sorted seeds with obvious cotyledons collected were immediately sown in experimental seedbeds. Medium-ripe cones were treated with readily-available fungicides and insecticides (Carbofuran – Furadan: FMC Corp.; Malathion: BIOSTADT) and sprayed with water (0.003 milliliter per liter concentration) every two days to evade dryness and potential attack from insects and pests that can damage cones whilst maturing. Some other cones were hung in a nearby firewood hob, allowing smoke to deter insects and/or pests that could potentially damage them as an alternative protection method during cone maturation. These cones were sorted for seeds after they became fully mature, which took between 7 and 14 days, and seeds were then planted in experimental seedbeds.

Three types of seed bedding treatments were initiated. Soil from the seedbeds of 1 m width and 2 m long were dug about 10 cm deep and mixed top soils available in the nurseries. Linear furrows of about 3 cm deep, at 20 cm distance from each other, were prepared and seeds were distributed in the furrows with about 5 cm distances from each other. In all, approximately 200–250 seeds were planted per treatment, and approximately 4500 seeds were used in total for the experiments. Seeds were covered with soil of about 1 cm thick. The soil was analyzed for nitrogen, phosphorus and potassium content, alkalinity, moisture, temperature and humidity using a Rapitest soil test kit (Spoerri, Inc.), a 3 way soil meter (Shenzen Yago Technology Co., Ltd.) and a GM1360 humidity and temperature meter (Shenzen Leyi Industrial Co., Ltd.).

The effect of watering quantity (factor A) and pesticide/insecticide application (factor B) were tested for the germination of seeds. Two replicates were performed for each factor in the experimental seed beds. To assess water quantity effects, four seedbeds were covered with a tarpaulin (to protect soil from possible overwatering due to rainfall) and supplied with water twice a week, to a total of 30 liters per seedbed. Four seedbeds were covered with fine nets, which allowed equal distribution of rainwater. These seedbeds were not supplied with additional watering. The control treatment had no roofing system and received no additional watering. Within each watering treatment, one seedbed was treated with Furadan at the time the seeds were sown, and sprayed with Malathion every three days to control insects and pests. The other two seedbeds within each treatment were treated by either one of the two types of pesticide/insecticide used respectively. One seedbed without any chemical treatment was also prepared. Similar pesticide/insecticide treatments procedures were performed in the net roofed experimental seedbeds. Control seedbeds received no pesticide/insecticide treatment for both factor A and factor B (Table 1). The layout of the experiments is presented in Table 2.

Table 1. Details of the factors tested in the experiment.

Factor A - Watering effect	**Factor B - Insecticide/pesticide effect**
A1- seedbed covered with tarps and supplied with 30 Liter of water per week	B1 – seedbed treated with both Furadan and Malathion
A2 – seedbed covered with fine net that blocks direct rainwater	B2 – seedbed treated with Furadan
A3 – seedbed without roof cover (Control)	B3 – seedbed treated with Malathion
	B4 - No insecticide/pesticide treatment (Control)

Table 2. Layout of the Almaciga seed propagation experiments. A refers to the effect of watering quantity, and B refers to the pesticide/insecticide application.

A1B1	A1B2	A1B3	A1B4
A2B1	A2B2	A2B3	A2B4
A3B1	A3B2	A3B3	A3B4

Five days old sprouting seedlings in the seedbeds were transplanted to individual seed pots, using topsoil acquired from local nurseries and the seedlings were counted. Seedlings in the nursery were monitored on a weekly basis parallel to monitoring of cone/seed traps and data gathering.

Identification and Mitigation of Pests, Diseases and Monitoring of Seedlings

Information on the presence of pests and diseases was documented. The number of seedlings germinated in the experimental seedbeds was recorded. Mortality was monitored when the seedlings were transplanted in seed pots. Heights and leaf sizes were measured prior to reforestation time. Initial data of mortality, growth and survival rates recorded from October to November 2015, were the only available data and are treated in the analysis.

Group Meetings and Key Informant Discussions

Group meetings and key informant discussions with members of stakeholder communities, particularly with the Batak and Tagbanua tribes, were performed to identify pressures and approaches to address unsustainable resin harvesting and to develop a management plan.

Data Analysis

Data gathered from the experiments was organized for analysis. A Canonical Correspondence analysis (CCA) was carried out to test correspondence of seed germination, seedling growth and survival, with the measured soil nutrient contents, soil and external environment temperature and humidity and moisture contents of soil and seed pot substrates. A single factor Analysis of Variance (ANOVA) was performed for the total propagation performances of seedlings in the three nurseries of different elevations. Multivariate ANOVA was used to analyze the effects of watering and pesticide/insecticide treatments on the germination of the seeds during the seed bedding processes. A Tukey's test was done for all ANOVA results that were found significant.

RESULTS

Six cone/seed collection expeditions were initiated yielding nearly 12,000 viable seeds from cones collected from six mother trees. These seeds were sown and propagated in experimental seedbeds in the nurseries. A total of 6,397 seedlings were germinated from the experiment. Eighty-three wildlings were also collected during expeditions and were grown successfully in seed pots in the Lipso and Binduyan nurseries. No cones and/or seeds were collected from net traps.

Rots caused by molds and fungus were common problems with cone and seed storage. These might be the consequences of incalcitrant seeds which might require more technology, laboratory and expertise in cone/seed handling and storage. Nevertheless, stored cones and seeds treated with fungicides and insecticide retained their viability within two weeks of keeping them in the field prior to seed bedding processes.

Generally, the propagation performance of the seedlings in seed pots from the three nurseries showed significant difference ($F_{(2,57)} = 3.135$; $p = 0.05$) in favor of lower Tanabag (Pulang Bato) over the Binduyan nursery site (Tukeys $Q = 3.49$;$p = 0.04$). The lower and upper (Lipso) Tanabag nursery sites showed no significant difference (Tukeys $Q = 2.29$; $p = 0.25$) as well as the upper Tanabag and Binduyan (Tukeys $Q = 1.20$; $p = 0.68$).

The result of experiments on the effects of watering (factor A) and pesticide/insecticide (factor B) on the germination of seedlings is shown in Table 3. Analysis showed high significant difference in watering treatments to the germination of the seedlings.

Table 3. Multivariate ANOVA of the germination data revealed from the seedbed experiment. Factor A = watering; Factor B = Pesticides/insecticide.

Parameters	Sum of Squares	df	Mean Square	*F*	*p*
Factor A	10250.00	2.00	5123.00	15.80	0.01
Factor B	3403.00	3.00	1134.00	3.50	0.05
Interaction (A X B)	1556.00	6.00	259.40	0.80	0.59
Within Groups	3890.00	12.00	324.20		
Total	19100.00	23.00			

Tukey's post hoc comparisons on the effects of controlled watering to the germination of seedlings is significantly different to that of the uncontrolled watering treatments in the experiments ($F_{2,21} = 12.16$; $p = 0.01$). Pesticide/insecticide on the other hand, appears to have no significant effects in the seedlings germination ($F_{3,20} = 1.4$; $p = 0.26$) except that treatment C (Malathion) has more reliable data compared to the other three treatments and the control group has lesser data reliability compared to other two treatments (Figure 2). A separate ANOVA for Factor B however, indicated no significant difference ($F_{3,20} = 1.4$; $p = 0.25$).

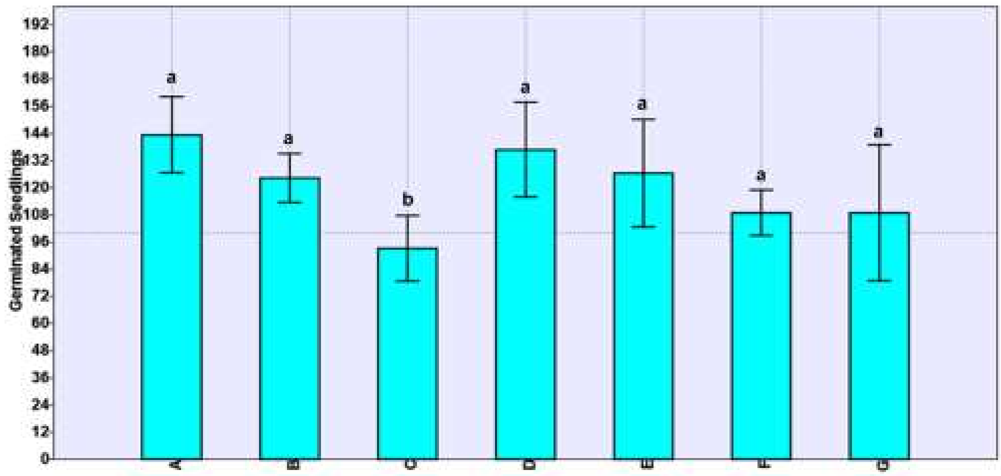

Figure 2. Effects of watering (A-C) and pesticide/insecticide treatments (D-G) to the germination of seedlings in the experimental seedbeds. A = Controlled Water; B = partly controlled water; C = Uncontrolled water; D = Treated with two types of pesticide/insecticide; E and F = Treated with one type of pesticide/insecticide; and; G = no pesticide/insecticide treatment.

Seeds without obvious cotyledons did not germinated in the preliminary seed germination test. Results of experimental seedbeds are shown in Figure 3. Propagation natality for Treatment 3, the control treatment, greatly corresponded towards trajectories of soil moisture and temperature and external temperature. Treatment 1 corresponded only to nitrogen and treatment 2 corresponds only to pH. Humidity, light and potassium did not correspond to any of the experimental treatments. This implies that seeds cannot tolerate too much or too little water and this greatly affects its success at propagation.

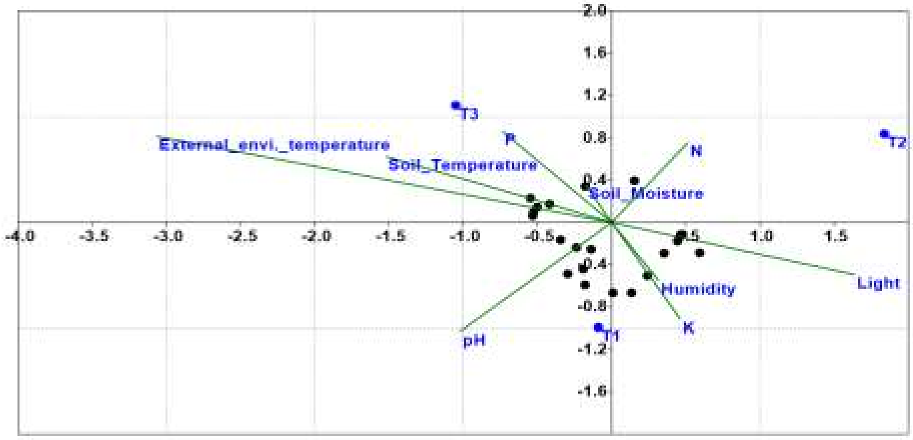

Figure 3. Canonical Correspondence Analysis showing environmental factors that correspond to the number of propagated seeds in the experimental seedbeds. T = treatments. Environmental parameters: N, P, K = soil nutrients; pH; soil moisture, humidity; light; and temperature.

Adequate nitrogen and slightly acidic substrate appears to be more favorable for germination in the case of Treatment 1 and 2 respectively. The pesticides used in these treatments might contributed to the amount of acidity in the case of treatment 2, while decaying organisms due to pesticide use might have added to the nitrogen content of the soil substrates of the Treatment 1, although this assumption requires further investigation. Additionally, rodents, ants and hoppers are the common problems consuming and/or damaging seeds and seedlings in the nurseries. Specific taxonomic identification of these pests is a necessity. Samples were collected and sent to the entomology expert in one of the local universities in Palawan for further investigations. Results of the taxonomic identification were not yet finalized during the course of this study, and therefore are not included in this paper. Finally, too much rain water caused seeds to rot, and after heavy rains, the soil substrates clump when dried, preventing sprouting seedlings from coming out. Cultivation to soften the soil substrates or replacing the entire soil substrates in the seed pots is required in such cases.

The mortality rate of the seedlings in the three nurseries was averaging 2.72% per month over three months. Mortality is negatively correlated with the age of the seedling (r = -0.5; p = 0.12) ranging from about 6% in the first month to nearly zero mortality in the fourth month (Figure 4). This implies that as seedlings mature they become more tolerant to causes of mortality.

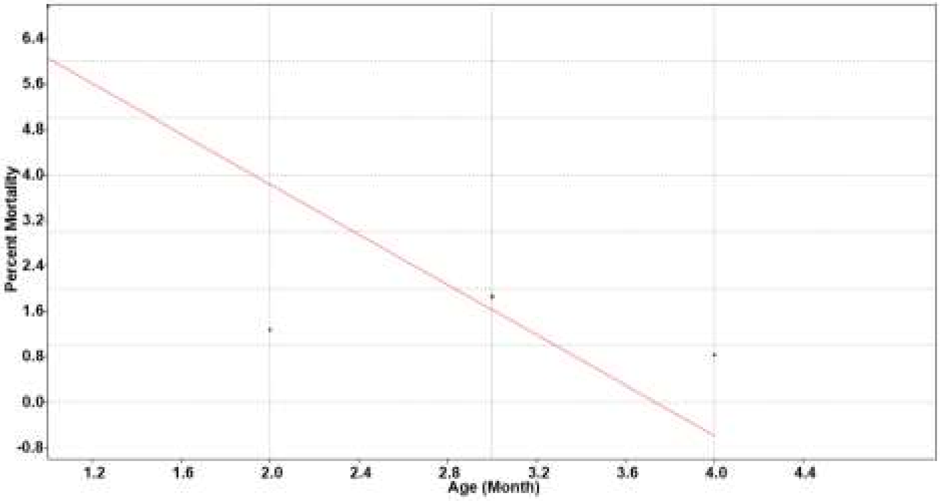

Figure 4. Linear correlation of the percentage mortality with the age of the seedlings.

DISCUSSION

The results imply that propagation of Almaciga is manageable and straightforward. Seedlings are not sensitive to elevation gradients and can be propagated from ≈1 to ≈200 meter above sea level. These biophysical limits were likewise documented for *A. microphylla*, which is tolerant to light salt sprays, well adapted to grow in windy and cyclone-prone locations, and likely to tolerate short dry periods (Orwa et al. 2009). The only factor that significantly affected seedling natality/mortality among sites was due to overwatering and/or water shortages in the seedbed and pot substrates, and fungi and pests as manifested in the canonical correspondence analysis result. Similar observations have been documented from other *Agathis* species. Pacific Kauri (*A. macrophyla*) seedlings had been proven susceptible to termite and beetle attacks, moths and root fungi that are usually associated to waterlogged substrate or sites (Orwa et al. 2009). Optimum mixtures of soil components in the seed pots are still subject for further experiments; however, our present result revealed that mixtures of 50% sand, 20% clay and 30% topsoil are appropriate for the growth and survival of the seedlings. Soil or soil mixed with sand has likewise been used and recommended as germination medium for *Agathis loranthifolia* in the greenhouse (Nurhasyni and Sudarat 2002). Despite wild-collected seedlings successfully surviving in the nurseries, we do not recommend collecting wild seedlings for it reduces the natural populations of the species and further increases workload, as these are being replanted back to the forest. Moreover, this practice could post additional threats as natural population recruits can be depleted while expanding inappropriate locations that is favored for plantation of the species. Based on the results of seeding experiments and nursery monitoring, the critical age of seedlings which needs ultimate care is from seed bedding up to four months of age – the stage where only primary root and cotyledon leaves support the growth of the seedlings. Seedlings growth becomes quicker once the true leaves and secondary roots start to come out, normally four months and beyond from time of transplanting in seed pots.

Kauri Dieback Management in New Zealand provided a brief guide for growing Kauri. This guidebook provided the basics of Kauri biology and ecology including care, seed germination and growing plantations. In the New Zealand setup, Kauri seedlings and young trees are susceptible to droughts and waterlog. Moreover, growth of Kauri occurs best in soil pH range of 4.8 and 6 but growth can be affected in soil pH below 4.5. The lack of knowledge and skills in monitoring and initiating appropriate measures to mitigate the threatening effects of catastrophic events occurring in the nurseries is likewise a problem in this study. This is also because the activity is the first of its kind for any Almaciga nursery in Palawan and the entire Philippines. The knowledge and experience gained in the whole process of the project together with the nursery manual subsequently developed can be used by the indigenous communities in the creation of community-based Almaciga nursery projects and by other interested parties on Almaciga propagation.

Options to conserve Almaciga include replacement of dead or badly damaged trees in the forest by either planting seedlings or allowing growth of naturally-generated young trees prior to extracting resins (Lacuna-Richman 2004; 2006). As such, this project/research intended to provide seed-propagated seedlings to reforest the degrading population of the species in the forest of Cleopatra's Needle. Development of a closed canopy and high diversity forest farming system that replaces slash and burn forming practices, preserves biodiversity, re-establishes ecosystem and ecological functions and provides subsistence to farmers, had been established in Leyte during the 1990s (Margaraf and Milan 1996; Göltenboth et al. 1999; Schulte 2002; Göltenboth and Hutter 2004). The seedlings propagated and planted in the CNMR added significantly to the number of surviving individuals in the population of the species, thus restoring the normal ecosystem and ecological functions in this ecologically important area, while also ensuring the future livelihood of the Batak and other inhabitants in the area that depend on Almaciga products. Although such projects will need external support from government and other concerned agencies for continuity. Moreover, similar projects should be adopted by the National Greening Program of the DENR for additional technical and financial support. Currently, the National Greening program of the DENR is rehabilitating degraded forest areas in the Philippines with non-native tree species which can potentially becoming additional threats in the future, such as possibilities of species invasion. Furthermore, monitoring and care of the planted seedlings in the reforestation areas is necessary to ensure the survival of the plants.

Based on discussions with the tribal people and key informants, the major challenges in the conservation of Almagica are unsustainable resin collection methods. This is due to the high demand of the resin product that causes an influx of resin collectors from areas where Almagica is locally scarce. Resin and other non-timber products are only allowed to be harvested by the tribal collectors and/or members of forest tenured agreements including community based forest management (CBFM), social industrial forestry management agreements (SIFMA) and other forest management agreement programs set by the government (Department of Environment and Natural Resources and Palawan Council for Sustainable Development). However, the documentation process in securing necessary permits for these forest management tenure instruments seems to be financed by middlemen buyers of the products. In such way, the local collectors or members of these community-based organizations (mostly tribal people) are obligated to pay for debt, and at worst, the debt of gratitude (as the tribal people treat it as such), by supplying more products to the middlemen financers. Moreover, middlemen financers are allowed to send non-IP workers to the sites to collect and meet the volume quota of resin they need. Apparently, pricing of these products are likewise being controlled by the middlemen financers. This allows the middlemen financers to profit greatly from Almaciga resin, while local collectors only receive a nominal income. A community share (PhP 1.00 per kilogram of resin sold to middlemen buyers) which was charged from the collectors and is intended for conservation and permitting processes. However, these shares are normally not liquidated and turned-over to the community to implement its purpose, but rather remain in the custody of the middlemen financers for unknown purpose (Nicknik Saavedra pers. comm. 2017.)

Finally, the indigenous peoples in the project area realized the imbalance in profit benefits that runs between them and middlemen financers. However, they do not have enough knowledge and finances to process and manage the Almaciga business on their own. This research, together with the other components of the project, helped the tribal people realized the importance of conservation which have prepared them to defend Almaciga and the CNMR – their ancestral domain – to the challenges of habitat and environmental destruction. The CNMR is finally declared as a protected area in 2016. Future plans for Almaciga management include the creation of tribal organization that sustainably controls and manages the resin collection business (Nicknick Saavedra pers. comm. 2017).

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