Early-stage Growth Dynamics of *Senegalia catechu* during Restoration of Lowland Flood Plains in Central Nepal

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ABSTRACT

Use of native species in restoring degraded land is an effective way of restoring integrity of ecosystems. However, there are very few studies assessing growth dynamics of plants in early stages of restoration interventions, and to our understanding there are very limited studies focusing on flood plain inhabiting plant species, particularly Senegalia catechu. The objective of this study, therefore, was to assess the early-stage growth pattern of native riverine S. catechu (locally known as 'Khair') in degraded Shakti Khola flood plain (with humans and grazing stressors) of Bara District, Nepal. Three-year growth assessment of S. catechu in the interval of 6 months was performed. Early-stage growth dynamics of S. catechu showed that this species can act as pioneer native species in restoration of lowland Terai flood plains in Nepal. We observed the mean growth ± standard error of basal diameter of S. catechu emerged from broadcast seeding during the first year was 0.43 ± 0.02 cm. During the second and third years, basal diameter reached 2.14 ± 0.10 and 3.76 ± 0.18 cm, respectively. Similarly, during first, second and third years, the mean height of the plant was 39 ± 2.48, 133 ± 5.95 and 260.56 ± 11.22 cm, respectively. The results indicate that the attempt was successful in establishing S. catechu seedlings and saplings in the sandy and nutrient poor flood plains areas. Future attempts should focus on establishing other co-existing native species and develop regional floodplain management strategy and co-benefit local communities.

Keywords: Early-stage growth, Flood plains, Nepal, Restoration, *Senegalia catechu*

Introduction

Use of native species in restoring degraded lands and forest ecosystems is recognized as an effective way of restoring integrity of the ecosystems (Lu et al.,

2017). Use of native plants can restore intact habitat which is suitable for supporting native wild faunal and floral species. Additionally, preference of native species for ecological restoration reduces the probability of introducing potentially invasive species (Csecserits et al., 2016; Ferreira et al., 2019). However, selection of native species which can successfully adopt to local conditions require in-depth knowledge about species ecology, which is often lacking, especially in the developing countries (Cao et al., 2011; Hall et al., 2011; Lu et al., 2017). The abundance and density of the planted species in restoration projects requires thorough investigation to understand how survival and growth of species can be maximized through different assemblages (Lasky et al., 2014). This provides a practical way of enhancing the outcomes of the restoration interventions. Ecological restoration activities in some cases use revegetation by planting and growing native plant species to rebuild disturbed soil and also to develop the place for restoration (Kaase & Kat, 2012; Vander Mijnsbrugge et al., 2010). This has two-way benefits of bank stability and also develop network of stabilized soil mass (Florsheim et al., 2008; Lennox et al., 2011). Plantation of seedlings of trees and shrubs where no source of natural regeneration occurs is of utmost importance (Kaase & Kat, 2012; Kauffman et al., 1997). Selection of suitable species for restoration of degraded areas might require longer period of research and innovation. However, in case of highly altered ecosystems (due to disturbances), native species might not always show success for restoration practices, especially when ecosystems are under abrupt shift or hysteresis (Jager & Soons, 2023).

In Nepal, a large proportion of plain areas, especially in Terai, are degraded by flood (Jha et al., 2013), and due to anthropogenic stressors, such as encroachment for agricultural activity, grazing, and cutting, resulting in very few scattered plant species. In higher elevation and reaches, the problem is mainly landslides, debris flows and river bank cutting, whereas in the low-lying areas floods generally overflow the bank and cause bank erosion, inundation of agricultural fields and fill with sediments (coarse sediments) every year during the monsoon (June - September) affecting poor people living in the flood plain areas. Terai and Siwaliks of Nepal are more vulnerable to flooding each year. Restoring flood plain areas is one of the effective ways to keep communities safe. The flood plain areas and associated forest are being degraded day by day from natural and anthropogenic pressures resulting into the changes in natural slope, river morphology and the drainage systems. Flood is the major causes of washing away agricultural lands (loss of top soil and also crops cultivated for subsistence and commercial purposes). Therefore, there is immediate need of identifying plant species that can successfully establish and act as a pioneer species for ecological restoration (Giannini et al. 2016).

There are very few studies aimed to select suitable native tree species for restoration at field level conditions with control of grazing and other disturbances over the longer period of time. Though there are some studies focusing on nursery research, experimental field trials are very rare. Keeping the degrading factors away for long period of time and monitoring in the highly disturbed flood plain in itself is a challenge, but there is urgent need to select the plant species that can act as pioneer species, colonizing degraded lands in a short period of time. Since understanding the growth dynamics of the specific plant which is useful for restoration of degraded areas is important, understanding its growth helps in selection of the species for future restoration works. There are very few studies relating to growth dynamics of plants in early stages of restoration, and to our understanding there are very limited studies focusing on flood plain plant species, particularly *Senegalia catechu*. The objective of this study, therefore, was to understand the early-stage growth pattern of native riverine tree species *S. catechu* (locally known as 'Khair'). This study has elucidated the growth of *S. catechu* seedlings for the period of three years in degraded system (with flooding as a major stressor, and the land used for grazing purposes), and assess whether these species can initiate characteristic species assemblage in the Terai flood plain areas of Nepal.

Materials and Methods

Ethics Statement

Prior to data collection, research permission was taken from the Department of Forests and Soil Conservation, Government of Nepal for working in the area. Coordination was made with the Division Forest Office of Bara District and the community forests user group of Shivashakteshwori Community Forest, Bara District, Nepal. The research did not involve human or other animal objects. Due respect was expressed for community norms and procedures while conducting the field experiment.

Study Area

The experiment was performed in Shivashakteshwori Community Forest of Bara District, Central Terai, Nepal (Figure 1). The area considered for the study was basically the flood plain area developed by Shakti Khola.

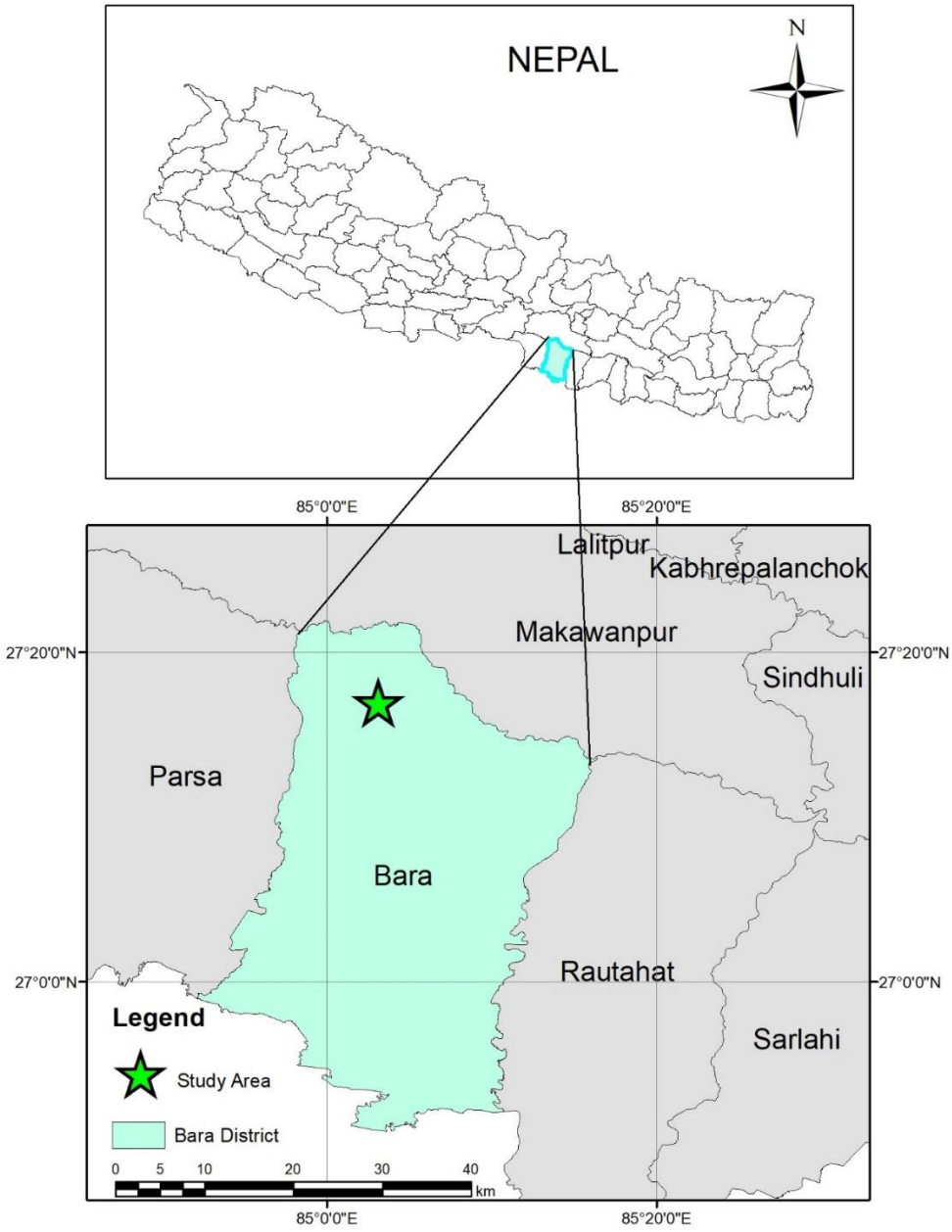

Figure 1: Location of Shivashakteshwori Community Forest in Bara District of central Terai Nepal.

The experimental plot was established in the flood plain area with an elevation of about 280 m above from sea level. The dominant species in nearby forest areas are *Shorea robusta*, *Holarrhena pubescens*, *Prasoxylon excelsum*, *Casearia graveolens*, *Dalbergia latifolia*, and *Terminalia alata*. The summers in the area are hot and humid (Figure 2). The rainfall during November, December and January are generally less than 15 mm. The higher rainfall intensities are observed during July and August.

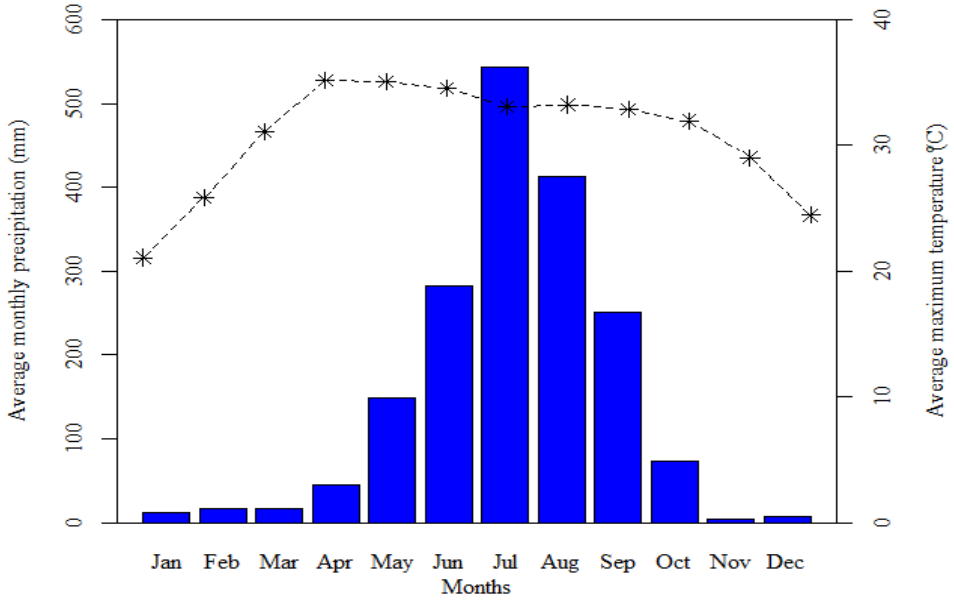

Figure 2: Average monthly precipitation and average maximum temperature of Simara Meteorological Station (one of the nearest meteorological station to Shivashakteshwori Community Forest in Bara District (bars represent the average monthly precipitation, and the line with points show the average maximum temperature).

Species Selection, Seed Sources and Germination

Senegalia catechu was selected as a native species for flood plain restoration of Terai, Nepal, which was based on the discussion with the community forest user group members and based on our observational judgement on the species performance under sandy soil conditions. The species was also under forest user groups' preference, site characteristics, species successional development history, niche complementarities and overlap, and hypothesis that they can grow well in the soils with low nutrient conditions (Bhattarai & Bhatta, 2020).

Senegalia catechu, locally known as 'Khair', is a deciduous, moderate-sized tree, growing up to the height of about 10 m (Table 1). The species is important resources and used for various purposes. The species is found in the lowland riverine areas of Nepal. Across globe, the species is found in Central and east Africa, Southern Asia, Bhutan, China, Pakistan, Myanmar, India, and Nepal (Ganges Basin) (Das, 2014; Thakur et al., 2018).

Table 1: General characteristics of *Senegalia catechu* and its habitat

Scientific Name	*Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb. (Basionym *Acacia catechu* (L.f.) Willd.)
Taxonomic position	Kingdom: Plantae; Division: Tracheophyta; Class: Magnoliopsida Order: Fabales; Family: Fabaceae
Family	Fabaceae
Common name	Khayar (Nepali name)
Locale of abundance	Central and east Africa, Southern Asia, Bhutan, China, Pakistan, Myanmar, India, and Nepal (Ganges Basin) (Thakur et al., 2018)
Stems and leaves	Short hooked spines, leaves: bipinnately compound, dark greyish-brown to dark brown barks and branches, straight and grayish-brown stem, white to pale yellow flowers (Thakur et al., 2018)
Habitat	Mostly riverine and also found in terraces (at lower elevation ranging from 80 – 1500 m)
Seed collection period	February
Uses	Fodder, timber, fuel, medicinal value, Katha, river bank stabilization, soil conservation (can even grow in low nutrient conditions)
Plant's average height	(mature)~10 m

The bark of the tree is dark and grayish brown, exfoliating in long and narrow strips. The leaves are bipinnately compound. The pale yellow or white *S. catechu* flowers measure about 3 mm in length and are in 5-10 cm long cylindrical spikes (Das, 2014). The brown colored pods are glabrous, oblong, and flattened, measure about 60 to 130 mm in length and contain 3 -7 flat and dark brown seeds (Thakur et al., 2018). The mature seeds are edible, and the hardwood extract is an important ingredient of "Paan" (usually found in Nepal and India).

The seeds of *S. catechu* were collected from the natural seed-bearing mature individuals of the area. One-hectare plot was selected for dispersing the seeds collected from mature native individuals of *S. catechu*. Freshly dispersed seeds

from the mature trees found in and around the area were collected during the end of February. Longitudinal study was carried out for the period of three years for determining the growth of *S. catechu* seedlings in the degraded flood plain area. The flood plain area was facing degradation due to constant flood damage, human pressures and livestock grazing. Of one-hectare plot under direct control from the community forest user group, 50 × 50 m plot was considered for the three-year study, and in-situ germination and growth of the species. After inspecting the collected seeds quality and treated with near boiling hot water for about 10 minutes, *S. catechu* seeds were sown on the area during mid of June 2014 in harrowed ground inside the fence so that broadcasting seeding allows the seeds to fall into crevices to retain moisture for germination. Broadcast seed application rates normally need to be higher than drilled seed rates because they have a lower germination rate. However, the advantage of broadcast seeding is that it is cheaper, easier, and creates a more natural look. Field germination success of *S. catechu* seeds was about 40% in the areas. This is because the germination of the seeds gets affected due to pathogen infestation, predation or dormancy (Burmeier et al. 2010). In the 50 × 50 m plot, 960 individuals emerged (from seeds) and of all the plants, randomly chosen 50 individuals were considered for observing growth trend over 3-year period of time in the flood plain degraded area. The individuals were tagged for the reference for future measurements.

The study area was characterized by sandy soil with poor soil nutrient environments as it was dominantly a flood plain area. Composite soil sample from depth of 5-20 cm was collected for soil texture analysis using sieve analysis. Organic matter content in the soil sample was determined by using Walkley and Black method (Walkley & Black, 1934).

Measurement of Seedling Growth

Seedling growth (stretched length: length of seedlings from ground level to highest living bud or leaf when seedlings are stretched and measured) and diameter at ground level (basal diameter) were measured using graduated tape and calipers, respectively, during June 2015, Dec. 2015, June 2016, Dec. 2016, August 2017, Dec. 2017 using non-destructive measurements (Figure 3). Of the total 50 individuals, at the end of 3 years period, despite the utmost care and protection, 2 of the individuals were damaged (broken) during the last measurement period (Dec. 2017).

Figure 3: Growth of *Senegalia catechu* plants in Shakti Khola floodplains. Left: Comparision of adjoining sites with and without restoration treatment, Right: Field measurement of basal diameter (after 2 and half years since the broadcast seeding).

Data Analysis

Exploratory data analysis showed right skewness of the data, therefore, generalized linear model (GLM) with gamma family was used to test significant in the mean growth of diameter, height and relationship between basal diameter and height of the individuals of the plants across years. The analysis was performed using R (R Core Team, 2016).

Results

We observed the mean basal diameter of *S. catechu* during first year to be 0.43 ± 0.02 cm (mean ± se). During second and third years they were 2.14 ± 0.10 and 3.76 ± 0.18 cm, respectively. Similarly, during first, second and third years, the mean height of the plant was 39 ± 2.48, 133 ± 5.95 and 260.56 ± 11.22 cm, respectively. Increase in variability in the data was observed in the values of basal diameters with increasing age, and similar pattern was also observed for the height of the individuals (Figure 4).

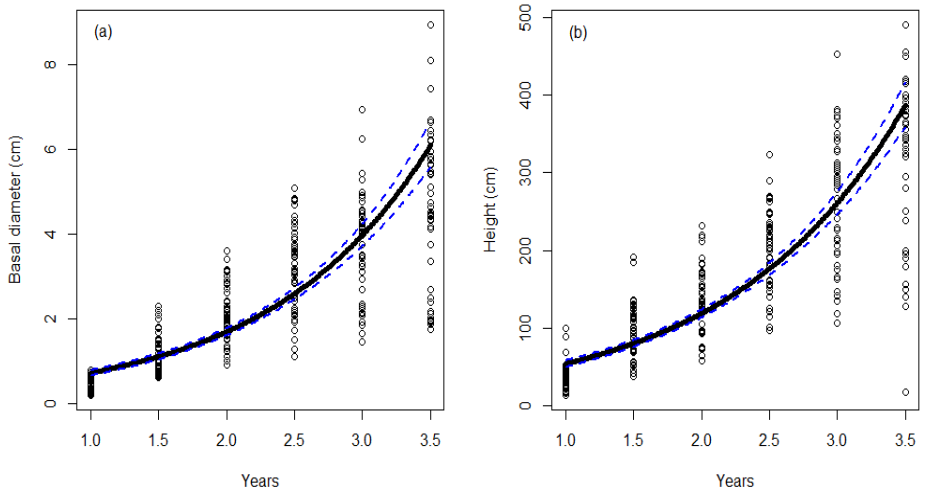

Figure 4: Change in basal diameter and height of *Senegalia catechu* over the period of 3 years. (a) Increase in year significantly increased ($p < 0.001$) the basal diameter (b) Increase in height across years was also significant ($p < 0.001$). In the figure, blue lines reflect 95% confidence intervals.

The increase in growth in basal diameter and height with time were both significant across years ($p < 0.001$ in both cases). Increase in basal diameter significantly increased ($p < 0.001$) the height of *S. catechu* (Figure 5). The growth of the species showed that the plant species successfully get established in the flood plain areas with high sand percentage (Figure 6), and very low organic matter content (not detectable during soil sample analysis in the laboratory).

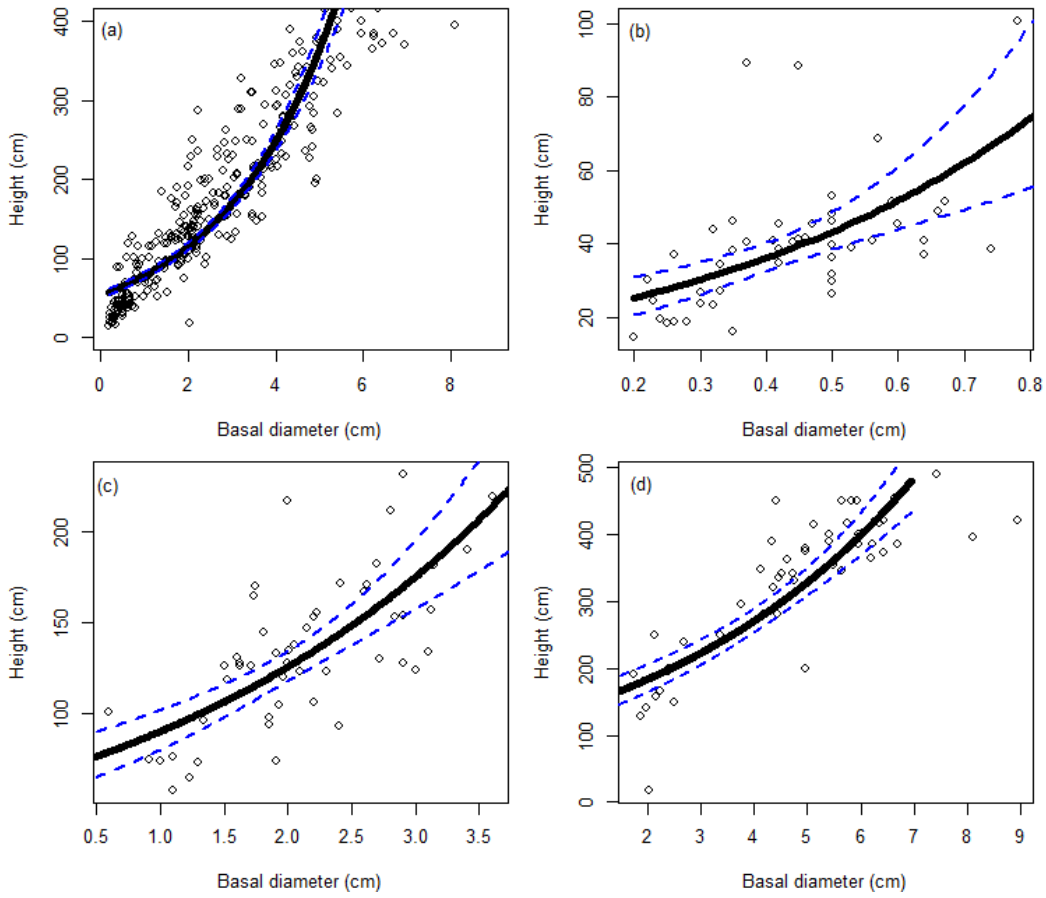

Figure 5: (a) Relationship between height and diameter during early stages of growth (3 years) of *Senegalia catechu*. (b), (c) and (d) show the relationship between height and diameter of *S. catechu* during 1, 2 and 3 years, respectively. In the figure, blue lines reflect 95% confidence intervals.

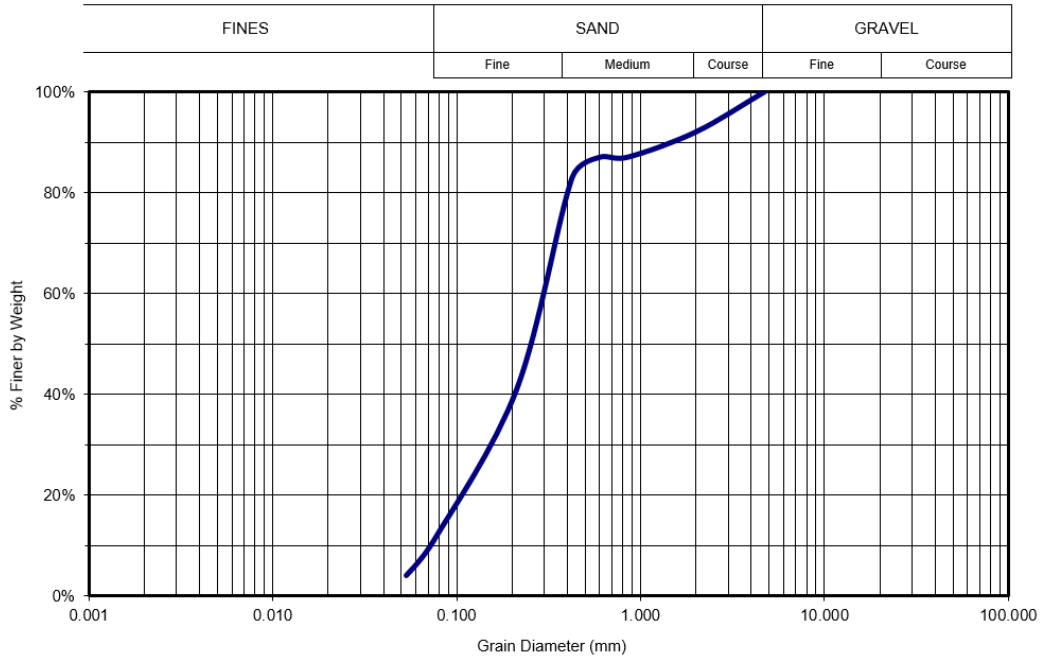

Figure 6: Soil texture analysis of samples from Shakti Khola flood plain area.

Discussion

In this field experiment, we monitored the early-stage development of the seedlings of *S. catechu* in lowland flood plain areas of Nepal. The juvenile individuals get established with continuous cessation anthropogenic disturbances (such as grazing activities) in the flood plain for the period of 3 years. Consistent reestablishment success was observed in the rehabilitated areas of North West Indian Himalayas (Raizada & Juyal, 2012). Our experiment focused on *S. catechu* because this species has the ability to colonize as pioneering species in naturally degraded flood plain areas even with sandy soils with very low nutrient conditions, consistent to the findings made by Bhattarai & Bhatta (2020). Study by Sharma et al. (2020), however, has demonstrated that the growth of *S. catechu* is accelerated by fertilized conditions. As there are large numerous flood areas in Terai, we suggest to initiate restoration of these areas with *S. catechu*, and simultaneously increase the heterogeneity with other plant species, after the individuals of the species get established and modify the physical and biological conditions of the area to support other native species. One of the paradigms for restoration in many areas across the world has been monoculture plantations (Davis et al., 2012). If a native plant community is to be established on a degraded site, disturbance patterns that will harm the growth dynamics of plants also requires to be eliminated. Natural intact ecosystems are required to be reinstated

to the highest extent possible. Similar to the results obtained by Bhattarai et al. (2009), the naturally occurring *S. catechu* can be impacted by anthropogenic pressures due to changing urbanization pattern, settlements and agriculture expansion. These riverine flood plains are ecotone for different land and water interfaces and loss of this area might result in loss of species diversity. Successful restoration of flood plain areas is an important strategy to be initiated as they act as a physical barrier against floods, debris flow etc., thereby preventing loss of livelihood, land and property. The plant parts, especially the root of the trees can reduce erosion of soils and thus save enormous amount of nutrients (Zhao & Riaz, 2024). The stems reduce the velocity of running water reducing river scouring and protection against floods. Trees and forests also act as water storage and recharge, and widely regarded as the good strategy to channelize flood (Tal & Paola, 2010).

We performed a controlled growth experiment for understanding the early-stage growth dynamics of *S. catechu* during restoration of lowland flood plain in Nepal. Consistent to the findings of Dangol et al. (2024) and Jha and Mandal (2019), the shoot height and volume of the individuals of the *S. catechu* increased with increasing time since sowing. This situation favors the recruitment of the seedlings under controlling conditions, consistent with the exclusion made in other studies for the disturbances (Roa-Fuentes et al., 2013; Tobo´n et al., 2011). The success and sustainability of restoration interventions can be assessed from early-stage growth dynamics of the plants. During this phase, combination of both abiotic and biotic factors shapes the establishment, survival and growth of the plants. Other edaphic (Barton et al., 2007; Kusuma et al., 2019; Ramoliya et al, 2004), allelopathic and competitive factors (Joly et al., 2001), and climatic factors (Royo & Carson, 2006) significantly affect the seedling growth. Similarly, invasive species also play important role in early-stage growth dynamics of the desired plant species (Hobbs & Harris, 2001; Weidlich et al., 2020). Certain co-existing plant species may also support in creating favorable microenvironments for seedlings growth reducing the harsh environmental factors (Callaway & Walker, 1997). Mycorrhizal symbiotic relationships can enhance nutrient absorption by the plants (Berta et al., 2005; Muthukumar & Udaiyan, 2000). Similarly, the species identity, density, proximity and the nearby plants are also the crucial aspects to consider for understanding the interactions between plant species in the natural conditions (Chen et al., 2019; Harms et al., 2000; Johnson et al., 2012; Potvin & Dutilleul, 2009).

The success of any restoration project depends on the attributes of individual seedlings planted in the restored site (Andivia et al., 2021; Gardiner et al., 2019; Grossnickle, 2012). Planted seedling species dominating subtropical rainforests were observed to accrue larger increment of growth (Gardiner et al., 2019). Tuttle et al. (1988) showed that larger seedlings can thrive at higher rates under

favorable conditions, but under unfavorable conditions, an increase in height of the seedlings have a negative effect of seedling survival. Similarly, functional traits of the species are likely to be dependent with the size (Prado-Junior et al., 2017; Westoby & Wright, 2006). Size and functional traits have crucial role for the investigation of plant species survival, existence and growth (Falster et al., 2018; Gibert et al., 2016). Early-stage growth dynamics of plants during restoration is a complex process influenced by multiple factors interacting with them. A thorough understanding of the early-stage growth strategies, and how the plants interact helps to guide effective restoration practices and promote the establishment of the resilient ecosystems.

Conclusion

Early-stage growth dynamics of *S. catechu* showed that this species can act as pioneer native species in lowland flood plain restoration in Nepal. Our approach was successful in establishing *S. catechu* individuals in the flood plains areas of Nepal. Because this approach is economical and simple, local stakeholders of various levels of technical knowledge on restoration interventions can spatially enlarge the extent of the establishment on the flood plain areas. Consequently, it is also important to understand the intensity and nature of anthropogenic disturbances (such as grazing) in the area. Practitioners need to consider the type of future disturbances that may affect the restoration sites. At this stage, we have considered only *S. catechu* species for the study, however seeking the association of this species with other co-existing species can be another step for future restoration interventions. This study can be a foundation step to develop regional floodplain management strategy, and an approach towards co-benefitting local communities.

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