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Original Article

Evaluating Survival Rate and Growth Performance of Multipurpose Species Raised Under Billion Tree Afforestation Project, Pakistan

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ABSTRACT

Afforestation initiatives are increasingly important in addressing global environmental challenges. This study focuses on the Billion Tree Afforestation Project in Pakistan and investigates the survival and growth of multipurpose species planted under the project in the Dera Ismail Khan Forest Division through a stratified random sampling technique. A total of 88 sample plots of 0.1 ha size were taken for 10 plantation sites extended over an area of 461.5 ha. Results showed that the average pit density was 1090 pits/ha, while the regeneration was recorded as 695 individuals/ha. Regarding survival rate, all plantation sites showed the best performance, mostly above 90%. Major species such as *Eucalyptus camaldulensis* have the highest composition (78%), followed by *Acacia nilotica* with 14%, while *Dalbergia sissoo* has the lowest percentage of 7%. The highest growth performance was exhibited by *Dalbergia sissoo* and *Eucalyptus camaldulensis*. *Dalbergia sissoo* attained an average girth of 19 cm and a height of 2.8 m. *Eucalyptus camaldulensis* attained a mean girth of 16.1 cm and 19.3 cm at 24 months and 27 months, respectively, whereas the mean height at 24 months and 27 months was 2.93 m and 2.8 m, respectively. Furthermore, scatterplots were developed for growth rate analysis between height and girth for all measured individual trees and mean values. The highest correlation was shown by *Acacia nilotica* with 0.81 and 0.99 coefficient of determination (R^2) for overall individual values and mean values. The study concluded that the plantation activities in the study area were successful as all the sites showed good survival rates.

Keywords: Bonn challenge, BTAP, Dera Ismail Khan (D. I. Khan), forest restoration, regeneration, tree physiology

Introduction

Forests are one of the few ecosystems that benefit humans and provide numerous biological, ecological, and environmental services (Trumbore et al. 2015). Forests are vital to the economy as a supply of lumber, pulpwood for paper production, fuel, and various non-wood items. Forests also serve as the foundation for many other commercial and non-economic assets, such as tourist resources (Komppula & Konu 2017; Oliveira et al. 2017), wildlife habitats, and water resource preservation (FAO 2008, Venable et al. 2017). Forest ecosystems are a reservoir of terrestrial biodiversity, accounting for roughly 90% of all terrestrial species on the planet (Novotny et al. 2006), and as such, they are necessary, self-sustaining reservoirs of genetic resources (Asner et al. 2017; Kuemmerle et al. 2017; Mori 2017). According to Food and Agriculture Organization (FAO 2015), the world forest has been reduced from 31.6% in 1990 to 30.6% in 2015. However, the rate of deforestation decreased in the past decades from 7.8 million ha per year to 4.7 million ha per year (FAO 2020). Deforestation and forest degradation contribute to climate change through carbon emissions to the atmosphere and biodiversity loss. On the other hand, reforestation and afforestation can help restore and conserve biodiversity, mitigate climate change, and enhance ecosystem services. Plantations provide a wide range of benefits including playing an important role in mitigating climate change through carbon sequestration and storage (Chen et al. 2015; Kongsager et al. 2013), reducing pressure on natural forests by timber production (Pirard et al. 2016), and regulating stream flow (Buendia et al. 2015). However, the success of plantations is hampered by various factors affecting plants' survival and growth performance. For instance, studies reported that changes in plant survival and growth can be attributed to various factors including limited light availability (Hattori et al. 2009; Kunstler et al. 2005), nutritional deficiency (Löf et al. 2007; Oscarsson et al. 2006), interspecific competition (Osunkoya et al. 2005), and shifting environmental conditions (Battles et al. 2008; Hattori et al. 2013; Soehartono et al. 2002). A recent study reported humidity and water availability being the critical factors in seedling plantation success (Sukhbaatar et al. 2020). Many restoration projects failed completely or fail to achieve their objectives. Survival rate and

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growth performance are considered as important factors of plantation success/failure (Wodehouse & Rayment 2019; Shehzad et al. 2022). By closely monitoring the operations/activities, producers can find ways to use resources more efficiently and achieve good results (Azizan et al. 2021). As a result, timely monitoring and evaluation of restoration sites is critical to inform the concern authorities about the present state of the plantations and ensuring the effectiveness of the restoration program.

To avoid the detrimental effect of climate and restore biodiversity, Bonn Challenge in 2011 committed to restoring around 350 million hectares of land by 2030. Countries such as China, the US, India, Mexico, Peru, Ethiopia, Ghana, Uganda, and Pakistan are committed to restoring and enhancing the forest area (IUCN 2018).

Pakistan is in the top 10 most vulnerable countries to climate change and has a very low forest area of around 4.6% of the total land area (FAO, 2020). Forest degradation and deforestation have been recorded in recent decades due to human activity and population growth (Ahmed et al. 2015). With a population of 207.774 million people, more than half of whom live in rural regions that rely primarily on wood for fuel and building, finding solutions to preserve and expand forest resources is critical for Pakistan.

In this context, the government of Khyber Pakhtunkhwa (KP), Pakistan, initiated a mass forest restoration project in the province. Khyber Pakhtunkhwa exists in the northern region of the country and is the most forested province in the country. Approximately 20.25% of the province is a forest with different forest types (Ullah et al. 2020). The KP province contains diverse ecological forest systems with elevations ranging from 250 m above sea level in the south to 7708 m in the north. This project was started by the provincial forest department with the primary goal of planning, supporting, designing methods, and launching sustainable forestry in KP with the participation of local people, as well as promoting forestry-based jobs (Ullah et al. 2020). This project covers the entire province, with more focus on the enclosure establishment in natural forests. The enclosure is the area in a degraded natural forest protected from anthropogenic activities to promote natural regeneration (Chazdon & Uriarte 2016). Plantations on communal and private land were also done, increasing wood production and reducing the pressure on natural forests. The initiative aims to create green jobs, promote gender equality, and empower women while simultaneously protecting Pakistan's forest resources and tackling the global issue of climate change (Go KP 2015). The project was completed in three phases within 5 years (i.e., 2014–2019). The initiative's operations were overseen by a third party, the World-Wide Fund for Nature Pakistan (WWF-Pakistan).

Focusing on the unknown achievements of Billion Tree Afforestation Project (BTAP), it is significant to examine various project interventions. In this context, the current study was designed. The study's primary goals were

(i) to determine species composition, survival rate, and regeneration status and
(ii) to assess the growth performance of several tree species grown under the BTAP in Dera Ismail Khan (D. I. Khan).

Methods

The Study Area: Dera Ismail Khan Forest Division

Dera Ismail Khan is in KP district at 31.8626° N, 70.9019° E (Figure 1). D. I. Khan Forest division has an area of 9005 km^2, including the districts

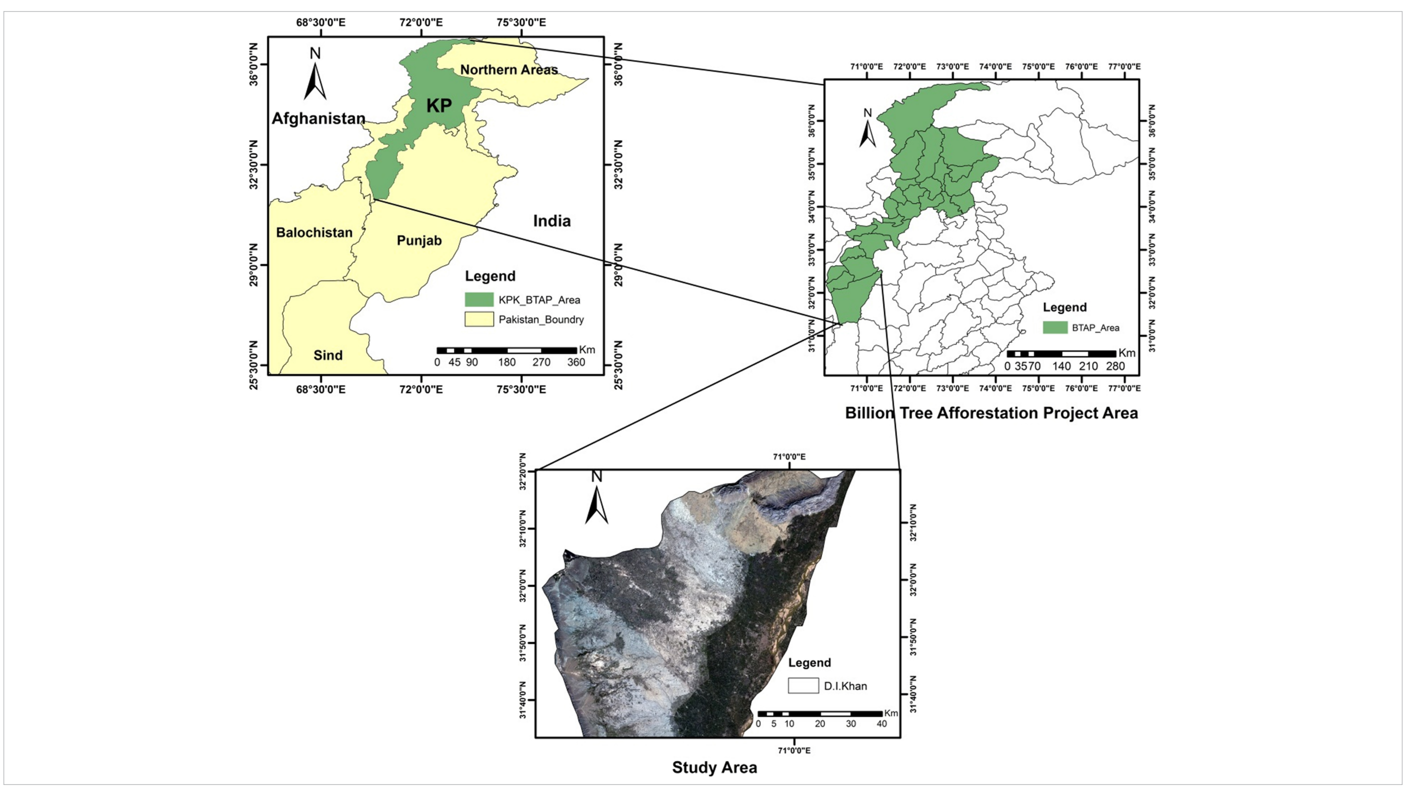

Figure 1.
Map of the Study Area.

Table 1.
Status of Species Composition and Natural Regeneration in Each Plantations Site

Site	Area (ha)	Species	No of Trees	Average Trees/Plot	Trees/ha	Total Trees (Site-wise)	Regeneration/Site
Athog Disty Chasma	10	Kikar	80	20	200	2000	500
Ch. Shafique	10	Eucalyptus	17	17	170	1700	1500
Dahb Chabak	21.8	Shisham	56	8	80	1744	11,400
	57.8	Eucalyptus	148	10	100	5780	
	20.3	Kikar	52	8.6	86	1745	
Jhok Samong	30	Eucalyptus	202	20.2	202	20,200	2460
Kala Gorh	10	Eucalyptus	98	19.6	196	19,600	660
Kirri Khesor	36.5	Eucalyptus	136	22.6	226	22,600	657
KirriShamozai	21.52	Kikar	120	17.1	171	3679	1125
	3.26	Eucalyptus	18	9	90	293	
Roda I and II	9.48	Kikar	29	9.6	96	910	5460
	41.86	Shisham	128	16	160	6697	
	53.64	Eucalyptus	164	13.6	136	7295	
Shinkee Pakka	46.92	Kikar	89	17.8	178	8351	8970
	67.9	Eucalyptus	129	16.1	161	10,931	
Musa Kahr	20	Eucalyptus	154	19.2	192	3840	740
Total	**461.5**					**117,365**	**33,472**

of D. I. Khan and Tank. The forest division is located in the southern part of KP. The area exists in the arid and semi-arid zone with a rainfall of 250–400 mm. The most prominent soil type in the study area is loamy sand and silty clay (Nasir & Ahmad 2012). The whole tract is in the tropical thorn zone, with a portion in the subtropical broad-leaved evergreen zone.

The primary species of the study area are *Prosopis spicigera*, *Tamarix aphylla*, *Zizyphus mauraitiana*, *Tamarix dioica*, *Capparis aphylla*, *Salvadora oleoides*, *Acacia nilotica*, *Acacia modesta*, and *Dodonaea viscosa*. These tree species can be found in rare open areas, particularly in the Rudkohi region and the graveyard. The Chashma right bank Canal presently irrigates the majority of the region. The sub-divisions of the D. I. Khan Division are D. I. Khan Forest Sub-division, Tank Forest Sub-division, Sheikh Buddin Forest Sub-Division, and Paroa Range.

The plantation and afforestation activities have been conducted in D. I. Khan Forest Division under Billion Trees Tsunami Afforestation Project. The afforestation was divided into departmental plantations, private nurseries establishment, waterlogged and saline areas reclamation, and roadside and canal-side plantation. The study explored plantation and afforestation activities in Paharpur Forest Sub-division, D. I. Khan Sub-division, and Parova Range. The areas of these sub-divisions and range and sampling sites and plots have been summarized (Supplementary Table 1).

Methodology

Sampling

The concerned office was approached to provide the list of plantation sites, and 10 sites were randomly selected from the list. As per the study's objectives, regeneration and plantation were assessed, and data on different attributes were collected for survival and growth performance. The data were collected through a Stratified random sampling technique to select sample plots within plantation sites. A total of 88 sampling plots were laid out in 10 plantation locations. Table 1 represents the detail regarding sites and sample plots.

Sampling Intensity

Sampling intensity is the sampled area divided by the total area of the plantation site (Equation 1). The sampling intensity of all plantation sites has been summarized in Supplementary Table 1. Each site has different sampling intensity due to the difference in the area, species composition, accessibility, and time limitation (Ullah et al. 2020).

$$\text{Sampling intensity} = \frac{\text{Area sample}}{\text{Total area}} \times 100 \tag{1}$$

$$\text{Number of plots} = \frac{\text{Total area}}{\text{Plot size}} \times \text{sampling intensity} \tag{2}$$

Data Collection

The field data were collected from September 25, 2017, through October 13, 2017. Field data were collected in 10 plantation sites using a circular sample plot having 18 m radius while considering slope correction. Due to the difference in the site's area, the number of sample plots varies for each site as per sampling. A measuring tape and Sunnto Clinometer were used for data collection. Circular plots of 18 m radius were established through measuring tape and reference points. Count the regeneration within the sample plot, measure the girth and height of about 20 plants in each sample plot, and note it in the prescribed inventory forms. Then, 200 fixed measured steps were taken to ensure the proper position of the next sampling plot and so on to avoid overlapping. The sampling and measurements were done with great care because the accuracy of assessing growth performance is dependent on these characteristics. Furthermore, pit density was calculated using departmental procedures and then scaled per hectare. The pit density is the number of pits per unit area. Pit density was estimated for the 10 sampled sites with 10′ × 10′ spacing. To determine the species composition of all studied plantation sites, all enumerated plants were grouped by species name, the number of trees per plot, and location. Natural regeneration was evaluated by measuring the number of regenerations concerning height in inches. The enumeration of regeneration was separated into two groups, one with a height of fewer than 9 inches (not established) and the other with a height of more than 9 inches (established).

The plantation's survival rate was calculated using data on pit density and empty pits. The survival rate depends on how much out of the total sowed seed or planted plants survived and will likely become healthy in the future. Using pit density data and plantation areas, plot-wise survival rates were upscaled to site-wise survival rates.

The best indices of growth performance are height and girth. Hence, the growth rate of different species was evaluated by estimating the girth and height of the tree species.

Data Compilation and Analysis

All the obtained data were uploaded to Microsoft Excel sheets for compilation and tabulation. Data were prepared by average and percentage and statistically interpreted. Data behavior and spread were studied by boxplots and histogram analyses. Girth and height classes were plotted against the frequency of trees. Scatter plots were developed to examine the relationship between the girth and height values of significant species. Correlation and regression analyses were performed between girth and height for overall and mean values. Linear models for the growth of plantations were established. The coefficient of determination (R^2) was calculated for different species, including *Eucalyptus camaldulensis*, *Dalbergia sissoo*, and *Acacia nilotica*. In regards to the linear regression model, height was the dependent variable and girth was the

explanatory variable. The correlation was conducted as per the equation given below (with

a significance level of *p*-value less than .05.)

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{\left[n\Sigma x^2 - (\Sigma x)^2\right]\left[n\Sigma y^2 - (\Sigma y)^2\right]}} \quad (3)$$

where

N = number of sample plots

Σxy = the sum of the variables of paired points

Σx = sum of x variable

Σy = sum of y variable

Σx^2 = sum of squared x variable

Σy^2 = sum of squared y variable.

Results

Species Composition

Detailed site-wise species composition and number of trees per specie per plot and total trees per specie per plot have been summarized in Table 1. It was found that three main species (i.e., *Eucalyptus camaldulensis*, *Acacia nilotica*, and *Dalbergia sissoo*) have been raised under Billion Tree Afforestation Project in the study area. As depicted in Table 1, the *Eucalyptus camaldulensis* species has the highest composition, that is, 78%, followed by *Acacia nilotica* with 14%, while *Dalbergia sissoo* has the lowest percentage of 7%. More than five species have been planted in D. I. Khan, Parova, and Paharpur subdivision but *Eucalyptus camaldulensis*, *Dalbergia sissoo*, and *Acacia nilotica* were the major species in the sampled locations.

The total number of pits in all sampled areas (i.e., 461.5 ha) was 503,035 with 1090 pits/ha. The highest pit density was found at Shinkee Pakka village with 125 350 pits, while Athog Disty Chashma road and Kala Gorh have the lowest pits with 10 900 pits (Supplementary Table 1).

Natural regeneration was also seen in almost each sample plot during the sampling process. The total number of regenerations per hectare was 695, with 582 enumerated regenerations. The highest number of regenerations per hectare was 150 in Ch. Shafique Dam site, whereas the lowest was found in Kirri Khesohr II with 18 regenerations per hectare. The established regeneration was 508, and the un-established regeneration was 74 (Supplementary Table 2).

The site-wise natural regeneration was also estimated per collected data from sampled sites. The highest number of regenerations was found in Dhab Chabak with 11 400 regenerations, followed by the Shinkee Pakka Village and Rhoda I and II with 8790 and 5460 regenerations, respectively. The Atog Disty Chashma has the lowest number of regenerations (Table 1).

Survival Rate of Plantations

The most crucial factor for determining a plantation's status (of being successful or not) is its survival rate. The plot-by-plot survival rate of all studied locations is shown in Table 2. Almost all of the examined plantation sites had a higher survival rate, with an average of more than 83%. Kirri Shamozai had the most remarkable survival rate of 97.1%, while Musa Kahr had the lowest survival rate of 83.1%. The comparatively high survival rate of plantation is possibly due to species selection, that is, most of the study area is comprised of *Eucalyptus camaldulensis*, which shows low mortality in harsh conditions, and another reason could be the proper monitoring and care provided by the government and forest department.

The site-wise survival rate and pit density data are summarized in Table 2. The Kirri Shamozai II had the highest success rate of 97.1% survival, while Musa Kahr had the lowest success rate of 83.1% survival among the studied locations. Almost all plantation sites showed above 83% survival rates depicting the better success of these plantations.

Growth Rate of Different Species

The growth performance of various tree species is presented in Table 3. *Dalbergia sissoo* and *Eucalyptus camaldulensis* had the best growth performance. *Dalbergia sissoo* attained an average girth of 19 cm and a height of 2.8 m. This high growth was due to the excellent conditions of the locations where *Dalbergia sissoo* has been raised. However, it is worth mentioning that *Dalbergia sissoo* has been planted in a few locations. On the other hand, *Eucalyptus camaldulensis* attained a mean girth of 16.1 cm and 19.3 cm at 24 months and 27 months of age, respectively, whereas the mean height at 24 months and 27 months was 2.93 m and 2.8 m, respectively. Data on the growth performance of different tree species at various ages were also collected to identify growth variance over time.

Table 2.
Area, Sampling Intensity, and Survival Rate of Each Plantation Sites

Plantation Site	Area	Sampling Intensity	No of Sample Plots	Average Pit/ Plot	Average Pits/ hectare	Empty/hectare	Survival Rate (%)
Roda I and II	105	1.6	17	109	1090	62.3	94.2
Ch Shafiq Dam area	10	1.0	01	109	1090	80	92.6
Athog Disty Chashma road	10	4.0	04	109	1090	82.5	92.4
Kirri shamozai	25	4.4	11	109	1090	30.9	97.1
Kala gorh	10	5.0	05	109	1090	80	92.6
Kirri khesor	36.5	1.9	07	109	1090	151.4	86.1
Musa kahr	20	4.0	08	109	1090	185	83.1
Shinkee pakka village	115	1.0	12	109	1090	100.8	90.7
Dahab Chabak kacha	100	1.4	14	109	1090	69.2	93.6
Jhok samok wali	30	3.3	10	109	1090	89	91.8

The girth and height data of all individual sampled plants of *Eucalyptus camaldulensis*, *Acacia nilotica*, and *Dalbergia sissoo* have been summarized in Table 4 and graphically represented by boxplot (Figures 2 and 3). The girth boxplot showed the mean girth value, first quartile and third quartile, and extreme values for the significant species, which include *Eucalyptus camaldulensis*, *Dalbergia sissoo*, and *Acacia nilotica*, while the height boxplot also depicted the same for these species.

The highest number of trees was observed in the girth class 11–15 cm and 16–20 cm of *Eucalyptus camaldulensis* followed by *Acacia nilotica* with a more number of trees in the 6–10 cm girth class. On the other side, the highest number of trees for *Eucalyptus camaldulensis* was found in the 3.1–4.0 height class followed by *Acacia nilotica* for the 1.1–2.0 height class.

Further, scatterplots were developed for growth rate analysis between height and girth for all measured individual trees and also for mean values. The summary of the linear regression model has been presented in Table 5. The highest correlation was shown by *Acacia nilotica* with 0.81 and 0.99 coefficient of determination (R^2) for overall individual values and mean values (Figure 4). On the other side, *Eucalyptus camaldulensis* and *Dalbergia sissoo* show R^2 of 0.76 and 0.75 for overall individual values and 0.96 and 0.90 for mean girth and height classes (Figures 5 and 6).

Table 3.
Details of Species Age, Mean Girth, and Mean Height Grown Under Billion Tree Afforestation Project

S.No.	Species	Age (month)	Mean Girth (cm)	Mean Height (m)
1	*Eucalyptus camaldulensis*	24	16.1	2.93
2	*Eucalyptus camaldulensis*	27	19.32	2.8
3	Eucalyptus camaldulensis	16	14.91	3.0
4	*Acacia farnesiana*	16	9	1.3
5	*Dalbergia sissoo*	24	19.6	2.8
6	*Dalbergia sissoo*	16	17.4	2.8
7	*Ziziphus mauritiana*	16	8.81	1.1
8	*Acacia nilotica*	24	17.5	2.5
9	*Acacia nilotica*	16	10.6	1.5
10	*Melia azedarach*	24	13.5	2.2

Discussion

Species Composition

The high proportion of *Eucalyptus camaldulensis* in plantations is also reported by other studies (e.g., Ullah et al., 2020; WWF-Pakistan, 2016). This is partly because Eucalyptus is highly preferred by farmers and partly due to its high growth rate and high survival rate in dry and saline conditions. *Acacia nilotica* is a good option for promoting biodiversity. *Dalbergia sissoo* is also a promising species in arid areas, but its growth is hampered by frost, which is why it is so rare in plantations. Khan et al. (2022) reported that *Eucalyptus camaldulensis* has the highest ratio of 83.80% of the planted species, followed by *Pinus roxburghii* Sarg. As *Eucalyptus camaldulensis* grows quickly and has a higher probability of surviving in dry conditions, it was chosen for planting purposes while taking into account the priorities of the local people (WWF, 2017). Similarly, prior research found that the *Eucalyptus camaldulensis* was chosen for dry land industrial and rural afforestation (du

Table 4.
Summary Statistics of Different Species Growth Data

Parameters	*Acacia nilotica*		*Eucalyptus camaldulensis*		*Dalbergia sissoo*	
	Girth (cm)	Height (m)	Girth (cm)	Height (m)	Girth (cm)	Height (m)
Mean	13.5	1.94	15.4	2.99	18.2	2.83
Standard Error	0.32	0.04	0.17	0.03	0.43	0.05
Standard Deviation	6.34	0.94	5.67	0.98	5.87	0.80
Sample Variance	40.28	0.88	32.2	0.97	34.5	0.64
Range	33	4.7	32	4.6	33	4.6
Minimum	3	0.3	2	0.7	7	0.7
Maximum	36	5	34	5.3	40	5.3

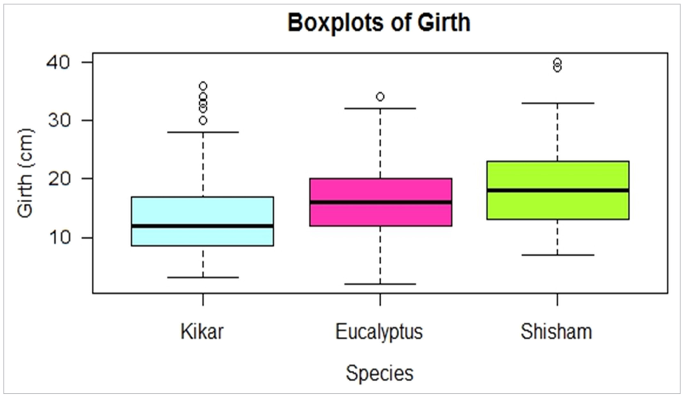

Figure 2.
Boxplots of Girth for Tree Species.

Table 5.
Linear Regression Model between Girth and Height for Different Species Growth

Indices		Equation	R^2	Standard Error	*F*-value
Eucalyptus camaldulensis	Overall	$Y=0.152x+0.64$	0.76	2.77	3421
	Mean	$Y=0.1349x+0.76$	0.96	0.27	225.8
Acacia nilotica	Overall	$Y=0.135x+0.13$	0.81	0.41	1578.1
	Mean	$Y=0.129x+0.124$	0.99	0.14	699.92
Dalbergia sissoo	Overall	$Y=0.119x+0.66$	0.75	0.39	574.90
	Mean	$Y=0.125x+0.77$	0.90	0.37	66.94

Toit et al., 2017), bigger biomass production (Phiri et al., 2015), as a bioenergy crop, and to satisfy wood requirements (Lundqvist et al., 2017). It can withstand soil salinity issues in deforested areas (Harper et al., 2017). Yet, given the area's ecological state, the ratio of native species should be enhanced. Because an abundance of *Eucalyptus camaldulensis* may have harmful long-term effects on natural vegetation (Miles et al. 2010; Sajwaj et al. 2008). de Farias et al. (2016) also stated that compared to the exotic *Eucalyptus camaldulensis*, the indigenous specie (*Tachigali vulgari*) should be promoted. According to Khan et al. (2021), the KP forest department has planted around 27 different species across the province. Some of the major species are *Eucalyptus camaldulensis*, *Pinus roxburghii*, *Robinia pseudoacacia*, *Acacia modesta*, *Acacia nilotica*, and *Dalbergia sissoo*. Also, it was shown that the plantation of Eucalyptus rose from 17% to 48% between 2016 and 2017. The primary reason for this was farmer's choice due to its adaptability and rapid development.

Growing *Eucalyptus camaldulensis* has significant implications for the environment and natural ecosystems, particularly in arid regions where water scarcity is a concern. The species has a high demand for water (Colloff 2014), which can exacerbate water scarcity, and its deep roots may compete with other vegetation for underground water sources. The species may also produce allelopathic compounds that inhibit the growth of other vegetation (Colloff 2014), leading to reduced biodiversity and nutrient cycling in the soil (Bayle 2019). However, some studies suggest that *Eucalyptus camaldulensis* can improve soil health by increasing soil organic matter and nutrient availability (Rousta et al. 2023).

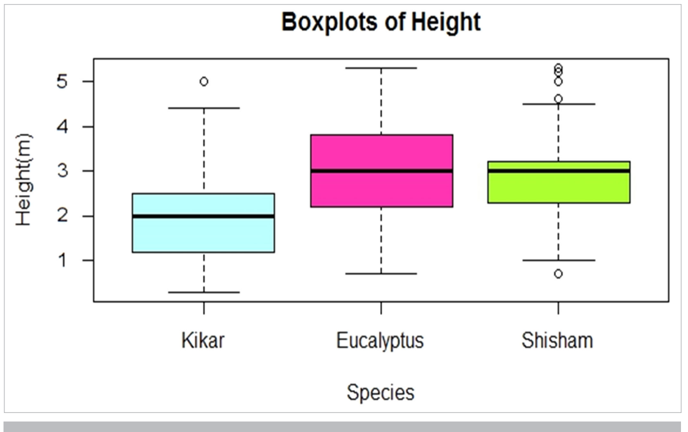

Figure 3.
Boxplots of Height for Tree Species.

Eucalyptus camaldulensis has varying effects on flora and fauna. It has been shown to inhibit the growth of other vegetation under its canopy, which can reduce food supplies and habitat for wildlife (Cordero–Rivera et al., 2017).

To mitigate the negative impacts of growing *Eucalyptus camaldulensis*, several recommendations could be considered. These include planting the species in areas with ample water resources, spacing the trees properly to reduce competition for water and nutrients, and implementing management practices to promote soil health and biodiversity. Additionally, alternative tree species that are better adapted to local conditions could be considered as a more sustainable option.

Survival Rate

Similar findings have been reported by WWF-Pakistan (2016) for various parts of the province with more than 80% of survival rate. Another study also recently reported a survival rate above 80% for the Dir Lower district (Ullah et al. 2020). A similar result of a good survival rate of plantations was also reported by Khan et al. (2021). The relatively high survival rate is likely the result of the department's careful care as well as the species' choice, as Eucalyptus makes up the majority of the plantations and has a very good survival rate under adverse conditions (Zahid et al., 2010). Eucalyptus species were introduced to Pakistan in the early twentieth century and were planted on millions of hectares of land (Zahid & Ahmad, 2016). Yamada et al. (2016) investigated the development and survival of several tree species planted to restore biodiversity along rivers and within palm plantations. Three years after planting, the survival percentage of 351 seedlings was greater than 90%. Rawat et al. (2017) assessed multifunctional trees grown in three villages in India for biodiversity conservation and degraded land rehabilitation. Following 4 years of cultivation, a good survival rate for the study area was reported.

Growth Performance

Khan et al. (2021) evaluated the success of planting efforts in the Malakand Forest Division and reported that *Pinus roxburghii* reached an average girth of 14.3 cm and height of 3.21 feet, whereas *Eucalyptus camaldulensis* and *Robinia pseudoacacia* reached mean girths of 10.3 cm and 12.1 cm and heights of 8.6 feet and 8.2 feet, in 27 months, respectively. While Leslie et al. (2018) claimed that eucalyptus attained a height of 6.56 feet in 29 months. Poersch et al. (2017) assessed the growth of *Eucalyptus camaldulensis* over a 12-month period in terms of its

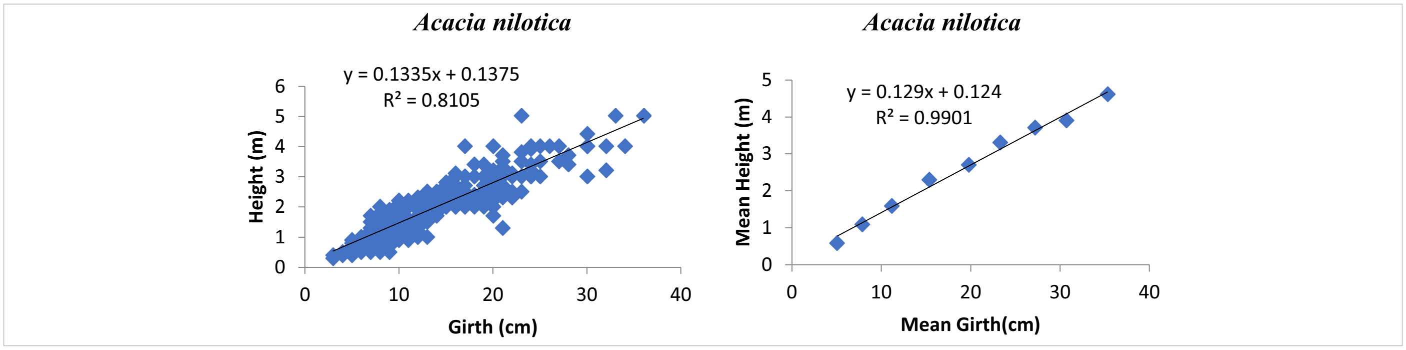

Figure 4.
Correlation for Individual and Mean Values for Acacia nilotica.

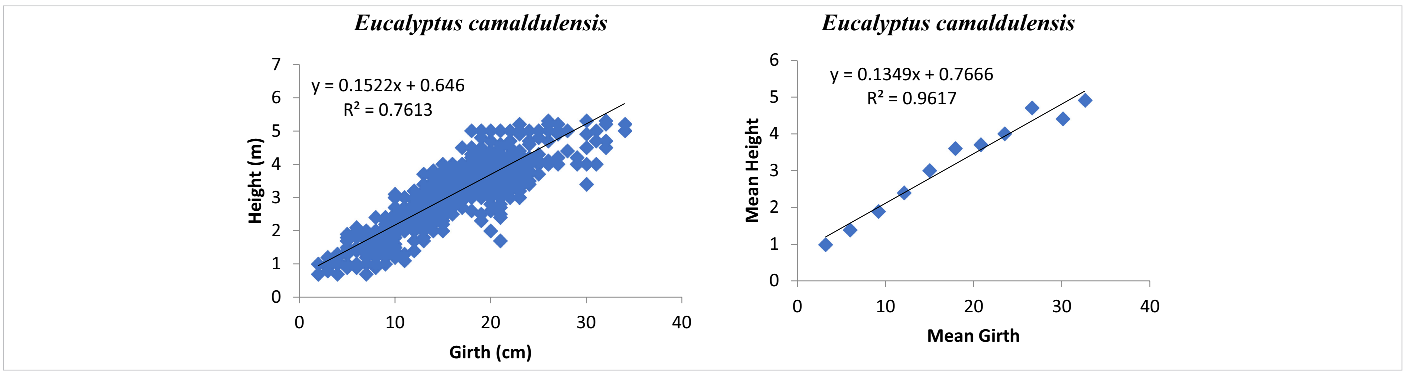

Figure 5.
Correlation for Individual and Mean Value for Eucalyptus camaldulensis.

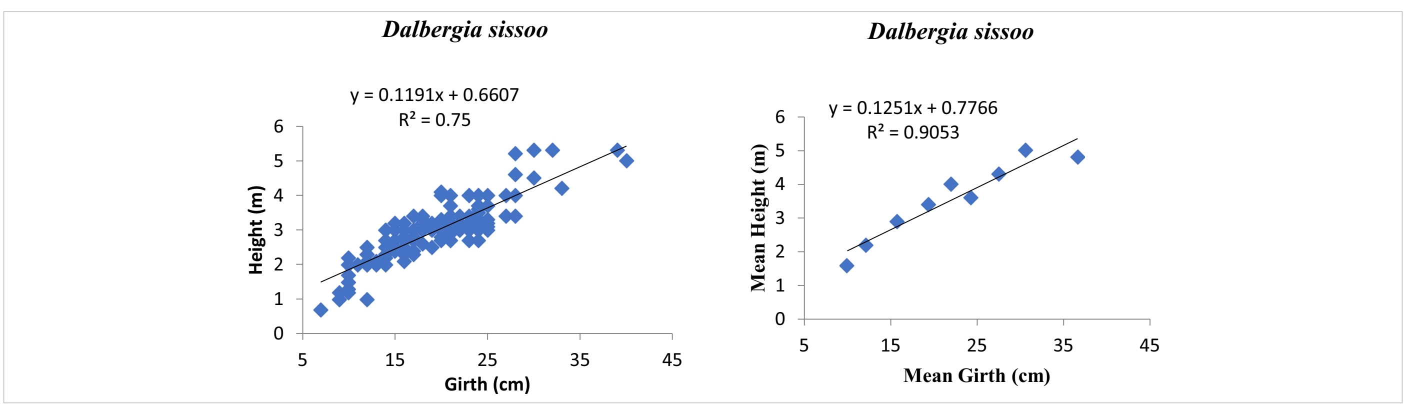

Figure 6.
Correlation for Individual and Mean Values for Dalbergia sissoo.

monthly diameter and height. Height increment ranged from 2.15 cm to 6.56 cm and diameter increment ranged from 3.35m to 10.27m. The same result of the highest growth performance by *Eucalyptus camaldulensis* was also recorded in lower Dir by Ullah et al. (2020). Khan et al. (2022) reported that in 19 months, *Eucalyptus camaldulensis* reached an average girth of 4.36 cm and a height of 1.5 m, whereas *Pinus roxburghii* reached an average girth and height of 6.53 cm and 0.6 m, in 26 months, respectively. Our study found that *Dalbergia sissoo* had a mean diameter of 6.05 cm and a height of 2.8 m at 2 years of age, and *Eucalyptus camaldulensis* had a mean diameter of 5.13 cm and mean height of 2.93 m at 2 years of age. While Arif et al. (2017) reported a mean diameter and mean height of 11.4 cm and 9.4 m for 0–5-year-old *Dalbergia sissoo* plants and a mean diameter and mean height of 14 cm and 14.6 m for 0–5-year-old eucalyptus, respectively. The difference in mean diameter and height between the two studies could be more possibly due to the difference in age. Similarly, the mean girth and height of *Robinia pseudoacacia* were 13.88 cm and 3.65 cm at 36 months, respectively, whereas *Cedrus deodara* girth was 3.94 cm and height was 0.70 m at 60 months. The study further reported that fast-growing plants including *Robinia pseudoacacia*, *Ailanthus altissima*, and *Eucalyptus camaldulensis* performed well and were deemed ideal for social forestry projects. However, due to the high-water requirements of eucalyptus, irrigated plantations in dry and semi-arid climates may have aquifer reservoir shortages (Zahid et al., 2010).

According to Rubilar et al. (2018), silvicultural, genetic, and environmental interactions may be regulated to ensure productivity and sustainability in intensively managed plantations. According to Sabastian et al. (2018), the performance of plantings is dependent on soil and slope since growth indices like diameter growth respond differentially to these factors.

Due to limited resources and time, this study could not cover all the plantation sites and therefore more studies are required to examine the survival rate and growth of other plantation sites. Moreover, the study recommends conducting more studies on the impact of plantations on biodiversity, soil, and hydrological pattern. The use of more native species and mixed plantations is recommended in the upcoming plantations.

Conclusion and Recommendations

The current research examined the growth performance and survival rate of various tree species grown under the BTAP.

- The proportion of *Eucalyptus camaldulensis* recorded more compared to other species in the study site. Natural regeneration was also observed in the sampled sites which show the project's success.
- The study concluded that the plantation activities in the study area were successful as the overall survival rate was above 90%.
- The study also found that the major species in the study area grew well, with *Dalbergia sissoo* reaching a mean girth of 19 cm and a height of 2.8 m, and *Eucalyptus camaldulensis* reaching mean girths of 16.1 cm and 19.3 cm at 24 months and 27 months, respectively, and mean heights of 2.93 m and 2.8 m at 24 months and 27 months. Furthermore, the highest correlation was shown by *Acacia nilotica* with 0.81 and 0.99 coefficient of determination (R^2) for overall individual values and mean values.
- The study suggests similar research in other restoration areas of the province to examine the survival rate and growth performance of plantations as well as natural regeneration.

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References

- Ahmed, K., Shahbaz, M., Qasim, A., & Long, W. (2015). The linkages between deforestation, energy and growth for environmental degradation in Pakistan. *Ecological Indicators*, *49*, 95–103. [CrossRef]
- Asner, G. P., Martin, R. E., Tupayachi, R., & Llactayo, W. (2017). Conservation assessment of the Peruvian Andes and Amazon based on mapped forest functional diversity. *Biological Conservation*, *210*, 80–88. [CrossRef]
- Azizan, F. A., Kiloes, A. M., Astuti, I. S., & Abdul Aziz, A. (2021). Application of optical remote sensing in rubber plantations: a systematic review. *Remote Sensing*, *13*(3), 429. [CrossRef]
- Battles, J. J., Robards, T., Das, A., Waring, K., Gilless, J. K., Biging, G., & Schurr, F. (2008). Climate change impact on forest growth and tree mortality: A data-driven modeling study in the mixed conifer forest of the Sierra Nevada, California. *Climatic Change*, *87*(S1), 193–213. [CrossRef]
- Bayle, G. K. (2019). Ecological and social impacts of eucalyptus tree plantation on the environment. *Journal of Biodiversity Conservation and Bioresource Management*, *5*(1), 93–104. [CrossRef]
- Buendia, C., Bussi, G., Tuset, J., Vericat, D., Sabater, S., Palau, A., & Batalla, R. J. (2016). Effects of afforestation on runoff and sediment load in an upland Mediterranean catchment. *Science of the Total Environment*, *540*(1), 144–157. [CrossRef]
- Chazdon, R. L., & Uriarte, M. (2016). Natural regeneration in the context of large-scale forest and landscape restoration in the tropics. *Biotropica*, *48*(6), 709–715. [CrossRef]
- Chen, Y. Q., Liu, Z. F., Rao, X. Q., Wang, X. L., Liang, C. F., Lin, Y. B., Zhou, L. X., Cai, X. A., & Fu, S. L. (2015). Carbon storage and allocation pattern in plant biomass among different forest plantation stands in Guangdong, China. *Forests*, *6*(12), 794–808. [CrossRef]
- Colloff, M. (2014). *Flooded forests and desert creeks: Ecology and history of the river red gum*. CSIRO Publishing.
- Cordero–Rivera, A., Martínez Álvarez, A. M., & Álvarez, M. (2017). Eucalypt plantations reduce the diversity of macroinvertebrates in small forested streams. *Animal Biodiversity and Conservation*, *40*(1), 87–97. [CrossRef]
- de Farias, J., Marimon, B. S., de Carvalho Ramos Silva, L. D. C. R., Petter, F. A., Andrade, F. R., Morandi, P. S., & Marimon-Junior, B. H. (2016). Survival and growth of native Tachigali vulgaris and exotic Eucalyptus urophylla× Eucalyptus grandis trees in degraded soils with biochar amendment in southern Amazonia. *Forest Ecology and Management*, *368*, 173–182. [CrossRef]
- du Toit, B., Malherbe, G. F., Kunneke, A., Seifert, T., & Wessels, C. B. (2017). Survival and long-term growth of eucalypts on semi-arid sites in a Mediterranean climate, South Africa. *Southern Forests: A Journal of Forest Science*, *79*(3), 235–249. [CrossRef]
- FAO (Food and Agriculture Organization) (2008). *Climate change and food security: A framework document*. Food and Agriculture Organization.
- FAO (Food and Agriculture Organization) (2015). *Global forest resources assessment*. FAO Forestry Research Paper 163.
- FAO (Food and Agriculture Organization) (2020). *Global Forest Resources Assessment 2020: Main report*. [CrossRef]
- Go KP (2015). *Revised PC-1 for Billion Trees Tsunami Afforestation Project in Khyber Pakhtunkhwa*. Department of Forestry, Environment & Wildlife Govt. of Khyber Pakhtunkhwa. http://103.240.220.71/btt/repos/files/2015/12/PC1-Phase1.pdf
- Harper, R. J., Sochacki, S. J., & McGrath, J. F. (2017). The development of reforestation options for dryland farmland in south-Western Australia: a review. *Southern Forests: A Journal of Forest Science*, *79*(3), 185–196. [CrossRef]
- Hattori, D., Kenzo, T., Kendawang, J. J., Irino, K. O., Tanaka, S., Ichie, T., Ninomiya, I., & Sakurai, K. (2009). Effect of light intensity and soil physiochemical properties on seedling mortality and growth of six dipterocarp species planted for rehabilitation of degraded grassland, secondary forest and logged forests in Sarawak. Malaysia. *Japanese Journal of Environmental Entomology and Zoology*, *51*(2), 105–115. [CrossRef]
- Hattori, D., Kenzo, T., Yamauchi, N., Irino, K. O., Kendawang, J. J., Ninomiya, I., & Sakurai, K. (2013). Effect of environmental factors on growth and mortality of Parashoreea macrophylla (Dipterocarpaceae) planted on slopes and valleys in a degraded tropical secondary forest in Sarawak, Malaysia. *Soil Science and Plant Nutrition*, *59*(2), 218–228. [CrossRef]
- International Union for Conservation of Nature and Natural Resources (n.d.). *The US Forest Service on tracing their Bonn Challenge Pledge*. – https://infoflr.org/news-media/us-forest-service-tracking-their-bonn-challenge-pledge. (Accessed on March 27, 2023).
- Khan, M. D., Ali, A., Iqbal, A., Rehman, Z. U., Ahmed, W., & Arooj, S. A. (2021). Monitoring of Afforestation Activities Using Landsat-8 Temporal Images, Billion Trees Afforestation Project, Pakistan. *Nova mehanizacija šumarstva: Časopis za teoriju i praksu šumarskoga inženjerstva*, *42*(1), 27–40.
- Komppula, R., & Konu, H. (2017). Designing forest-based wellbeing tourism services for Japanese customers. *Co-Creation in Tourist Experiences*, *5*, 50.
- Kongsager, R., Napier, J., & Mertz, O. (2013). The carbon sequestration potential of tree crop plantations. *Mitigation and Adaptation Strategies for Global Change*, *18*(8), 1197–1213. [CrossRef]
- Kuemmerle, T., Altrichter, M., Baldi, G., Cabido, M., Camino, E., Cuellar, R. L., Cuellar, J., Decarre, S., Díaz, I., Gasparri, I., Gavier-Pizarro, G., Ginzburg, R., Giordano, A. J., Grau, H. R., Jobbágy, E., Leynaud, G., Macchi, L., Mastrangelo,

M., Matteucci, S. D., Noss, A., … Zak, M. (2017). Forest conservation: Remember Gran Chaco. *Science*, *355*(15), 465–465.

- Kunstler, G., Curt, T., Bouchaud, M., & Lepart, J. (2005). Growth, mortality and morphological response of European beech and downy oak along a light gradient in sub-Mediterranean forest. *Canadian Journal of Forest Research*, *35*(7), 1657–1668. [CrossRef]
- Leslie, A. D., Mencuccini, M., & Perks, M. P. (2018). Preliminary growth functions for *Eucalyptus gunnii* in the UK. *Biomass and Bioenergy*, *108*, 464–469. [CrossRef]
- Löf, M., Karlsson, M., Sonesson, K., Welander, T. N., & Collet, C. (2007). Growth and mortality in underplanted tree seedlings in response to variations in canopy closure of Norway spruce stands. *Forestry*, *80*(4), 371–383. [CrossRef]
- Lundqvist, S. O., Grahn, T., Olsson, L., & Seifert, T. (2017). Comparison of wood, fibre and vessel properties of drought-tolerant eucalypts in South Africa. *Southern Forests: A Journal of Forest Science*, *79*(3), 215–225. [CrossRef]
- Miles, L., Kapos, V., & Dunning, E. (2010). *Ecosystem services from new and restored forests: Tool development* (pp. 1–43). Multiple Benefits Series, 5. [CrossRef]
- Mori, A. S. (2017). Biodiversity and ecosystem services in forests: Management and restoration founded on ecological theory. *Journal of Applied Ecology*, *54*(1), 7–11. [CrossRef]
- Nasir, T., & Ahmad, N. (2012). The effect of grain size on radon exhalation rate in soil sample of Dera Ismail Khan in Pakistan. *Journal of Basic and Applied Sciences*, *8*(2), 430–436.
- Novotny, V., Drozd, P., Miller, S. E., Kulfan, M., Janda, M., Basset, Y., & Weiblen, G. D. (2006). Why are there so many species of herbivorous insects in tropical rainforests? *Science*, *313*(5790), 1115–1118. [CrossRef]
- Oliveira, F., Pintassilgo, P., Pinto, P., Mendes, I., & Silva, J. A. (2017). Segmenting visitors based on willingness to pay for recreational benefits: the case of Leiria National Forest. *Tourism Economics*, *23*(3), 680–691. [CrossRef]
- Óskarsson, H., Sigurgeirsson, A., & Raulund-Rasmussen, K. (2006). Survival, growth, and nutrition of tree seedlings fertilized at planting on andisol soils in Iceland: six-year results. *Forest Ecology and Management*, *229*(1–3), 88–97. [CrossRef]
- Osunkoya, O. O., Othman, F. E., & Kahar, R. S. (2005). Growth and competition between seedlings of an invasive plantation tree, Acacia Mangium, and those of a native Borneo heath-forest species, *Melastoma beccarianum*. *Ecological Research*, *20*(2), 205–214. [CrossRef]
- Phiri, D., Ackerman, P., Wessels, B., du Toit, B., Johansson, M., Säll, H., Lundqvist, S., & Seifert, T. (2015). Biomass equations for selected drought-tolerant eucalypts in South Africa. *Southern Forests: A Journal of Forest Science*, *77*(4), 255–262. [CrossRef]
- Pirard, R., Dal Secco, L., & Warman, R. (2016). Do timber plantations contribute to forest conservation? *Environmental Science and Policy*, *57*, 122–130. [CrossRef]
- Poersch, N. L., França Filho, L. R. T., Miguel, E. P., Miguel da Cruz, G. H., Francisquette, K. L., & Cavalheiro, S. B. (2017). Influence of climate variables in the initial growth of *Corymbia citriodora* and different species of eucalyptus. *Bioscience Journal*, *33*(6), 82–98.
- Rawat, L. S., Maikhuri, R. K., Dhyani, D., Bahuguna, Y. M., & Pharswan, D. S. (2017). Ecological restoration of village common degraded land through participatory approach for biodiversity conservation and socio-economic development in Indian Himalayan Region. *Acta Ecologica Sinica*, *37*(4), 240–252. [CrossRef]
- Rousta, M. J., Matinizadeh, M., Zarafshar, M., & Nouri, E. (2023). Spate irrigation slightly ameliorates an arid soil's quality, but tree planting enhances its characteristics. *Soil and Tillage Research*, *229*, 105658. [CrossRef]
- Rubilar, R. A., Lee Allen, H. L., Fox, T. R., Cook, R. L.,Albaugh, T. J.,& Campoe, O. C. (2018). Advances in silviculture of intensively managed plantations. *Current Forestry Reports*, *4*(1), 23–34. [CrossRef]
- Sabastian, G. E., Kanowski, P., Williams, E., & Roshetko, J. M. (2018). Tree diameter performance in relation to site quality in smallholder timber production systems in Gunungkidul, Indonesia. *Agroforestry Systems*, *92*(1), 103–115. [CrossRef]
- Sajwaj, T., Harely, M., & Parker, C. (2008). *Eliasch review: Forest management impacts on ecosystem services*. AEA. http://www.occ.gov.uk/activities/eliasch/AEA_ecosystem_services.pdf
- Shehzad, K., Anwar, A., Samia, A., Areeba, B. I., & Naveed, A. (2022). Mapping and monitoring forest landscape restoration using Landsat-8 images. *Bulletin of the Transilvania University of Brasov. Series II: Forestry Wood Industry Agricultural Food Engineering. Series II*, 43–64. [CrossRef]
- Soehartono, T., Newton, A., & Mardiastuti, A. (2002). Factors influencing the survival and growth of *Aquilaria malaccensis* seedling in Indonesia. *Journal of Tropical Forest Science*, *14*(3), 364–378
- Sukhbaatar, G., Ganbaatar, B., Jamsran, T., Purevragchaa, B., Nachin, B., & Gradel, A. (2020). Assessment of early survival and growth of planted Scots pine (*Pinus sylvestris*) seedlings under extreme continental climate conditions of northern Mongolia. *Journal of Forestry Research*, *31*(1), 13–26. [CrossRef]
- Trumbore, S., Brando, P., & Hartmann, H. (2015). Forest health and global change. *Science*, *349*(6250), 814–818. [CrossRef]
- Ullah, I., Saleem, A., Ansari, L., Ali, N., Ahmad, N., Dar, N. M., & Din, N. U. (2020). Growth and survival of multipurpose species; assessing Billion Tree Afforestation Project (BTAP), the Bonn challenge initiative. *Applied Ecology and Environmental Research*, *18*(2), 2057–2072. [CrossRef]
- Venable, N. B., Lockwood, R., DiMaria, J., Duda, J., Rhoades, C., & Mason, L. (2017). *Forest management to protect Colorado's water resources*. Colorado Water Conservation Board, Department pf Natural Resources, Colorado State University.
- Wodehouse, D. C. J., & Rayment, M. B. (2019). Mangrove area and propagule number planting targets produce sub-optimal rehabilitation and afforestation outcomes. *Estuarine, Coastal and Shelf Science*, *222*, 91–102. [CrossRef]
- World Wildlife Fund (2016). *Third party monitoring of billion trees tsunami afforestation project in Khyber Pakhtunkhwa*. World Wide Fund for Nature Pakistan.
- World Wildlife Fund (2017). *Third party monitoring of the billion trees afforestation project in Khyber Pakhtunkhwa Pakistan*. http://103.240.220.71/btt/repos/files/2018/02/THIRD-PARTY-MONITORING-OF-THE-BTAP-PHASE-2-Part-2.pdf
- Yamada, T., Watanabe, K., Okuda, T., Sugimoto, T., & Azlin, Y. N. (2016). Growth and survival of trees planted in an oil palm plantation: Implications for restoration of biodiversity. *Journal of Tropical Forest Science*, 97–105.
- Zahid, D. M., & Ahmad, R. (2016). Effect of age of Farm-grown Eucalyptus on seasoning quality of wood and its utilization in Pakistan. *International Journal of Agriculture and Biology*, *4*, 315–317.
- Zahid, D. M., Shah, F. U. R., & Majeed, A. (2010). Planting *Eucalyptus camaldulensis* in arid environment–is it useful species under water deficit system. *Pakistan Journal of Botany*, *42*(3), 1733–1744.

Supplementary Table 1.
Area, sampling intensity, and pit density of each Plantations site

Plantation Site	Area (ha)	Sampling intensity	No of sample Plots	Average no. of pits/plot	Average Pits per ha	Total No. of pits
Roda I and II	105	1.6	17	109	1090	114450
Ch Shafiq Dam area	10	1.0	01	109	1090	10900
Athog Disty Chashma road	10	4.0	04	109	1090	10900
Kirri shamozai II	25	4.4	11	109	1090	27250
Kala gorh	10	5.0	05	109	1090	10900
khari khaisor Part II	36.5	1.9	07	109	1090	39785
Musa kahr	20	4.0	08	109	1090	21800
Shinkee pakka village	115	1.0	12	109	1090	125350
Dhab Chabak kacha	100	1.4	14	109	1090	109000
Jhok samok wali	30	3.3	10	109	1090	32700
Total	461.5					503035

Supplementary Table 2.
Plot-wise and site-wise status of natural regeneration in Plantations

	Height (inches)					
Site	<9"	>9"	Area (ha)	Avg No of Reg/plot	Reg/ha	Total Regeneration
Roda I and II	--	90	105	5.2	52	5460
Dahb chabak	--	160	100	11.4	114	11400
Ch.shafique dam	--	15	10	15	150	1500
Athog disty chashma	--	15	10	05	50	500
Kiri shamozai II	2	48	25	4.5	45	1125
Jhoke samok	36	46	30	8.2	82	2460
Kirri khesohr II	12	1	36.5	1.8	18	657
Shinkee paka	13	81	115	7.8	78	8970
Kalagorh	3	30	10	6.6	66	660
Mosa kahr	8	22	20	3.7	37	740
Total	74	508	461.5	69.5	695	33472