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Leveraging Preexisting Exotic *Piper aduncum* L. Vegetation as a Nurse Plant to Restore Successional Grasslands in Mindanao, the Philippines

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Restoration planting with nurse plants is an effective strategy for forest restoration in harsh habitats. In cases where native nurse plants are absent, colonizing exotic vegetation in degraded successional grasslands may be used as nurse species in restoration projects, provided they do not outcompete or suppress the target native plants beneath their canopy. In this study, a three-year restoration planting trial was conducted within a successional grassland using different manipulative planting techniques to test the potential of the invasive exotic *Piper aduncum* L. to serve as a nurse plant for indigenous tree species. The treatments included understory planting, edge planting, and open grassland. Three shade-tolerant species from the Dipterocarpaceae family were used for restoration – namely *Rubroshorea polysperma* (Blanco) P.S.Ashton & J.Heck., *Rubroshorea ovata* (Dyer ex Brandis) P.S.Ashton & J.Heck., and *Parashorea malaanonan* (Blanco) Merr. Seven seedlings per species were planted in each treatment, replicated across six locations, totaling 378 seedlings. The treatments varied significantly in terms of canopy openness and light conditions. No significant differences in growth performance were observed among the dipterocarp species, regardless of treatment. However, seedlings – irrespective of species – grew significantly better and had higher survival rates at the canopy edge sites, where moderate canopy openness and light conditions were present, compared to understory and open sites. Seedling growth performance, measured in relative height and diameter growth, and survival rates were positively correlated with moderate light levels, particularly between 1.1 to 1.4 mol m^{-2} d^{-1}, found at the edge sites. This study demonstrates that preexisting invasive exotic *P. aduncum* can be managed to act as a nurse plant to facilitate the establishment of canopy species in harsh and degraded environments such as successional grasslands.

Keywords: exotic species, nurse plant, *Piper aduncum* L., restoration planting, successional grassland

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INTRODUCTION

Restoration planting in recent years has become an area of increasing interest worldwide. Programs implementing reforestation projects require a comprehensive approach and strategy to ensure newly planted seedlings will survive. In many instances, reforestation programs consider early-colonizer vegetation (such as shrubs and grassland) to be a source of competition for newly planted tree seedlings (Berkowitz *et al*. 1995). Thus, early-colonizer communities are often cleared prior to restoration planting, and in other instances, seedlings are planted away from these communities [*e.g.* Eldridge and Soliveres (2015)]. These interventions are especially critical in areas where non-native plant species are colonizing native communities, although studies addressing the effect of invasive alien plants in restoration planting are still few [*e.g.* Svriz *et al.* (2013)]. This invasion by non-native plant species is a growing conservation problem worldwide and threatens local and regional biodiversity (Langmaier and Lapin 2020).

Positive and negative interactions among individuals within plant communities and biomes have been widely documented across numerous ecological experiments. A study by Hischier *et al.* (2023), for instance, found evidence of the net positive effects of preexisting vegetation on seedling establishment at low-elevation sites, primarily due to microsite amelioration provided by these plants. In contrast, at high-elevation sites, net negative effects were observed, driven by increased competition from the high establishment rates of low-elevation grasses in bare soil plots. This suggests that the use of preexisting vegetation as a nurse crop can have variable effects on the establishment of new plants across environmental gradients. Nonetheless, the positive effects of preexisting vegetation as nurse plants are generally considered more pervasive than their competitive effects, especially in degraded environments (Flores and Jurado 2003; Gómez-Aparicio *et al.* 2004).

Plant facilitation, or the positive interaction between species, is essential in structuring plant communities, especially in disturbed ecosystems. The study by Gómez-Aparicio *et al.* (2004) reported that pioneer shrubs facilitate the establishment of woody, late-successional Mediterranean species, and can, therefore, positively influence reforestation success across various ecological settings. Numerous studies have proven that using nurse plants in restoration planting can increase survivorship and facilitate the growth and development of target species beneath its canopy. For example, nurse plants can reduce excessive solar radiation, conserve soil moisture, increase soil nutrients, and protect young plants against livestock grazing (Castro *et al.* 2004).

Moreover, the complexity and unpredictability of nurse-protégé interaction in degraded communities is a major consideration in recent research about the use of nurse crops in restoration projects (Tulod and Norton 2020). However, the use of vegetation as nurse plants with known competitive potential, especially invasive alien plants, is unpopular for several obvious reasons. For example, Herrera *et al.* (2018) found that invasive alien plant species like *Kalanchoe daigremontiana* can restrict native seedling establishment due to its allelopathic effects, which alter the composition and physiognomy of native plant communities in tropical arid environments. Nonetheless, Becerra and Montenegro (2013) suggest that the overall impact of an exotic plant on native species – whether negative or positive – depends on various mechanisms. For instance, the shade provided by exotic species can negatively affect native plants by reducing light availability (Williams and Wardle 2007), or it may have a positive effect by alleviating soil moisture stress (Dewine and Cooper 2008). In degraded ecosystems, however, plant-plant interaction is often facilitative (Pugnaire *et al*. 2011), even when exotic plants are used as nurse crops [*e.g.* Svriz *et al.* (2013)]. This approach can be a more cost-effective option for forest restoration projects than their removal, although the latter may be implemented later, once the target species have become established.

In the Philippines, many post-disturbance grasslands – especially in Mindanao – are often invaded by exotic species, especially *Piper aduncum* L. (Piperaceae), and its eradication can be both costly and labor-intensive. Most ecological studies on *P. aduncum* were centered on its negative impact and eradication [*e.g.* Padmanaba and Shiel (2014)]. Due to its rapid growth and reproduction, it can significantly affect rural livelihoods, particularly in areas where agriculture is the primary means of subsistence. The plant's invasive nature can lead to reduced crop yields and increase labor demands for farmers, who must continually clear the plant from their fields (Siges *et al.* 2005). Furthermore, there are currently no records of its management being used in restoration programs in the Philippines.

It is widely known that late-successional canopy-forming species may persist under shaded conditions, but their growth and survival may be poor under heavy shade (Tulod and Norton 2020). This has implications for the importance of canopy manipulation to facilitate the growth and establishment of target species in nurse plant canopies. Some studies have also recommended the use of manipulative intervention (*e.g.* artificial gaps, edge planting) in restoration planting to reduce the effect of canopy over-shading by nurse plants on the target species (Callaway 2007).

This study was conducted to examine the potential of invasive *P. aduncum* shrubs to act as nurse plants for the restoration planting of shade-tolerant dipterocarp species in degraded grassland conditions. Specifically, the study aimed to [1] evaluate the growth performance and survival of seedlings of *Rubroshorea polysperma* (Blanco) P.S.Ashton & J.Heck., *Rubroshorea ovata* (Dyer ex Brandis) P.S.Ashton & J.Heck., and *Parashorea malaanonan* (Blanco) Merr. under the invasive *P. aduncum* canopies; as well as [2] determine whether canopy treatments (*i.e.* understory planting, edge planting, and open planting as a control) can create favorable growing conditions for these species. The results of this study are highly important for developing options to establish native canopy tree species in degraded open environments in the Philippines, especially in areas colonized by *P. aduncum* and other invasive alien plant species.

MATERIALS AND METHODS

Location and Characteristics of the Study Site

The study was conducted at the Experimental Forest Area (EFA), (ca. 1,227 hectares) of Western Mindanao State University (WMSU). EFA is situated at *Barangay* Upper La Paz (7° 2' 48.98" N, 122° 0' 52.39" E), Zamboanga City, Province of Zamboanga del Sur, in the southwestern part of Mindanao, the Philippines (Figure 1). The study site has an altitudinal range of 600–1200 m above sea level and is characterized by flat terrain to very steep mountain slopes. Based on the modified Coronas classification, the climate in the area falls under Type III, which is characterized generally by unpronounced seasons, although it can be relatively dry from November–April and wet for the rest of the year (Corporal-Lodangco and Leslie 2017). The temperature of the area can go down close to 15 °C. The study site is a logged-over area but was historically dominated by patches of dipterocarp forest. Presently, the vegetation in the area is a mosaic of grassland and shrubland communities with the latter being dominated by the invasive alien *P. aduncum* species (Figure 2).

Experimental Design

The field trial was set up using a 3 x 3 factorial design with six locations as replicates, three dipterocarp species as Factor A, and three canopy treatments as Factor B. The canopy treatments included: [1] understory planting, [2] edge planting, and [3] open grassland (control). Each location replicate was subdivided into three planting sites, and the distance between these three sites was about 50 m (Figure 3), whereas the distance between each location

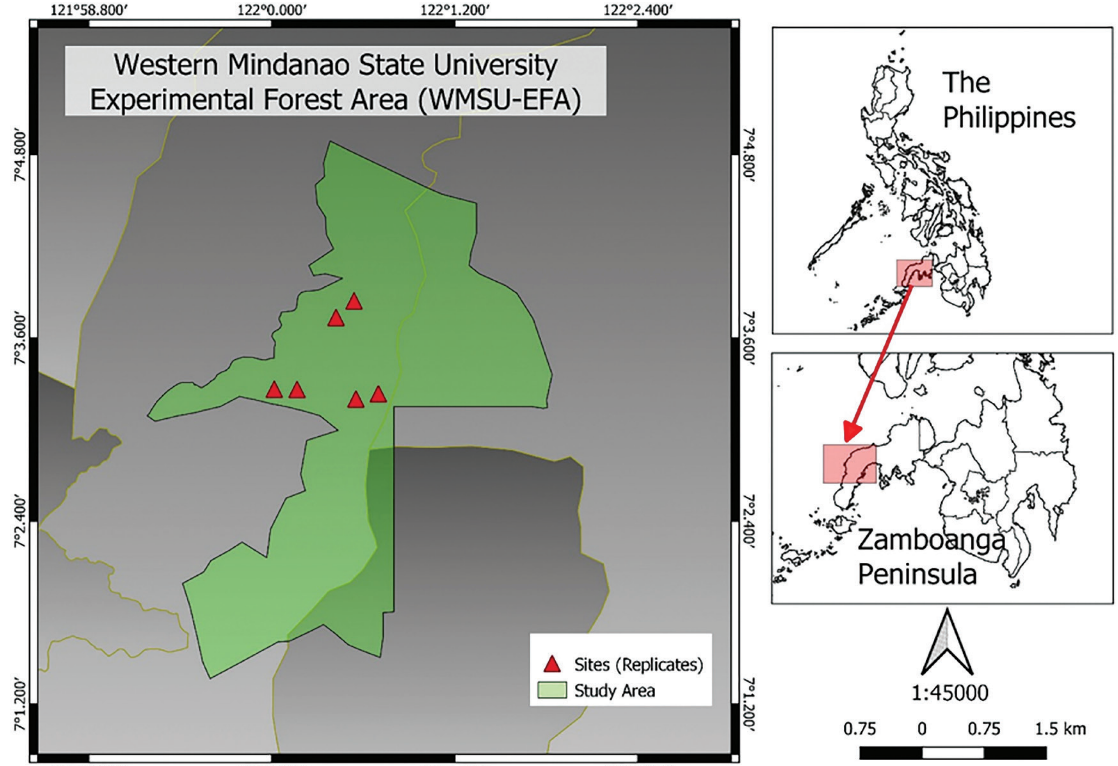


Figure 1. Geographic location of the study area.

Figure 2. Early-successional shrubs dominated by *P. aduncum* at Western Mindanao State University's Experimental Forest Area.

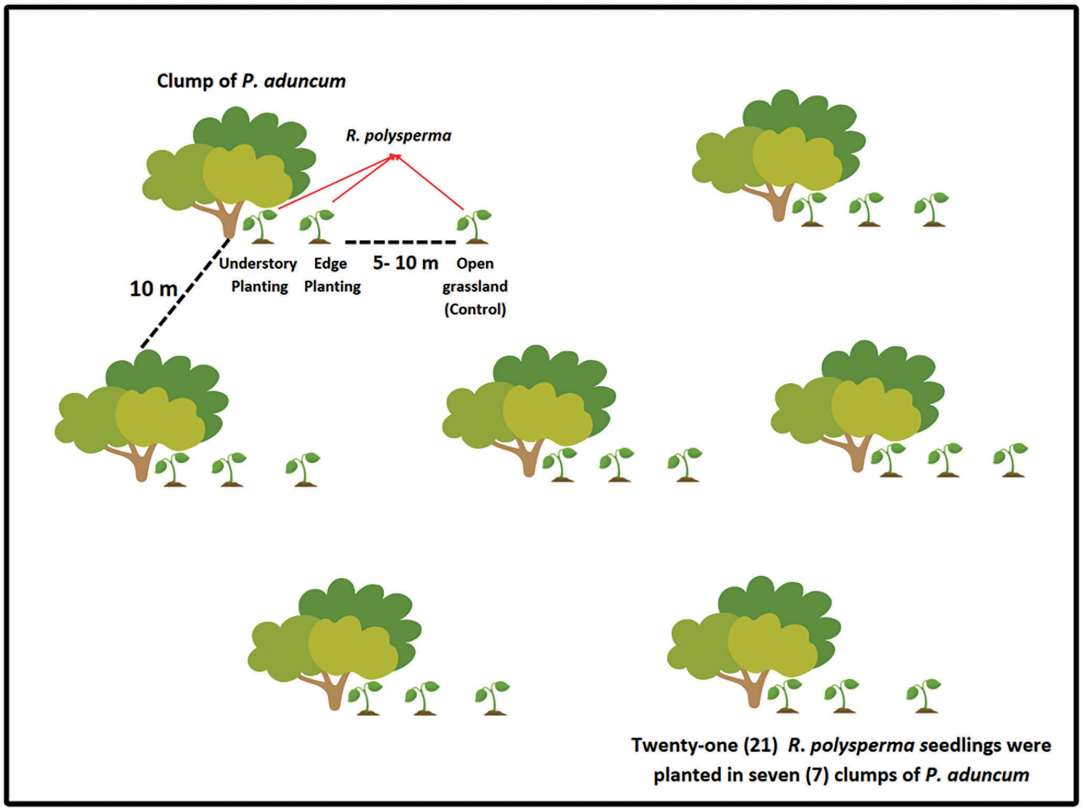


Figure 3. Schematic representation of three canopy treatments (understory planting, edge planting, open grassland, or control).

replicates was approximately 1 km apart with more or less similar conditions of aspect (231 ± 2.0º) and slope aspect (11 ± 1.0 º).

The planting sites for the study include an open grassland (control) and seven individual clumps of *P. aduncum*, where the different canopy treatments were located and the seedlings of the three dipterocarp species were planted. The three dipterocarp species used in the study were *R. polysperma*, *R. ovata*, and *P. malaanonan*. The canopy treatments included understory planting, edge planting, and open grassland (control) (Figure 3). In the understory planting, seedlings were planted under the canopy of *P. aduncum*, whereas edge planting treatment involved planting at the edge of the crown dripline of *P. aduncum.* In the open grassland planting (control), seedlings were planted about 5–10 m away from the closest *P. aduncum* clumps in the area. The distance between *P. aduncum* clumps was at least 10 m. Thus, a total of 126 individual *P. aduncum* clumps and 378 seedlings were used in the study.

Seedling Preparation and Measurements

Each out-planted seedling was tagged individually for periodic monitoring. Initial measurements of seedling height and diameter were taken immediately after transplanting. Height was measured from the base of the stem to the topmost bud using a meter stick, and diameter was measured 1 cm above the soil surface using a seedling caliper. Subsequent measurements started two months post-planting in June 2020 and continued every two months until August 2023. Seedlings were deemed dead if their stems and leaves became brittle or if they were missing from the site.

The relative growth in height and diameter, as well as the percent survival of seedlings by treatment over time, were calculated using the formulas from Tulod and Norton (2020):

$$\textit{Relative height growth} = \frac{HT2-HT1}{HT1} \quad (1)$$

where:

HT1 = seedling height at planting
HT2 = seedling height at different measurement periods

$$\textit{Relative diameter growth} = \frac{DT2-DT1}{DT1} \quad (2)$$

where:

DT1= seedling diameter at planting
DT2= seedling diameter at different measurement periods

$$\textit{Percent survival} = \frac{s}{N} \times 100 \quad (3)$$

where:

s = number of seedlings that survived in every experimental unit
N = number of potted seedlings

Additional parameters measured for each treatment included slope, slope aspect, light levels, and canopy openness. These measurements were taken once at each planting site. The slope and slope aspect were determined using a clinometer and compass, respectively. Hemispherical photography was used to quantify light levels and canopy openness (Figure 4). Photos were taken under overcast conditions using a fisheye lens. The camera was positioned at a height of 1.5 m, just above the seedlings, aligned to magnetic north, and leveled with a bubble level. Percent light transmittance was then estimated using Gap Light Analyzer software version 2.0 (Frazer *et al.* 2000).

Soil Collection

Before initiating the main study activities, soil samples were collected to analyze the physicochemical properties of the study site. A total of 18 soil samples were collected from six sites, with three representative samples from where the three species were planted. These samples were taken at a depth of 0–30 cm and thoroughly mixed, and a composite sample of at least 1 kg was prepared for laboratory analysis. The analyses conducted included measurements of moisture content (MC), nitrogen (N), phosphorus (P), potassium (K), pH, organic matter (OM), and cation exchange capacity (CEC).

Data Analysis

Data analysis was performed using R software (R Core Team 2023). Differences in physical site variables, slope, and aspect were assessed using nonparametric tests on ranks. Slope aspect differences among treatments were evaluated using the Wallraff test of angular distances with the "circular" package (Lund *et al.* 2017), equivalent to the Kruskal-Walli’s rank-sum test.

For soil properties, differences in OM, N, and MC among treatments were analyzed using the generalized linear model (GLM) function in the lme4 package with a quasibinomial family due to model overdispersion. Soil pH, CEC, P, and K differences among treatments were examined using linear regression models in the lme4 package (Bates *et al.* 2015).

Canopy openness and light-transmitted photosynthetic active radiation (PAR) (mol m^{-2} d^{-1}) differences among treatments were assessed using mixed models, with treatments as fixed effects and replicate sites as random effects. Since no variation was found in the random effect, the analysis proceeded with a GLM using the binomial family. Differences in log-transmitted total PAR among treatments were examined using linear regression models in the lme4 package. Treatment effects on light and canopy openness were assessed using the Wald chi-squared

Figure 4. Representative hemispherical photos of the three experimental treatments: [a] understory planting; [b] edge planting; [c] open grassland.

test (ANOVA function) in the "car" package (Fox and Weisberg 2011). Differences in initial height and diameter data were assessed using a one-way analysis of variance (ANOVA).

Relative height growth (RHG) and relative diameter growth (RDG) among treatments and species (fixed factor) were assessed using mixed models, which are robust for unbalanced repeated measures data and account for seedling mortality. Seedling growth rate data were fitted using mixed models with the lm function in the lme4 package, applying maximum likelihood. Significance was tested using the ANOVA function in the "car" package, and Sidak pairwise comparisons were conducted using the "emmeans" package (Lenth and Lenth 2018).

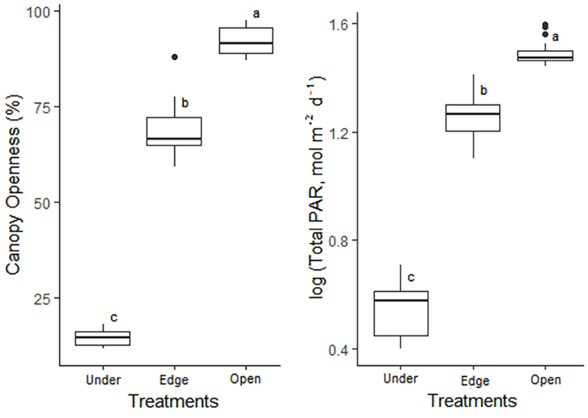
Relationships between per annum scaled seedling growth and log-transformed total transmitted PAR were fitted using polynomial regression models. Models were compared using ANOVA and compareLM functions in the "rcompanion" package (Mangiafico and Mangiafico 2017), with the model having the lowest AIC selected as the best fit. Mixed models with binomial distribution were used to define relationships between survival rates among treatments and species and tested for significance using the ANOVA function in the "car" package. Mean seedling survivorship was calculated per treatment across six site replicates for analysis. Sidak pairwise comparisons of significant treatment effects were also conducted.

For the relationship between per annum scaled seedling growth and survivorship (%) and log-transformed total transmitted PAR, polynomial logistic regressions were fitted. The best model was selected based on AIC estimates and the R statistic. The pseudo-squared of logistic regression models was estimated using the nagelkerke function in the "rcompanion" package (Mangiafico and Mangiafico 2017).

RESULTS

Canopy Openness and Light Transmittance among Treatments

The canopy openness and light transmittance varied significantly among the treatments (W^2 = 69913, $p < 0.001$); (W^2 = 58550, $p < 0.001$). As expected, open grassland (control) had the highest percent canopy openness with 91.93 ± 0.12%, followed by edge site and understory treatments with 68.95 ± 0.24% and 14.41 ± 0.07%, respectively (Figure 5a). As expected, the transmitted PAR was also higher in the open grassland (control) (1.5 ± 0.002 mol m^{-2} d^{-1}) compared to the edge site (1.25 ± 0.003 mol m^{-2} d^{-1}) and in the understory canopy (0.55 ± 0.003 mol m^{-2} d^{-1}) (Figure 5b).



[a] [b]

Figure 5. [a] Mean percent canopy openness and [b] log-transformed mean PAR (mol m^{-2} d^{-1}) of three experimental treatments: [under] understory planting; [edge] edge planting; [open] open grassland planting (control). Box-and-whisker plots with different letters indicate significant differences at $p < 0.05$. The filled lines inside the box-and-whisker plot represent the mean value, whereas the points outside the box-and-whisker plot are the outliers.

Table 1. The mean and SE values of soil properties in the understory of *P. aduncum*, edge of *P. aduncum*, and open grassland (control) where the three species were planted.

Soil properties	Understory	Edge	Open (control)
CEC (cmol/kg)	30.37 ± 0.04	35.60 ± 0.05	28.13 ± 0.1
OM (%)	1.30 ± 0.02	2.26 ± 0.02	0.83 ± 0.01
MC (%)	10.97 ± 0.1	13.98 ± 0.1	9.20 ± 0.1
N (%)	0.10 ± 0.002	0.15 ± 0.002	0.07 ± 0.001
P (ppm)	7.52 ± 0.13	10.62 ± 0.16	5.81 ± 0.11
K (ppm)	100 ± 1.50	125 ± 1.28	75.68 ± 0.84
pH	6.73 ± 0.001	6.73 ± 0.001	6.72 ± 0.001

Description of Soil Properties among Three Different Planting Treatments

In this study, various soil properties were measured under three different planting treatments: understory planting, edge planting, and open grassland (control). The results showed that the CEC was highest in the edge sites (35.60 cmol/kg), followed by the understory (30.37 cmol/kg), with the lowest levels observed in the open grassland (28.13 cmol/kg). Similarly, the OM content was greatest in the edge sites (2.26%), followed by the understory (1.30%), and the lowest levels in the open grassland (0.83%), whereas the MC followed the same trend, with the highest moisture levels in the edge sites (13.98%), followed by the understory (10.97%) and the open grassland (9.20%). In terms of nutrients, the N content was highest in the edge sites (0.15%), followed by the understory (0.10%), and the lowest in the open grassland (0.07%). Similarly, P levels were highest in the edge sites (10.62 ppm), followed by the understory (7.52 ppm) and open grassland (5.81 ppm). The K content was also highest in the edge sites (125 ppm), followed by the understory (100 ppm), and the lowest levels were found in the open grassland (75.68 ppm). Lastly, the pH values were similar across all sites, with both the edge and understory sites having a pH of 6.73, and the open grassland slightly lower at 6.72. These soil properties provide background information on the characteristics of each site.

Seedling Planted in August 2020 (36-mo Growing Period)

a. Seedling survival.

The survival rates of seedlings planted in August 2023 varied significantly among treatments throughout the measurement period ($p < 0.0001$) (Figure 6). The significant variations were largely due to the lowest survival recorded in control compared to other treatments. Survival rates were relatively higher in edge and under. The mean percent seedling survival ± SE (or mean percent survival per year) values after the 36-mo growing period ($W^2 = 1149.7, p < 0.001$) were 70.2 ± 1.2% for edge, 45.5 ± 2.3% for under, and 20.0 ± 2.5% for the control.

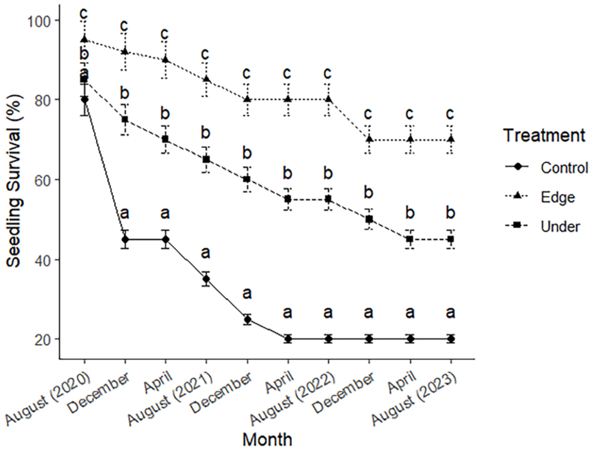


Figure 6. Seedling survival of dipterocarp seedlings planted in August 2023 in the three treatments. Significant differences ($p < 0.05$) between treatments are indicated with different letters next to the treatment symbols. Error bars represent ± SE.

There was a significant relationship between the seedling survival (%) and the log-transformed total transmitted PAR (mol m^{-2} d^{-1}) after the 36-mo growing period: $Y = 46.7 + -45.6 \log(x) -80.5 \log(x)^2 + -29.7 \log(x)^3$, $p = 0.001$, $R^2 = 0.30$. The model showed a better survival rate at log PAR values approximately between 1.0–1.3 (mol m^{-2} d^{-1}) (Figure 7).

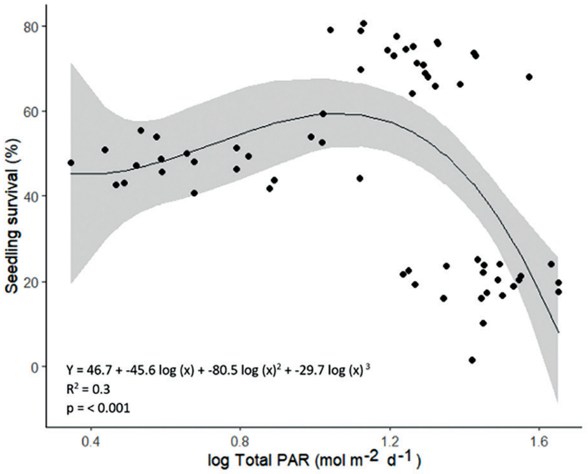


Figure 7. Relationship between the survival rate and total transmitted PAR measured at the seedling height at the three nurse vegetation treatments. The shaded region around the regression line is the confidence interval (0.95).

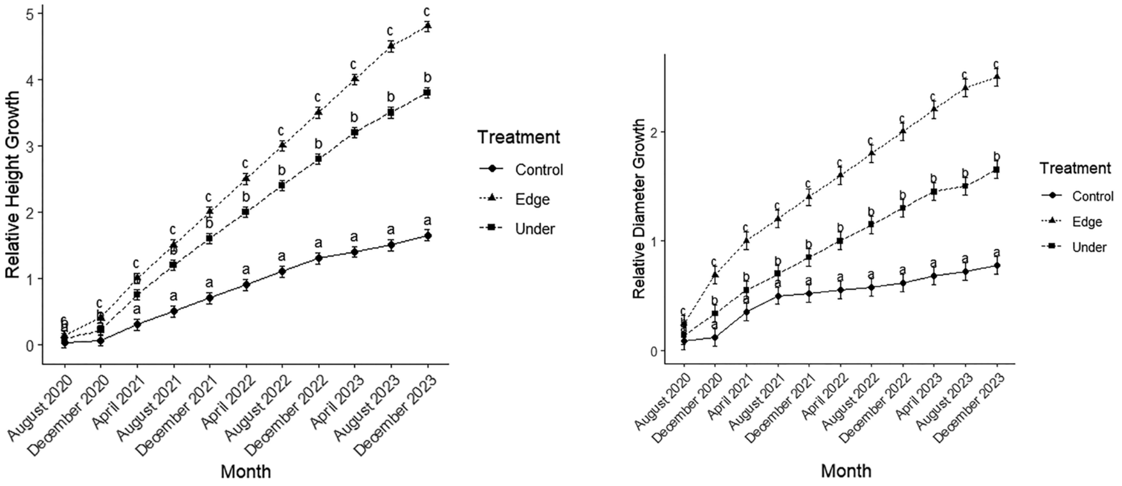
b. Seedling height and diameter

The mean initial height (cm) and diameter (cm) of the seedlings of the three species at planting were 30.26 ± 0.37 cm and 0.39 ± 0.01 cm for *R. polysperma*, 30.67 ± 0.33 cm and 0.49 ± 0.01 cm for *R. ovata*, and 29.21 ± 0.21 cm and 0.37 ± 0.01 cm for *P. malaanonan*, respectively. However, there were no significant differences found for both the initial absolute height ($F = 1.36$, $p = 0.21$) and diameter ($F = 0.06$, $p = 0.94$) of these seedlings.

RHG and RDG of Seedling Planted in August 2020–2023 (36-mo Growing Period)

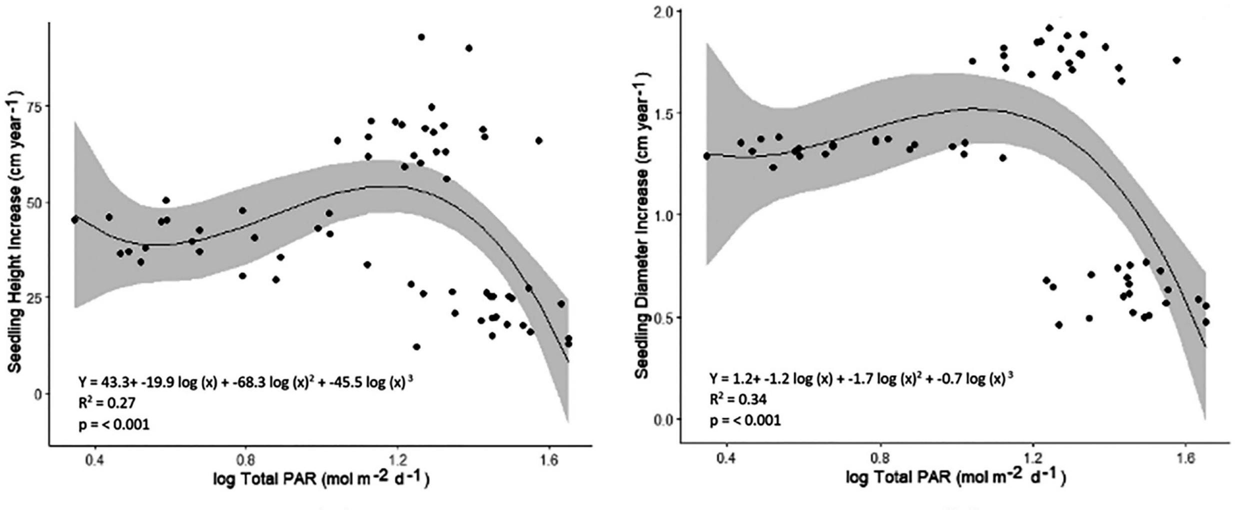
Based on the result, the RHG ($F = 0.011$, $p = 0.989$) and RDG ($F = 0.003$, $p = 0.997$) of the seedlings did not differ significantly among species; however, significant differences in RHG and RDG occurred among treatments per measurement period (Figure 8) Significant difference among treatments might be due to the adaptation ability of the seedlings after 36 mo of growing period.

In terms of canopy treatment, the seedlings planted at the edge of the crown dripline (or edge planting) of *P. aduncum* still grew significantly faster in terms of height (Figure 8a) and diameter (Figure 8b) compared to seedlings planted in the understory as well as in open grassland (control), and this observation was still consistent throughout the measurement period.



(a) (b)

Figure 8. [a] RHG and [b] RDG of dipterocarp seedlings in three canopy treatments in a 36-mo growing period. Different letters next to the treatment symbols indicate significant differences ($p < 0.05$) between treatments. Error bars represent ± SE.



(a) (b)

Figure 9. Relationship between the per annum scaled seedling height growth and total transmitted PAR measured at the seedling height at the three nurse vegetation treatments: [a] seedlings height growth and [b] seedlings diameter growth of three dipterocarp species. The shaded region around the regression line is the confidence interval (0.95).

The mean relative height growth (RHG) ± standard error (SE) after 36 months was as follows: 3.8 ± 0.40 RHG, corresponding to an actual height of 144 cm in understory planting of *P. aduncum*; 4.8 ± 0.49 RHG, corresponding to an actual height of 174 cm in edge planting of *P. aduncum*; and 1.65 ± 0.39 RHG, corresponding to an actual height of 80 cm in open grassland (control). Meanwhile, the mean relative diameter growth (RDG) ± SE (mm per year) after 36 months was: 1.65 ± 0.21 RDG, corresponding to an actual diameter of 1.19 cm for understory planting of *P. aduncum*; 2.5 ± 0.22 RDG, corresponding to an actual diameter of 1.57 cm for edge planting of *P. aduncum*; and 0.78 ± 0.12 RDG, corresponding to an actual diameter of 0.80 cm for open grassland (control).

There was a significant association between the per annum scaled seedling height and diameter growth (cm yr^{-1}) and the log-transformed total transmitted PAR (mol m^{-2} d^{-1}) after a 36-mo growing period: $Y = 43.3 + -19.9 \log(x) - 68.3 \log(x)^2 + -45.5 \log(x)^3$, $p = 0.001$, $R^2 = 0.27$. The model showed a better seedling height growth at log PAR values approximately between 1.1–1.3 (mol m^{-2} d^{-1}) (Figure 9a), whereas the diameter is $Y = 1.2 + -1.2 \log(x) - 1.7 \log(x)^2 + -0.7 \log(x)^3$, $p = 0.001$, $R^2 = 0.34$. The model showed a better seedling diameter growth at log PAR values approximately between 1.1–1.4 (mol m^{-2} d^{-1}) (Figure 9b).

DISCUSSION

Invasive alien species can play a crucial role in restoration ecology by serving as nurse plants in degraded environments (Ewel and Putz 2004). Our study investigated the influence of different planting treatments – specifically at the edge of the crown dripline of *P. aduncum*, within the understory, and in open grassland on seedling growth performance and survival. The significant variations in growth rates and survival among these treatments underscore the critical role of microenvironmental factors in shaping plant establishment and development. Notably, seedlings planted at the edge of the crown dripline exhibited accelerated growth rates in both height and diameter compared to those in the understory and open grassland. This finding highlights the importance of light availability and reduced interspecific competition in edge environments, which create optimal conditions for seedling establishment. These results align with previous research emphasizing the benefits of edge habitats in promoting biodiversity and ecosystem resilience (Ewel and Putz 2004).

Furthermore, a significant finding of our study was the variation in survival rates across the different planting treatments. Seedlings at the edge of the crown dripline demonstrated the highest survival rates, indicating enhanced resilience to environmental stressors relative to those in the understory and open grassland. This observation underscores the significance of selecting appropriate planting sites within restoration areas to maximize seedling survival success. Previous studies have documented positive outcomes where invasive plants contribute substantially to biomass production and soil stabilization, thereby facilitating ecological restoration. For example, certain invasive species have been shown to enhance soil fertility and provide habitat structure, supporting the establishment of native plant communities (d'Antonio *et al.* 2016). Regarding soil properties, our study measured factors such as CEC, OM levels, and nutrient content (N, P, and K) to characterize site conditions. Although these measurements provided background information, they were not directly linked to seedlings' success in this study. Future research could explore the interactive effects of soil properties and microenvironmental conditions on seedling growth and survival to optimize restoration practices further.

Our findings highlight the critical role of microenvironmental factors, particularly light availability and planting site selection, in influencing seedling growth and survival in restoration ecology. By integrating ecological principles with practical management strategies, we can enhance the resilience and sustainability of forest ecosystems, contributing to biodiversity conservation and ecosystem health. Further research, including comparative analyses and long-term monitoring, will be crucial for refining restoration practices and advancing our understanding of plant-environment interactions in dynamic ecosystems.

CONCLUSIONS

In conclusion, our study demonstrates that the invasive species *P. aduncum* can function as a nurse plant, facilitating the growth and survival of native seedlings when planted at the edge of its canopy drip line. This finding highlights the critical influence of microenvironmental factors, particularly light availability, on seedling establishment and development in restoration settings. The strategic utilization of invasive species such as *P. aduncum* in restoration efforts may offer a novel approach to ecological recovery, although its effectiveness is likely contingent upon local environmental conditions and species interactions. Our research contributes to the broader understanding of the complex plant-environment interactions that govern ecosystem recovery pathways and underscores the potential for innovative restoration strategies that integrate invasive species management. Future studies should aim to expand upon these findings through larger-scale experimental designs and long-term monitoring to validate the efficacy of such approaches and inform evidence-based conservation practices.

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REFERENCES

BATES D, MAECHLER M, BOLKER B, WALKER S, CHRISTENSEN RHB, SINGMANN H, DAI B, GROTHENDIECK G, GREEN P, BOLKER MB. 2015. Package 'lme4'. Convergence 12: 2.

BECERRA PI, MONTENEGRO G. 2013. The widely invasive tree *Pinus radiata* facilitates regeneration of native woody species in a semi-arid ecosystem. Appl Veg Sci 16: 173–183.

BERKOWITZ AR, CANHAM CD, KELLY VR. 1995. Competition *vs.* facilitation of tree seedling growth and survival in early successional communities. Ecology 76: 1156–1168.

CALLAWAY RM. 2007. Positive interactions and interdependence in plant communities. Springer Science & Business Media.

CASTRO J, ZAMORA R, HODAR JA, GOMEZ JM, GOMEZ-APARICIO L. 2004. Benefits of using shrubs as nurse plants for reforestation in Mediterranean mountains: a 4-year study. Restor Ecol 12: 352–358.

CORPORAL-LODANGCO IL, LESLIE LM. 2017. Defining Philippine climate zones using surface and high-resolution satellite data. Procedia Comput Sci 114: 324–332.

D'ANTONIO CM, AUGUST-SCHMIDT E, FERNANDEZ-GOING B. 2016. Invasive species and restoration challenges. In: Foundations of Restoration Ecology. p. 216–244.

DEWINE JM, COOPER DJ. 2008. Canopy shade and the successional replacement of tamarisk by native box elder. J Appl Ecol 45: 505–514.

ELDRIDGE, DJ, SOLIVERES S. 2015. Are shrubs really a sign of declining ecosystem function? Disentangling the myths and truths of woody encroachment in Australia. Australian Journal of Botany 62: 594–608.

EWEL JJ, PUTZ FE. 2004. A place for alien species in ecosystem restoration. Front Ecol Environ 2: 354–360.

FLORES, J, JURADO E. 2003. Are nurse-protégé interactions more common among plants from arid environments? Journal of Vegetation Science 14: 911–916.

FOX J, WEISBERG S, ADLER D, BATES D, BAUD-BOVY G, ELLISON S, HEIBERGER R. 2012. Package 'car'. Vienna: R Foundation for Statistical Computing.

FRAZER GW, CANHAM CD, LERTZMAN KP. 2000. Gap light analyzer, version 2.0. Bulletin of the Ecological Society of America. p. 191–197.

GÓMEZ-APARICIO L, ZAMORA R, GÓMEZ JM, HÓDAR JA, CASTRO J, BARAZA E. 2004. Applying plant facilitation to forest restoration: a meta-analysis of the use of shrubs as nurse plants. Ecological Applications 14: 1128–1138.

HERRERA I, FERRER-PARIS JR, BENZO D, FLORES S, GARCIA B, NASSAR JM. 2018. An invasive succulent plant (*Kalanchoe daigremontiana*) influences soil carbon and nitrogen mineralization in a neotropical semiarid zone. Pedosphere 28: 632–643.

HISCHIER CM, HILLE RIS LAMBERS J, ISELI E, ALEXANDER JM. 2023. Positive and negative plant-plant interactions influence seedling establishment at both high and low elevations. Alpine Botany. p. 1–13.

LANGMAIER M, LAPIN K. 2020. A systematic review of the impact of invasive alien plants on forest regeneration in European temperate forests. Frontiers in Plant Science 11: 524969.

LENTH R, LENTH MR. 2018. Package 'lsmeans'. Am Stat 34: 216–221.

LUND U, AGOSTINELLI C, AGOSTINELLI MC. 2017. Package 'circular'. Repository CRAN 775: 5.

MANGIAFICO S, MANGIAFICO MS. 2017. Package 'rcompanion'. Cran Repos 20: 1–71.

PADMANABA M, SHEIL D. 2014. Spread of the invasive alien species *Piper aduncum via* logging roads in Borneo. Tropical Conservation Science 7: 35–44.

PUGNAIRE FI, ARMAS C, MAESTRE FT. 2011. Positive plant interactions in the Iberian southeast: mechanisms, environmental gradients, and ecosystem function. J Arid Environ 75: 1310–1320.

R CORE TEAM. 2023. R: a language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/

SIGES TH, HARTEMINK AE, HEBINCK P, ALLEN BJ. 2005. The invasive shrub *Piper aduncum* and rural livelihoods in the Finschhafen area of Papua New Guinea. Human Ecology. p. 875–893.

SVRIZ M, DAMASCOS MA, ZIMMERMANN H, HENSEN I. 2013. The exotic shrub *Rosa rubiginosa* as a nurse plant: implications for the restoration of disturbed temperate forests in Patagonia, Argentina. Forest Ecology and Management 289: 234–242.

TULOD AM, NORTON DA. 2020. Early response of late-successional species to nurse shrub manipulations in degraded High Country, New Zealand. New Forests 51: 849–868.

WILLIAMS MC, WARDLE GM. 2007. *Pinus radiata* invasion in Australia: identifying key knowledge gaps and research directions. Austral Ecol 32: 721–739.