Tropical Forest Restoration in the Eastern Himalaya: Evaluating Early Survival and Growth of Native Tree Species

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ABSTRACT

Asian tropical forests have among the highest rates of forest loss in the world. Ecological restoration is a vital step for biodiversity maintenance and climate change mitigation. For restoration practice, evaluation of species performance at early stages is crucial to avoid failure of the efforts and for screening species suitable to a region. Though the long-term performance of restoration plantings has been well-documented, few studies have evaluated the performance during the establishment of the planted saplings, especially in South and Southeast Asia. Restoration efforts in Northeast India, a region experiencing high forest loss, is limited by the lack of species-specific data on survival and growth. We compared inter-specific variation in seasonal survival and growth rates (diameter and height) for multiple native rainforest species from this region. We planted 3022 saplings of 50 species at a degraded open forest site. After 18 months, sapling survival varied between 9.1–94.3% for 32 species, and only six species showed "excellent" survival after 18 months. Eight out of 17 species that were tested for seasonal variation in survival showed significant differences in survival between seasons. While the diameter growth rate varied for species between seasons, the height growth rate was different between both species and season, but the interaction term between species and season was not significant. Certain animal-dispersed, medium to large-seeded primary forest species performed well and are vital for future restoration efforts in this region.

Keywords: active restoration, Arunachal Pradesh, sapling diameter growth rate, sapling height growth rate, sapling survival

Restoration Recap

- Active restoration is essential even at sites within Protected Areas that show poor natural regeneration and are heavily infested with weeds.
- Despite pronounced seasonality in these tropical forests, certain species performed well across both the wet and dry seasons, highlighting their value for restoration.
- Determining survival and growth rates across species at every site is important as it can vary across species and sites. This information along with the ecological role and functional traits of species may play an important role in determining the initial choice of saplings for restoration efforts.

The biodiverse forests of South and Southeast Asia experience the highest rate of forest loss (Laurance 2007), with a conservative estimate of 1% forest cover loss in insular Southeast Asia annually (Miettinen et al. 2011). The main drivers include habitat conversion to tree plantations, including oil palm, rubber (Boucher et al. 2011), and illegal encroachments (Hughes 2017). Intensification of anthropogenic pressure over the past few decades have resulted in alarming rates of forest conversion and land use changes in the Indian Himalayan region (Pandit et al. 2007). The wet forests of northeast India are experiencing high deforestation rates that can be attributed to the expansion of agriculture and plantation areas, developmental projects, illegal logging, ethno-civil conflicts and poor law enforcement (Kushwaha and Hazarika 2004, Velho et al. 2014). Given this scenario, ecological restoration is becoming more important to address the increasing areas of degraded landscapes and to avoid the impending biodiversity losses driven by it (Lamb 2011, Elliott et al. 2013). Apart from conserving native biodiversity, ecological restoration is crucial for reconnecting fragmented

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forests, improving water quality and carbon sequestration, minimising soil erosion, improving livelihoods and facilitating climate change mitigation (Chazdon 2014).

There is a need for restoration, even in Protected Areas (dedicated areas managed and protected for wildlife conservation), to restore their ecological integrity by recovering the degraded or lost habitat (Dudley et al. 2010, Keenleyside et al. 2012). Generally, Protected Areas are known to be better than non-Protected Areas in preventing forest loss and ensuring species conservation (Bruner et al. 2001, Joppa et al. 2008). Laurance et al. (2012), however, found that the ecological condition of 50% of Protected Areas were deteriorating through decreasing forest cover causing a loss of large-seeded plant species and favouring invasive, pioneer and generalist species that thrive in disturbed areas.

Many Protected Areas in Northeast India have a history of anthropogenic disturbances such as past logging and the associated weed invasion that have stalled forest recovery. Re-colonization by native tree species is precluded at such sites due to biotic, abiotic, and dispersal limitations (Benayas et al. 2008, Chazdon 2014), thereby requiring an active intervention in the form of restoration. Active restoration is preferred at such sites, as it helps overcome ecological barriers to natural regeneration (Parrotta 2002, Elliott et al. 2013, Chazdon 2014) and accelerates forest recovery by establishing a complete tree community with early representation of large-seeded climax species (Holl and Aide 2011).

Identifying native tree species that will enable faster recovery is a fundamental step in active restoration. Species selection for restoration can be difficult due to various interacting biotic and abiotic factors at multiple temporal and spatial scales that can affect species performance (Erskine et al. 2005, Charles et al. 2018). Mixed species plantings accelerate the re-establishment of tree canopy cover over degraded areas, potentially improving the site conditions resulting in increased species recruitment (Lamb 2011). Using the right species mix can increase functional diversity and improve ecosystem resilience (Benayas et al. 2008, Rodrigues et al. 2009).

Early-stage monitoring of saplings after planting is useful in determining their survival potential and growth patterns to avoid failure of restoration projects (Breugel et al. 2011). Previous studies from Northeast India have explored the factors affecting natural regeneration and seedling survival at different sites (Khumbongmayum et al. 2005, Deb and Sundriyal 2007, Deb and Sundriyal 2008). However, to the best of our knowledge, this is the first study from this region, which has quantified the performance (survival and growth) of native tree species planted at a site that is being actively restored.

Given this background, we aimed to identify key species for ecological restoration that could be used for faster recovery in degraded or open sites based on their performance at a restoration site inside the Pakke Tiger Reserve in Arunachal Pradesh. The main objectives are to 1) assess the initial sapling survival, 2) compare interspecific variation in sapling survival between seasons and 3) compare sapling growth rates (diameter and height) between different seasons.

Methods

Study Area

The restoration site is located in Pakke Tiger Reserve (PTR; area: 861.9 km², 92°36′–93°09′ E and 26°54′–27°16′ N), a Protected Area in Arunachal Pradesh, India. The elevation in PTR varies from 150 to 1800 m ASL. The area has a tropical and subtropical climate. Cold weather occurs from November to February, which is relatively drier with May and June being the hottest months. The mean (± SD) minimum and maximum temperature varies between 18.3°C (± 4.7) and 29.3°C (± 4.2) respectively (Datta and Rawat 2008). The average annual rainfall is 2500 mm. The region receives more than three-quarters of the annual rainfall from May to September (southwest monsoon), with occasional showers throughout the year, and the second rainy period from December to April (northeast monsoon) (Datta and Rawat 2008). The vegetation is classified as Assam valley tropical semi-evergreen forest 2B/C1 (Champion and Seth 1968). For additional details on the study site, see Datta and Rawat (2008).

Although there are primary undisturbed forested areas inside the reserve, the lower-elevation forests in Pakke have been logged in the past (~40 years ago) (Datta and Goyal 2008). The vegetation in these patches has not recovered and has sparse tree cover with very poor regeneration owing to weed (*Mikania micrantha*, *Chromolaena odorata*, and *Ageratum conyzoides*) infestation.

Planting

In May 2018, we planted 3022 saplings of 50 species in an open degraded patch (1.32 ha) of forest inside PTR, at an altitude of 250 ASL. The site had remained fallow due to occasional cool season burning by the Forest Department to maintain it as a grassland for attracting ungulates. The site was heavily invaded by *M. micrantha*. Species were selected based on past information on plant species composition from the study area (Datta and Rawat 2008). The selected species for planting had a higher representation (39 species; 78%) of biotically-dispersed species as compared to abiotically dispersed species (11 species; 22%), similar to the relative proportions of biotically and abiotically dispersed species (78% animal-dispersed plant species) earlier reported from the study area (Datta and Rawat 2008). We raised the saplings in a nursery at Seijosa, a village adjoining PTR. We collected mature seeds from trails and roads in the forest and villages and from under hornbill nest and roost trees where seeds have a low probability of survival (Datta 2001). We sowed the collected seeds in shaded seedbeds in soil. After germination, when 1–3 pairs of leaves had fully expanded, the seedlings were transplanted to polythene bags containing a mixture of soil and manure (2:1). We also used saplings raised from wildlings, following Raman et al. (2009). We collected wildlings of some species from trails and seasonally dry streams, where their survival chances were poor. For certain species such as *Tetrameles nudiflora*, *Syzygium formosum*, *Bombax ceiba* and *Litsea monopetala*, all the saplings were raised from wildlings. For *Chukrasia tabularis*, *Artocarpus chaplasha* and *Gmelina arborea*, the saplings were raised from seeds as well as wildlings. The wildlings and seedlings were initially grown under shaded conditions and gradually moved out in the sun for exposure to sunlight (to acclimatize them to conditions at our restoration site). The wildlings and seedlings were pooled and any distinction between them was lost after their collection and planting, as the proportion of saplings raised using wildlings was very low as compared to the ones raised from seeds. Watering was reduced two months before planting to harden the saplings. At the time of planting, the saplings were 10 to 20 months old, with height ranging from 25 to 180 cm. We planted only healthy saplings without any fertilizer application or watering after planting.

The restoration site preparation included manual weed clearing and digging pits of a diameter of approximately 15 cm and depth of approximately 40 cm. Since the area had poor regeneration, we planted the saplings at a spacing of 1.5 to 2.5 m following Raman et al. (2009). We carried out the planting at the onset of monsoon in May 2018, to avoid potential desiccation of saplings. We tagged the planted saplings using metal tags with unique codes.

Monitoring

We divided the plot into five subplots, which were of approximately equal area and had similar numbers of saplings. The subplots were adjacent to each other. From June 2018, following stabilization (two weeks after planting), we monitored one of the five subplots every month for survival. The plots were weeded in each subplot at an interval of 3–4 months after planting. We determined sapling survival at the end of 18 months. Out of the 50 species planted, 32 species represented by at least 10 individuals were considered for the analysis. To determine seasonal differences in survival of select species (n = 17 species), we monitored subplot 2 at the end of the first wet period (November–December), end of the first dry period (April–May), and end of the second wet period (i.e., after 18 months) in consecutive years. Subplot 2 had 38 of the 50 species. Of these 38 species, 17 species represented by at least 10 individuals in subplot 2 were considered for the analysis. We marked the saplings as dead if they could not be located.

To determine growth (height and diameter) rates, we monitored 15 individuals of nine species (Supplementary Material Table S3). We measured the sapling stem diameter 2 cm above the ground and marked the measurement location using waterproof oil paint to avoid errors while remeasuring following Sangsupan et al. (2018). We measured the stem height from the marked point to the shoot tip. The taller stem was measured when the saplings exhibited a split stem. If there were broken shoots, then it was noted, and we took the measurements till the highest point of the stem. The measurements were carried out in six-month intervals from June 2018. Most saplings were in subplot 1. If subplot 1 lacked sufficient representation of the target species, then individuals from neighbouring subplots were monitored.

Statistical Analyses

Based on sapling survival after 18 months, species survival was classified as excellent (76–100% survival), good (51–75%), moderate (26–50%) and poor (< 25%) following Raman et al. (2009). The species with more than ten individuals planted that were still alive at the time of monitoring were used for calculating percent survival.

We used Kaplan-Meier survival analysis to compute the survival probability for different species between the three seasons (first wet, first dry, and second wet seasons) in subplot 2 (Kaplan and Meier 1958). The survival data were right-censored as some saplings were still alive at the end of the study. We used the log-rank test to determine differences in survival between species. We used means and confidence intervals to infer differences in survival probability within species across seasons.

Individual saplings (out of the 135 belonging to the nine species that were marked) that did not survive 18 months after planting were not considered for the growth rate analysis. We used growth rate monitoring data from December 2018, June 2019, and December 2019 for seasonal comparison as it overlapped with the end of wet (December) and dry (June) period respectively. The negative values obtained for the difference in diameter at different intervals during sapling measurement were converted to zero as they may be indicative of negligible growth, which can be ecologically important (Charles et al. 2018). However, we did not exclude the negative values of height growth as the reason for shoot breakage was either natural shoot dieback or herbivory. We were careful during weeding, and only four saplings were damaged during weeding and these were not part of the growth rate study. Following Charles et al. (2018), we calculated the relative growth rate (RGR) for diameter and height as $RGR_i = (R_{i,t1}-R_{i,t2}) / (t_2-t_1)$, where $R_{i,t1}$ and $R_{i,t2}$ are the diameters or heights of stem i at time 1 and time 2, respectively, and (t_2-t_1) is the number of days between time 1 and time 2. We used Two-way Repeated-measures Analysis of Variance (ANOVA) to determine differences in diameter and height growth rates between seasons and species. Post-hoc tests were used to determine differences between statistically significant dependent variables ($p < 0.05$). We conducted all the data analysis using the R statistical software package (R v. 3.6.3, R Foundation for Statistical Computing, Vienna, AUT).

Results

Overall Survival

Post-planting mortality (after two weeks) of the 32 tree species caused due to transplantation shock or poor handling was 0.17%. After 18 months, average percent survival of 32 species was 53.7% and varied between 9.1% for *Choerospondias axillaris* to 94.3% for *Pterygota alata* (Supplementary Material Table S1). Six out of 32 species showed excellent survival (> 75%). Thirteen species showed good survival (51–75%). Ten species showed moderate survival (26–50%), while three species showed poor survival (< 25%) (Supplementary Material Table S1).

Survival after the Wet and Dry Period

To determine the influence of season on sapling survival, we monitored 504 saplings of 17 species for which more than ten individuals were planted in subplot 2. The proportion of individuals surviving for the different species varied across seasons (Supplementary Material Figure S1). Kaplan-Meier survivorship curves that were tested using the log-rank test showed statistical difference in survival probabilities across the 17 species ($\chi^2 = 104$; $p < 0.001$; Figures 1A and B). Based on the survival probability across seasons, we were able to classify species into two groups, 1) species which showed no difference in survival probability across seasons (as inferred from overlapping means and 95% CI) (Figure 1A) and 2) species which showed a difference in survival probability across seasons (Figure 1B). Figure 1B shows few species, such as *Dysoxylum gotadhora*, *Horsfieldia kingii*, *A. chaplasha*, with a reduction in survival probability in the first dry season. It also shows that species like *Phoebe cooperiana*, *Bauhinia purpurea*, *Sterculia villosa*, *T. nudiflora*, *C. tabularis* had a difference in their survival probability in the first and second wet season (as inferred from overlapping means and 95% CI).

Growth

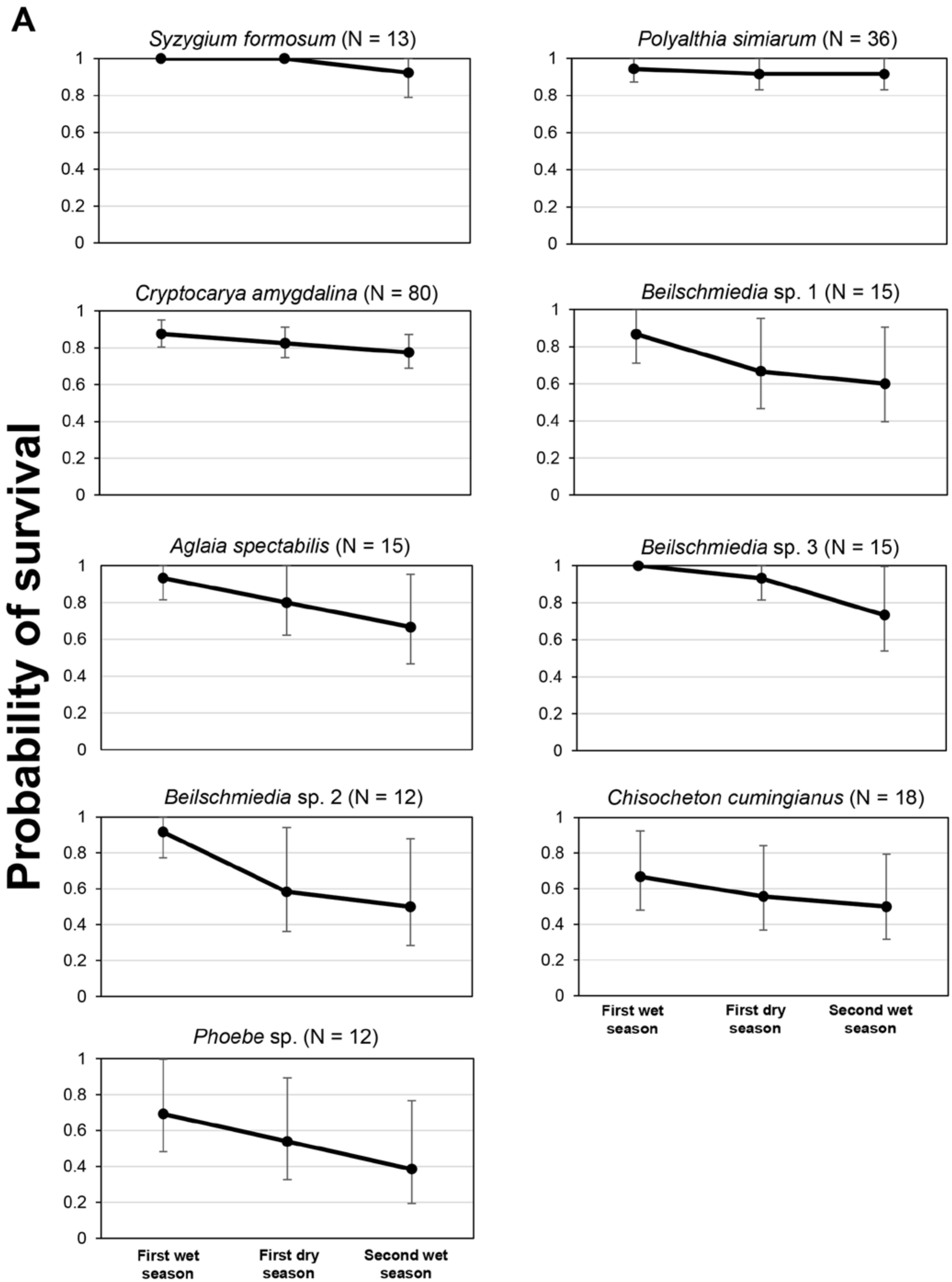
We monitored 135 saplings of nine species for growth (height and diameter). The number of saplings that survived after 18 months varied from nine to 15 (Supplementary Material Table S2). Out of the 15 individuals of each of the nine species, maximum mortality (40%) was observed in *G. arborea* and *T. nudiflora*, with zero mortality in *Polyalthia simiarum*. The average diameter and height attained at the end of 18 months varied between species (Supplementary Material Figure S2).

Seasonal Variation in Growth

The average diameter and height growth rate varied between species across seasons (Supplementary Material Table S3). Eight of the nine species showed maximum growth rate in diameter in the second wet season (Figure 2A, Supplementary Material Table S3). The mean growth rate in diameter for *T. nudiflora* was similar in the first and second wet season (Figure 2B, Supplementary Material Table S3). Seven species except for *Chisocheton cumingianus* and *G. arborea* showed maximum growth rate in height in the second wet season (Figure 3, Supplementary Material Table S3). Except for *Aglaia spectabilis*, there was a decline in the diameter and height growth for all the species in the first dry season followed by a peak in the second wet season (Figure 2B, Supplementary Material Table S3). *Aglaia spectabilis* showed a steady growth rate across all three seasons (Figure 2A and B, Supplementary Material Table S3).

We found a significant interaction between season and species in the mean diameter growth rate, indicating that diameter growth rates differed between species across seasons (Table 1). The main effect of species was significant across the three seasons ($p < 0.001$) as revealed by Bonferroni-adjusted p-values (Supplementary Material Table S4). Post-hoc tests revealed that in the first wet season, diameter growth rates of *T. nudiflora* were significantly different from seven other species except *Cryptocarya amygdalina* (Figure 2A). In the first dry season, diameter growth rates of *A. spectabilis* were significantly different from six species except for *C. amygdalina* and *P. cooperiana* (Figure 2A). In the second wet season, diameter growth rates of multiple species differed from each other, but no one species emerged consistently different like the previous two seasons (Figure 2A). The main effect of season was significant for five out of the nine species ($p < 0.05$) as revealed by Bonferroni-adjusted p-values (Supplementary Material Table S5). The diameter growth rates for *D. gotadhora* were significantly different across three seasons (Figure 2B). On the other hand, diameter growth rates did not differ for *P. cooperiana* and *G. arborea* across the three seasons (Figure 2B). The remaining species showed differences between pairs of seasons but not consistently across all seasons (Figure 2B).

For height growth rate, the interaction between season and species was not significant (Table 1). Only the main effects were significant, indicating that the height growth rate differed between species and seasons (Table 1). Post-hoc tests revealed that growth rate in height was consistently lower for *G. arborea* as compared to all species (Figure 3). The height growth rates in the second wet season were significantly higher compared to the first wet and first dry season, indicating potential lag before increase in growth rates (Figure 3).


A
Probability of survival
Syzygium formosum (N = 13)
Polyalthia simiarum (N = 36)
Cryptocarya amygdalina (N = 80)
Beilschmiedia sp. 1 (N = 15)
Aglaia spectabilis (N = 15)
Beilschmiedia sp. 3 (N = 15)
Beilschmiedia sp. 2 (N = 12)
Chisocheton cumingianus (N = 18)
Phoebe sp. (N = 12)
First wet season
First dry season
Second wet season

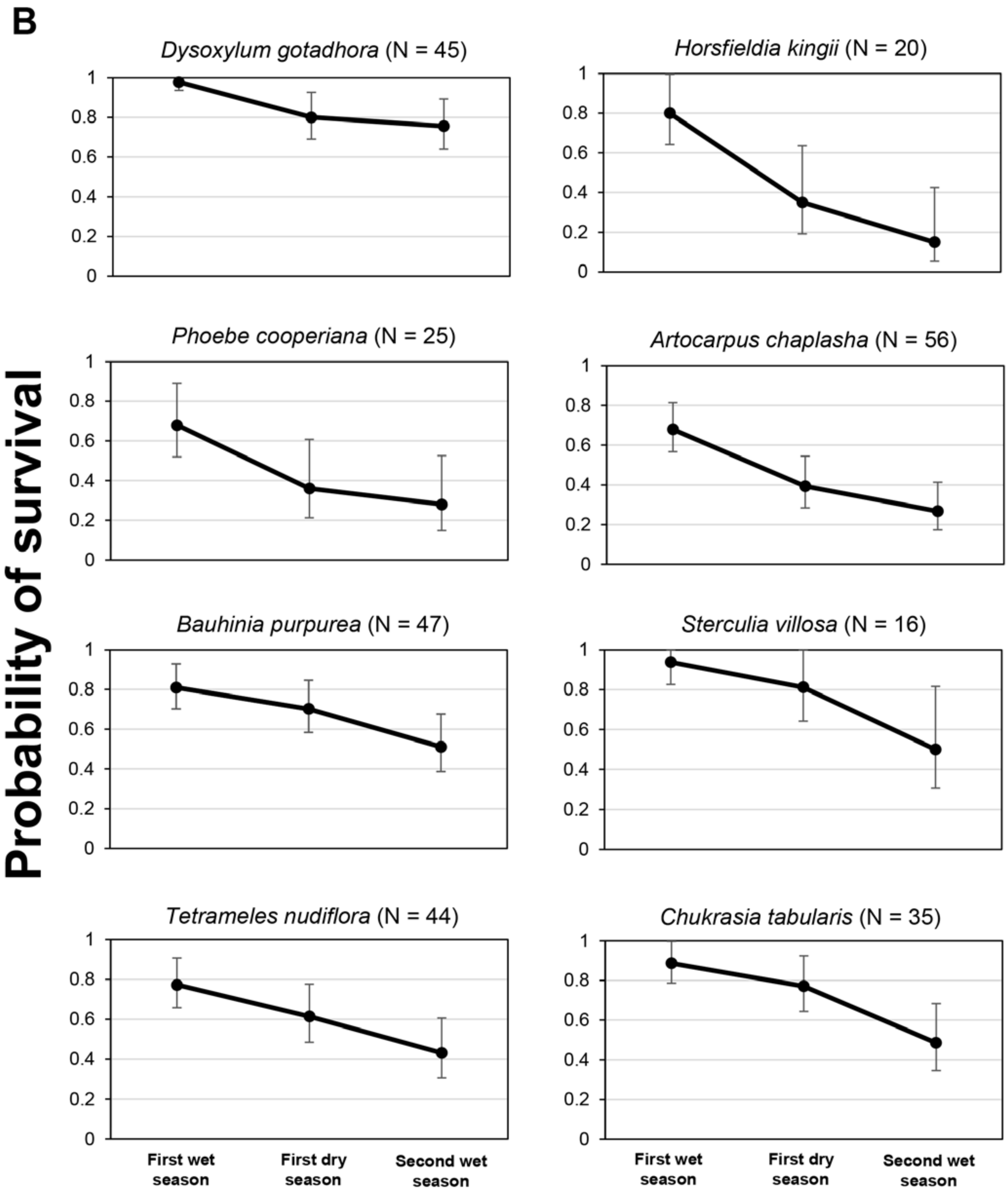


Figure 1. Survival curves (mean survival probability and 95% CI) of 17 selected tree species (in subplot 2 with more than 10 individuals) at the end of three seasons at the restoration site inside Pakke Tiger Reserve, Arunachal Pradesh, India. The species have been grouped into two categories—no difference in survival probability across seasons (A) and differences in survival probability across seasons (B). Differences are inferred based on non-overlapping means and 95% CI. Survival probability at the start was one.

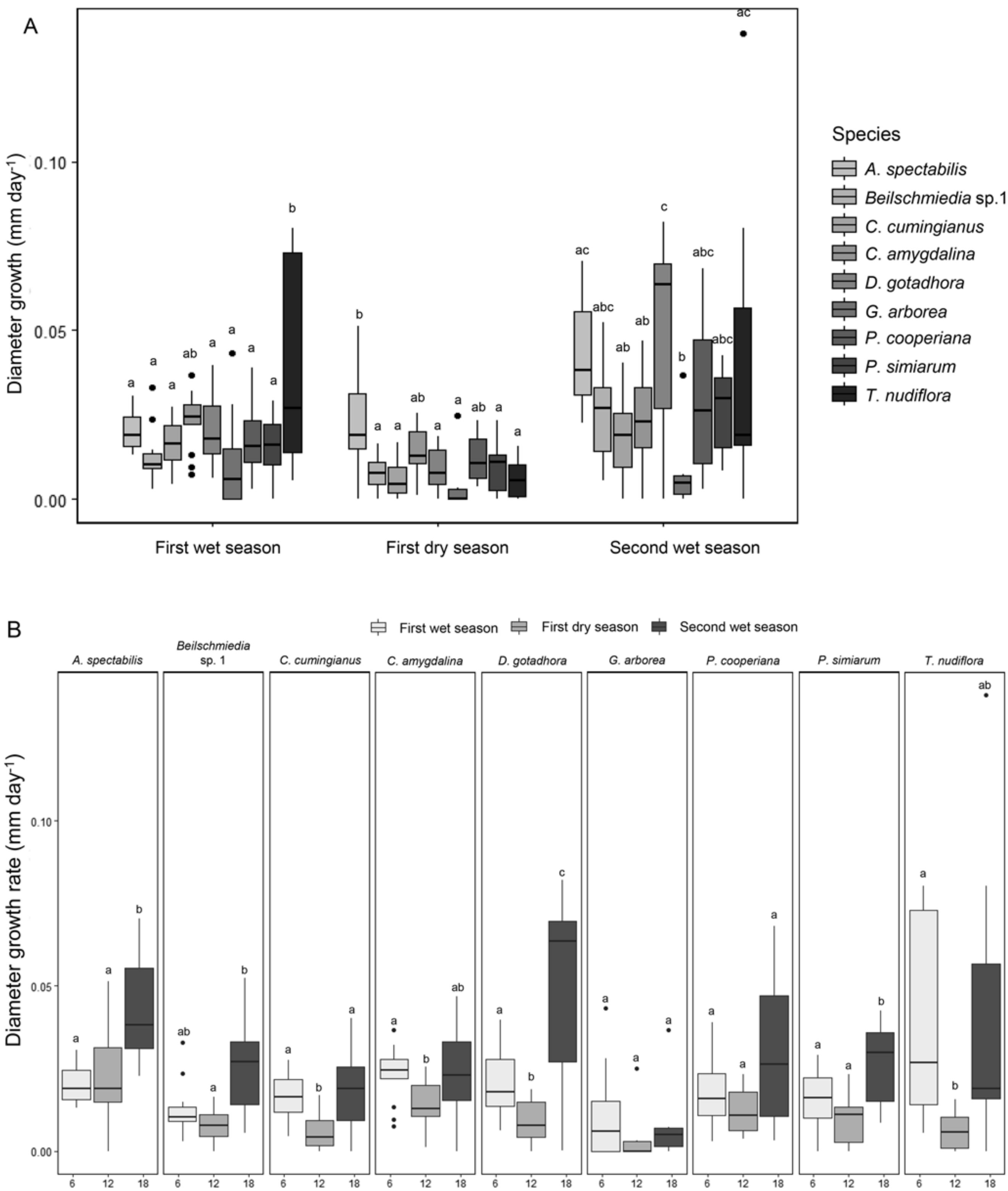


Figure 2. Box plots displaying diameter growth rate (mm day^{-1}) of surviving saplings (n given in Table S2) of nine species across seasons at a restoration site inside Pakke Tiger Reserve, Arunachal Pradesh, India. Different letters indicate significant differences (as inferred by analysis of variance (ANOVA) with post-hoc Tukey's test, *p* < 0.05) between species (A) and between seasons (B).

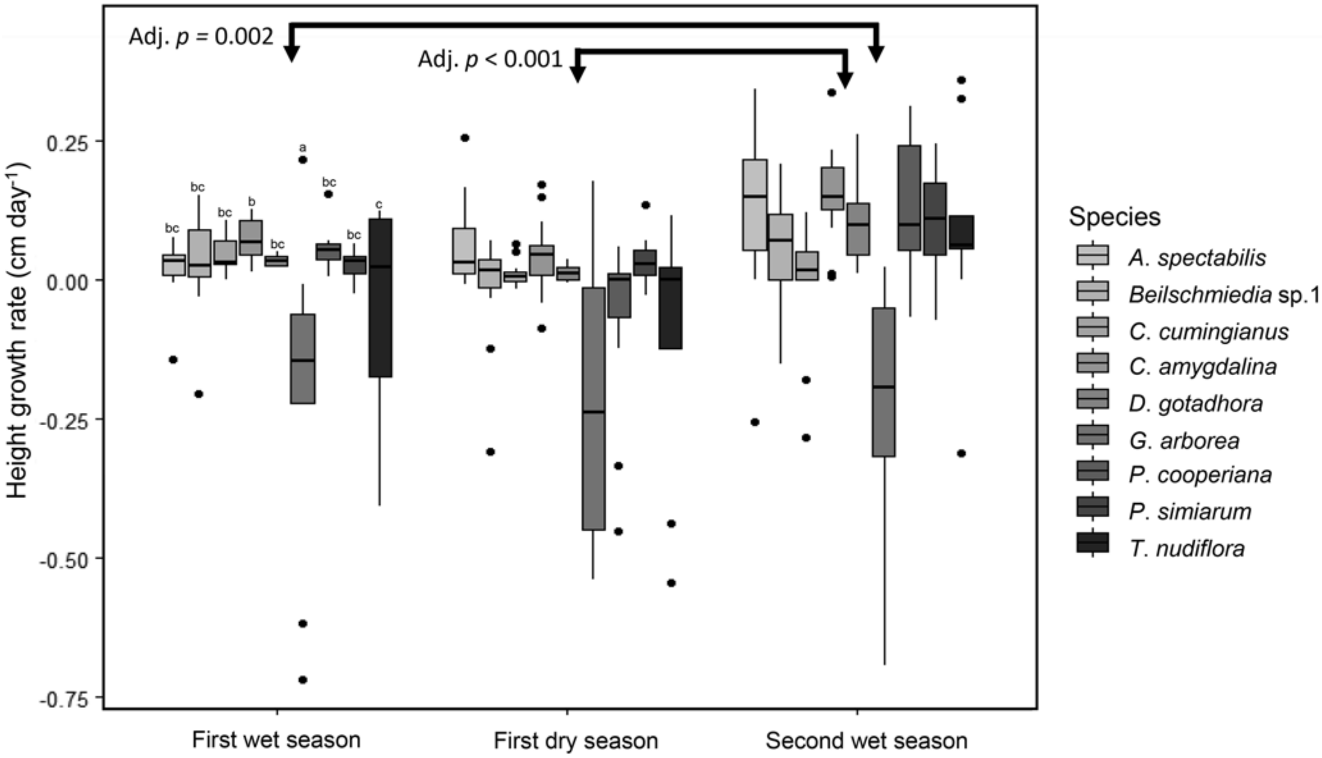


Figure 3. Box plots displaying height growth rate (cm day^{-1}) of surviving saplings (n given in Table S2) of nine species across seasons at a restoration site inside Pakke Tiger Reserve, Arunachal Pradesh, India. Different letters indicate significant differences between species and arrows indicate significant differences between seasons (as inferred by analysis of variance (ANOVA) with post-hoc Tukey's test, $p < 0.05$). Since the interaction between species and season was not significant, differences between species have been indicated with alphabets for the first wet season only.

Discussion

This study systematically documents, for the first time, the performance (survival and growth) of native tree species planted at a degraded forest site in Northeast India. Our results suggest that there is an influence of season on early-stage sapling survival and diameter growth rate, as most species performed well in the wet season compared to the dry season. We found that the survival probability varied across species, and there were inter-specific differences in sapling survival across seasons. We found significant interactive effects between season and species in diameter growth rates, and significant differences in height growth rates for species in different seasons. This study has enabled us to identify key species that are suitable for planting in this region, which will be valuable in future restoration efforts to maximise the returns on restoration investment.

Sapling Survival

Sapling survival is known to vary across years, seasons and sites and is likely influenced by multiple factors, including site-level characteristics (e.g., soil, slope, aspect, distance to forest), climatic (e.g., rainfall), species functional traits (e.g., wood density) (Breugel et al. 2011, Román-Dañobeytia et al. 2012, Charles et al. 2017). In Asian tropics, sapling survival has been shown to vary between 54.1–75.9% after 17 months of planting over two years (calculated from Table 2 of Elliott et al. [2003]); and 39–95% after 18 months across different years and sites (Raman et al. 2009). Fertilizers have been added during planting at these study sites (Elliott et al. 2003, Raman et al. 2009). Despite no addition of fertilizers, sapling survival was 53.8% after 18 months at our site. Trampling or herbivory may have influenced the survival at our site. We have anecdotally documented

Table 1. Mixed Two-way Repeated Measures ANOVA results comparing growth rates of stem diameter and height between species and season at a restoration site inside Pakke Tiger Reserve, Arunachal Pradesh, India.

Effect	DF	F	*p*
Stem Diameter			
Species	08, 096	05.487	< 0.001
Season	02, 192	53.977	< 0.001
Species*Season	16, 192	03.808	< 0.001
Stem Height			
Species	08, 096	34.941	< 0.001
Season	02, 192	09.224	< 0.001
Species*Season	16, 192	01.195	0.275

trampling or browsing of saplings by large herbivores resulting in mortality and shoot breakage. Given that the site is within a Protected Area that has good densities of large herbivores, like the Asian Elephant *Elephas maximus*, Gaur *Bos gaurus*, Sambar *Rusa unicolor* and Wild Pig *Sus scrofa* (Selvan et al. 2014), herbivory is likely to have influenced the sapling performance. *Prunus ceylanica*, which is listed by IUCN as Endangered, is found in our study site (WCMC 1998). *Prunus ceylanica* saplings experienced heavy herbivory (N. Borawake, pers. obs.) by ungulates and exhibited poor survival.

Past literature has documented higher survival in the wet season compared to the dry season (Raman et al. 2009, Girma et al. 2010) or similar survival across seasons (Alvarez-Aquino and Williams-Linera 2014). Inter-specific differences in survival probability have been reported in other studies (Raman et al. 2009, Alvarez-Aquino and Williams-Linera 2014). We also documented inter-specific differences in survival across different seasons. Several species (*Phoebe* sp., *A. chaplasha*, *C. cumingianus*) exhibited a sharp drop in survival at the end of the first wet period. Species like *B. purpurea*, *S. villosa* did not exhibit a dip in survival probability at the end of first dry season, but a dip was noted at the end of the second wet season indicating that the survival of these species is influenced by other factors. Saplings that survived well included a mix of biotically- and abiotically-dispersed species and small- and large-seeded plant species. We could not identify certain key traits that were consistently associated with higher survival in this study. Further studies are required to determine the key traits that likely influence the survival of saplings.

Sapling Growth

Unlike sapling survival, we consistently found higher RGR in the stem diameter for almost all species in the wet season compared to the dry season. Despite strong seasonality in these tropical forests, species like *A. spectabilis*, *P. simiarum*, and *P. cooperiana* did not show a significant dip in diameter growth rate in the dry season, while *G. arborea* showed a uniform diameter growth rate in both seasons. Sapling growth is known to be influenced by season, with higher growth in the wet season compared to the dry season (Charles et al. 2018). However, consistent higher growth rates in the wet season for diameter did not necessarily imply higher height growth rates. We did not find greater height growth rates in the wet season compared to the dry season. Lack of consistent patterns in height could be due to shoot dieback and herbivory observed at the site, which resulted in a negative growth rate for a few species. We did not quantify the extent of damage caused by herbivory in this study, however, species like *C. amygdalina*, *G. arborea*, *P. cooperiana* seemed to have been affected by it (N. Borawake, pers. obs.). This highlights that for the choice of species in restoration, the differences in growth and height rates need to be considered separately. Species that have higher rates of growth in height might be useful for shading that might inhibit weed growth enabling faster recovery of degraded patches, but they need not necessarily have high diameter growth rates.

Species Performance at the End of the Second Growing Season

Restoration success is known to be a result of a combination of tree survival and growth rates at a particular site, making it important to consider both factors while evaluating the performance of the planted saplings (Charles et al. 2018). The use of native tree species with high field performance (survival and growth rate) is essential for faster forest recovery. Our results suggest that certain species exhibited successful seedling performance while others either displayed better survival or growth. The survival rates of most species were high except for *G. arborea* and *P. cooperiana* with moderate survival. The RGR in diameter was good for all the species, a few species exhibited negative growth rates in height (*G. arborea*, *T. nudiflora*) while others showed good height growth. Among the species that had high survival rates (*C. amygdalina*, *D. gotadhora* and *P. simiarum*), the growth rates of *C. amygdalina* and *D. gotadhora* were among the highest for diameter and height, and *P. simiarum* had similar growth rates compared to the other species. These three species emerge as the key species. They are all animal-dispersed and have medium- (*C. amygdalina* and *P. simiarum*) to large seeds (*D. gotadhora*). They exhibited better survival and growth for restoration at our site. The fruits of these species are also consumed by many frugivores, making them ecologically important (Naniwadekar et al. 2019).

Two other large large-seeded tree species *A. spectabilis* and *C. cumingianus* (important hornbill food plants in breeding season) had good survival. *Aglaia*, a commercially important tree, was also among the best in growth, whereas *Chisocheton* showed average growth. *T. nudiflora* showed good survival and the highest diameter growth rate but poor height growth rate. *T. nudiflora* is an emergent, wind-dispersed, shade-intolerant species and is the most important nest tree of the secondary-cavity nesting hornbills in the region (Datta 2001, Günter et al. 2011). Certain species (*A. spectabilis* and *Beilschmiedia* sp. 1) showed a lag phase before showing accelerated growth in the second wet season. This trend could be a consequence of inter-annual variation in weather conditions or an initial period of stabilisation, after which there is growth acceleration.

P. cooperiana is a bird-dispersed tree species and a commercially important timber species whose fruits are also in demand for consumption by local people (Payum et al. 2013). It exhibited good growth rate but low survival. *G. arborea*, a shade-intolerant species which is considered a good candidate for planting in open degraded areas because of fast-growth and dense spreading crown that can effectively shade out weeds (Elliott et al. 2000, Lamb 2011), performed poorly at our site. The cause of the poor performance may be due to shoot dieback due to heavy browsing by insect pest *Calopepla leayana* on its leaves which caused complete defoliation, which has also been reported elsewhere (Barman 2014). This highlights that certain species identified as a suitable candidate for planting at one site may not be ideal everywhere. Another factor that may have affected the performance of a few species (*A. chaplasha*, *G. arborea*, *L. monopetala*) is the use of wildlings, as in the study carried out by Raman et al. (2009), lowest survival was observed at the restoration sites where mostly wildlings were planted. It may therefore be important to determine the difference between the performances of saplings raised from seeds and wildlings in restoration planting.

Restoration Implications

A database on the performance of planted species can improve our ability to screen species that grow well and the ones that show high initial mortality which might render them unsuitable for restoration planting in open areas (Parrotta 2002, Breugel et al. 2011). Performance-based species selection is vital for restoration success and these characteristics are likely to be specific for a region and dependent on biotic and abiotic factors (Goosem and Tucker 2013), highlighting the need to generate reliable information on survival and growth for different species. This study provides critical information on the early stage performance of the native tree species which is needed to generate a preliminary list of species suitable for restoration, which was previously unknown. Based on the survival or growth rates determined by this study, species like *A. spectabilis*, *C. amygdalina*, *D. gotadhora*, *P. simiarum*, *P. alata* and *S. formosum* performed well. However, additional studies on other species found in the landscape are required to add more species to this list. Restoration planting in relatively more open sites would be aided by using the species identified through this study. These species can be used to establish faster recovery in such sites, while to maximize diversity, other species can be planted at later stages when there is more shade and canopy. For example, certain large-seeded tree species such as *D. gotadhora* also did exceedingly well in the open conditions of the site. Given this, restoration approaches should also include planting such species which otherwise would not be able to overcome various ecological barriers (e.g., absence of seed dispersers) to get to such sites (Parrotta 2002). In addition, the study identifies species that were poor performers and future investigations need to understand the mortality factors (like herbivory and trampling) and reasons for lower performance and determining how survival and growth can be augmented for such species. In future, replication within and outside the study area is required to determine the generalizability of these results.

The study highlights the need to monitor both the diameter and height, as a single measure may not be sufficient to assess the recovery of the restored sites. Given the high deforestation rates (Kushwaha and Hazarika 2004), ecological restoration with local community support will be crucial for ensuring persistence or recovery of the diversity of flora and fauna in the region.

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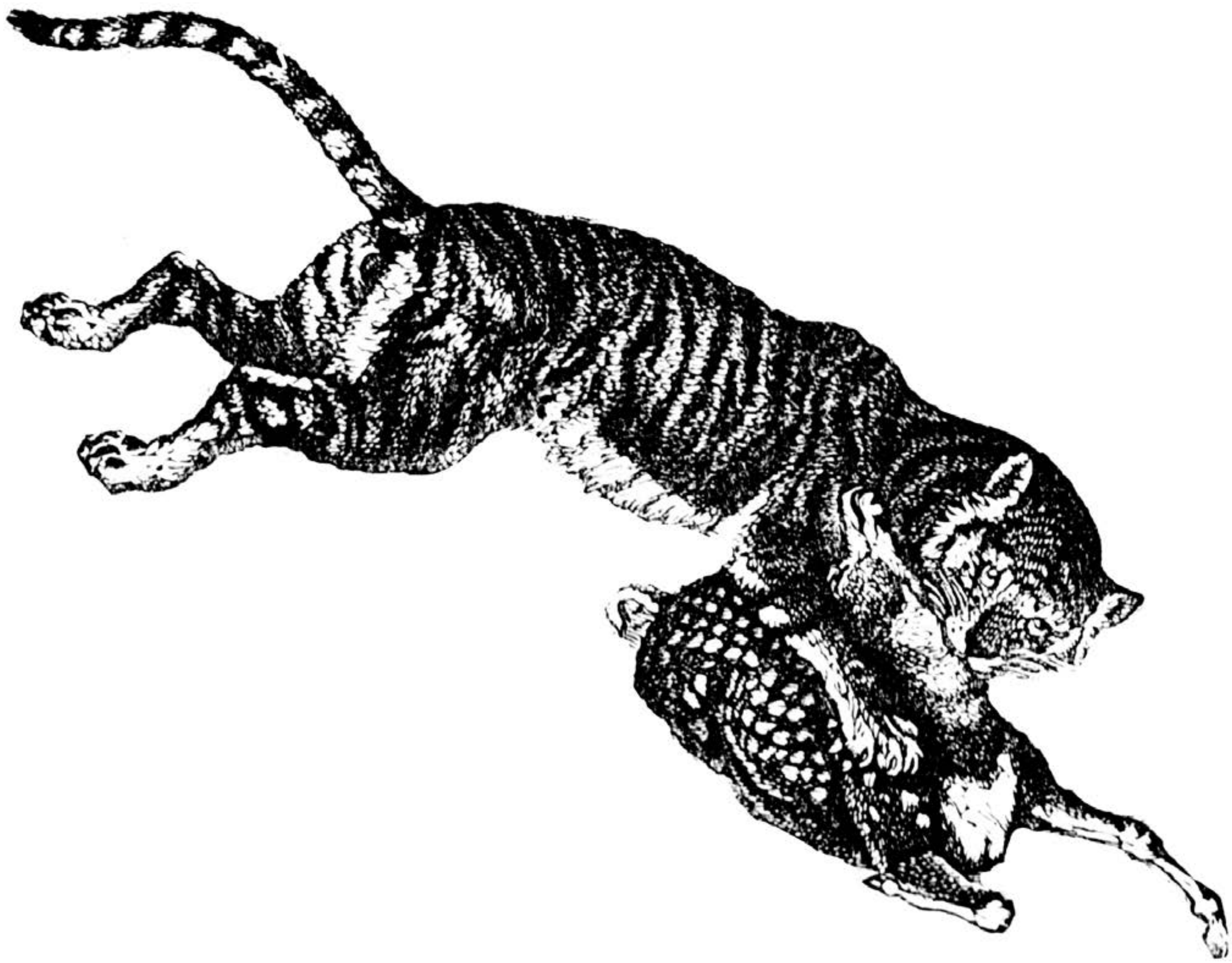

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