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Research Article

Growth of *Sonneratia apetala* Buch.-Ham. (Keora) in relation to Stand Age at the Western Coastal Belt of Bangladesh

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Abstract

Plantation Trial Unit Division of Bangladesh Forest Research Institute (BFRI) carried out a research in the western coastal area of Bangladesh during 2018–2020 in order to assess the growth of Sonneratia apetala (Keora) in relation to stand age. For this purpose, in the Char Kukri-Mukri area, 32 PSPs were established for eight age classes (11, 15, 20, 30, 35, 40, 42, and 45 years), and in the Rangabali area, 28 PSPs were established for seven age classes (30, 35, 42, 44, 45, 48, and 50 years), followed by a stratified random sampling method. A significant difference was found ($p < 0.05$) for the height and diameter at breast height (DBH) growth of S. apetala stand among the different ages of plantation in both areas. At the Char Kukri-Mukri area, for 11 years old plantation found the highest height (0.357m) and DBH (0.570cm) growth rate after 1 year and continued after 2 years (0.662m; 1.085cm). On the other hand, for a stand age of 30 years, the highest height (0.216m) and DBH (0.246cm) growth rate were found in the Rangabali area after 1 year and continued after 2 years (0.353m; 0.390cm). A positive and strong relationship was found between height and DBH growth rate after 1 and 2 years (r=0.850 and r=0.891) in the Char Kukri-Mukri area respectively. On the other hand, a positive and very strong relationship was found between height and DBH growth rate after 1 and 2 years (r=0.931 and r=0.913) in the Rangabali area successively. This result will aid in the selection of appropriate forest management practices for managing S. apetala plantations on a sustainable basis in the western coastal belt of Bangladesh.

সারসংক্ষেপ

বাংলাদেশ বন গবেষণা ইনস্টিটিউট এর অধীন প্লান্টেশান ট্রায়েল ইউনিট বিভাগ, বাংলাদেশের পশ্চিম উপকূলীয় অঞ্চলে ২০১৮ থেকে ২০২০ সাল পর্যন্ত বাগানের বয়স অনুযায়ী Sonneratia apetala (কেওড়া) এর বর্ধন হার পরিমাপের জন্য একটি গবেষণা চালায়। চর চুকরি-মুকরি এলাকায় বয়স অনুযায়ী আটটি শ্রেণির (১১, ১৫, ২০, ৩০, ৩৫, ৪০, ৪২, এবং ৪৫ বছর) জন্য ৩২টি পিএসপি এবং রাঙ্গাবালী এলাকায় সাতটি শ্রেণির (৩০, ৩৫, ৪২, ৪৪, ৪৫, ৪৮, এবং ৫০ বছর) জন্য ২৮টি পিএসপি স্ট্র্যাটিফায়েড র‍্যান্ডম স্যাম্পলিং পদ্ধতি অনুসরণ করে নির্ধারণ করা হয়। কেওড়া গাছের বিভিন্ন বয়সের (রোপণ অনুযায়ী) মধ্যে উচ্চতা এবং ব্যসার্ধ বৃদ্ধির ক্ষেত্রে একটি উল্লেখযোগ্য পার্থক্য পাওয়া গেছে (p < ০.০৫)। এক বছর পর চর কুকরি-মুকরি এলাকায়, ১১ বছর বয়সী গাছের ক্ষেত্রে সর্বোচ্চ উচ্চতা (০.৩৫৭মি.) এবং বুক সমান উচ্চতায় ব্যসার্ধ (০.৫৭০সে.মি.) বৃদ্ধি পেয়েছে এবং পরবর্তী ২য় বছরে (০.৬৬২মি.; ১.০৮৫সে.মি.) তা অব্যাহত ছিল। অন্যদিকে, ১ বছর পর রাঙ্গাবালি এলাকায় ৩০ বছর বয়সী গাছের ক্ষেত্রে সর্বোচ্চ উচ্চতা (০.২১৬মি.) এবং বুক সমান উচ্চতায় ব্যসার্ধ (০.২৪৬সে.মি.) বৃদ্ধি পেয়েছে এবং পরবর্তী ২য় বছরে (০.৩৫৩ মি.; ০.৩৯০সে.মি.) তা অব্যাহত ছিল। চর কুকরি-মুকরি এলাকায় উচ্চতা এবং বুক সমান উচ্চতায় ব্যসার্ধ বৃদ্ধির মধ্যে যথাক্রমে ১ এবং ২ বছর পরে ইতিবাচক এবং শক্তিশালী সম্পর্ক (r=০.৮৫০ এবং r =০.৮৯১) পাওয়া যায়। অন্যদিকে, রাঙ্গাবালি এলাকায় উচ্চতা এবং বুক সমান উচ্চতায় ব্যসার্ধ বৃদ্ধির মধ্যে যথাক্রমে ১ এবং ২ বছর পরে ইতিবাচক এবং খুবই শক্তিশালী সম্পর্ক (r=০.৯৩১ এবং r=০.৯১৩) পাওয়া যায়। গবেষণার এই ফলাফল,

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বাংলাদেশের পশ্চিম উপকূলীয় এলাকায় কেওড়া বাগান সুষ্ঠুভাবে ব্যবস্থাপনা করার জন্য একটি উপযুক্ত বন ব্যবস্থাপনা পদ্ধতি নির্বাচন করতে সহায়তা করবে।

Keywords: Coastal belt, Diameter, Growth, Height, *Sonneratia apetala.*

Introduction

The coast has been defined as the area where terrestrial and marine habitats interact and vice versa (Carter 1991). The coastal ecosystem is one of the most dynamic ecosystems on the planet (Serajuddoula *et al.* 1995). Bangladesh's coastline extends over 710 km along the Bay of Bengal (Das and Siddiqi 1985; Siddiqi 2001), and the coastal zone encompasses 47,201 square kilometers between latitudes 21^0 and 23^0 north and longitudes 89^0 and 93^0 east (Islam and Rahman 2015). Because mangrove roots and pneumatophores efficiently impede water velocity and operate as efficient sediment trappers, fast accretion occurs along the shoreline (Woodroffe 1992). Plantation is a frequent approach for recovering mangrove forests (Chen *et al.* 2009), and Bangladesh is one of the leading countries in the world for coastal afforestation with several mangrove species (Islam *et al.* 2016). In the coastal regions, approximately 1,90,000 hectares (ha.) of accreted land were afforested with mangrove species until 2010 (Islam *et al.* 2013) and 1,92,000 ha. till 2013 (Hasan 2013). The most successful planted species is *Sonneratia apetala* (Keora), while *Avicennia officinalis* (Baen) is the second most successful species in coastal mangrove plantations (Siddiqi 2001). Because *S. apetala* has the best survival and growth performance in newly accreted areas throughout the coastal belt, it is the most common species planted in coastal afforestation programs (Islam *et al.* 2016). Currently, *S. apetala* alone accounts for 94.4% of all established mangrove plantations, whereas *A. officinalis* accounts for only 4.8% (Siddiqi and Khan 2004).

Sonneratia apetala is an ecologically significant tree species in Indo-Malayan mangroves (Tomlinson 1986) and is commonly used for mangrove restoration operations in a variety of locales (Lu *et al.* 2014). It is a light-demanding (Rashid and Rahman 2012; Lu *et al.* 2014; Hossain 2015), fast growing pioneer (Das and Siddiqi 1985; Chen *et al.* 2003; Lu *et al.* 2014; Hossain 2015), woody evergreen tree species (Ren *et al.* 2009; Hossain 2015). It can grow up to 20 m (Siddiqi 2001; Kairo *et al.* 2009; Ren *et al.* 2009; Hossain 2015) and DBH varies between 30-70cm (Hossain 2015). It improves soil fertility significantly and exhibits a number of desirable qualities as a pioneer restoration species (Chen *et al.* 2003; Ren *et al.* 2009). It accounts for around 4.5% of the Sundarbans' merchantable growing stock (Chaffey *et al.* 1985) and 95% of Bangladesh's coastal afforestation (Siddiqi and Shahjalal 1997). This tree was the most successful all along the coastal line and accounted for 94.4% of the total plantation in coastal areas of Bangladesh (Siddiqi and Khan 2004). Tree growth is frequently quantified using stem DBH and tree height (Sumida *et al.* 2013), and it continues for years as both diameter and height increase (Henry and Aarssen 1999). The diametric and hypsometric tree growth trends varied by tree species or forest stands (Sumida *et al.* 1997). Without a doubt, tree growth is influenced by their age (Lukaszkiewicz 2010), and the growth of all forests follows a predictable pattern with age (Binkley *et al.* 2002). While radial growth continues throughout the tree's life, the tree's height may only reach a maximum, which is unique to each tree species (Woolhouse 1972; Koch *et al.* 2004; Niklas 2007). Forest development is significant both economically and ecologically (Binkley *et al.* 2002), and knowing tree growth can help with CO_2 reductions in the atmosphere, air quality advantages, storm water runoff, and tree maintenance costs (Lukaszkiewicz 2010). To improve biodiversity and ecosystem services, as well as to ensure long-term sustainable forest resources, forest growth studies have been needed on site quality, tree competitive status, stand density management, and silvicultural management (Briseño-Reyes *et al.* 2020). Because of the importance of *S. apetala* plantations in Bangladesh, a better understanding of their growth in relation to their stand age is needed at the regional, national, and worldwide levels. The objective of this study is to find out the variation or changes in the growth (height and DBH) of *S. apetala* in relation to stand age or increasing stand age. With the knowledge of the growth rate of this species, policymakers and decision-makers will be able to make decisions about *S. apetala* species for future coastal plantation, restoration, and management programs.

Materials and Methods

Study area

The research was conducted at Char Kukri-Mukri research station in Bhola district and Rangabali research station in Patuakhali district. The Char Kukri-Mukri area is located between the latitudes of 21°54' and 22°52' north, and the longitudes of 90°34' and 91°01' east (Dey *et al.* 2021a). On the other hand, the Rangabali area is located between the latitude of 21°59' and 21°59' north, and the longitudes of 90°28' and 90°28' east (Moula and Miah 2020). The site conditions in these two areas are almost similar (Islam *et al.* 2015). Annual rainfall ranges from 2500 to 3000mm, with mean minimum and maximum temperatures ranging from 18 to 32^{0}C (Siddiqi 2002). The delta of the extended Himalayan drainage ecosystem, which makes up the lowest landmass, includes this region. The combined actions of the rivers Brahmaputra, Meghna, and Ganges have created low-lying terrain, estuaries, and inlands along the seacoast. Water salinity varies between 3-27 ppt during the monsoon season and 10-33 ppt during the dry season (Siddiqi and Khan 1990). The soil type in the research region is silt-clay-loam, with salinity varying from 0.3-4.2 ds/m in December to 9 ds/m in April-May (Hasan 1987). The soil pH ranges from 7.5 to 8.0, and it is slightly alkaline (Siddiqi and Khan 2000).

Sampling design

At each station, different available stand ages were considered for establishing permanent sample plots (PSP). The PSP size was 10m x 10m. Thirty-two PSPs (four PSPs for each age class) were established in the Char Kukri-Mukri area under eight age classes (11, 15, 20, 30, 35, 40, 42, and 45 years), covering a total area of 3200 square meters. On the other hand, in the Rangabali area, 28 PSPs (four PSPs for each age class) were established under seven age classes (30, 35, 42, 44, 45, 48, and 50 years), covering a 2800 sq. m. area. The PSPs were selected following the stratified random sampling method. All PSPs were demarcated by bamboo or wooden sticks, and all trees in the study plots were numbered sequentially.

Data collection

Data from the permanent sample plots were collected during December for three subsequent years: 2018, 2019, and 2020. Diameter tape was used to measure the DBH at 1.3m. above the tree from the ground. On the other hand, Haga altimeter was used to measure tree height.

Statistical analysis

The variations in height and DBH increment over time in relation to stand age were analyzed using a one-way ANOVA (analysis of variance). When a significant difference was identified, pairwise comparisons were performed using post hoc testing (Tukey's HSD). To the findings of all statistical analysis, a significance value of $p < 0.05$ was used. The normality and homogeneity of variance assumptions were met prior to the ANOVA test. The data was computed and analyzed using a Microsoft Excel spreadsheet, SPSS (Version 23.0) and the Statistix 10 statistical program.

Results

In Char Kukri-Mukri area, the highest mean height was found at the age of 42, followed by 35, 40, 30, 45, 20, 15 and 11 years of *S. apetala* plantation (Fig. 1). On the other hand, in the same area, the highest mean DBH was found at the age of 42, followed by 45, 35, 40, 30, 15, 20 and 11 years (Fig. 2). A significant difference was found for the mean height growth rate after 1 year (2019) and 2 years (2020). The highest mean height growth rate was found for the age of 11 years (0.357m), followed by 15 (0.255m), 20 (0.197m), 30 (0.160m), 40 (0.118m), 35 (0.100m), 45 (0.095m) and 42 (0.075m) years after one year of measurement in 2019 (Table 1). On the other hand, in the same plantation, the highest mean height growth rate was found at the age of 11 years (0.662m), followed by 15 (0.525m), 20 (0.412m), 30 (0.375m), 40 (0.186m), 35 (0.180m), 42 (0.150m) and 45 (0.147m) years after 2 years of measurement in 2020 (Table 1). In the same area, a significant difference was

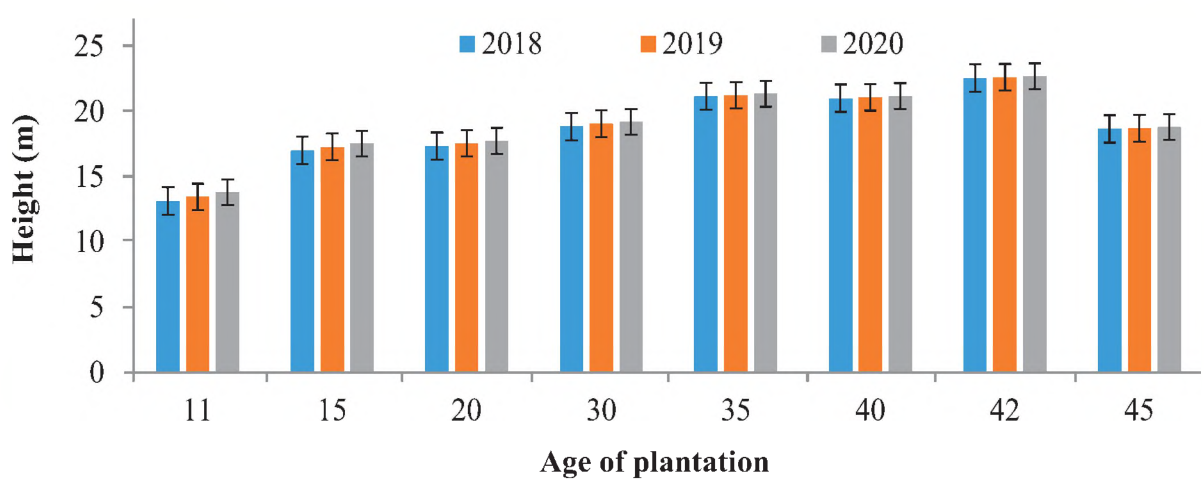


Figure 1. Height of Keora at Char Kukri-Mukri area in three subsequent years.

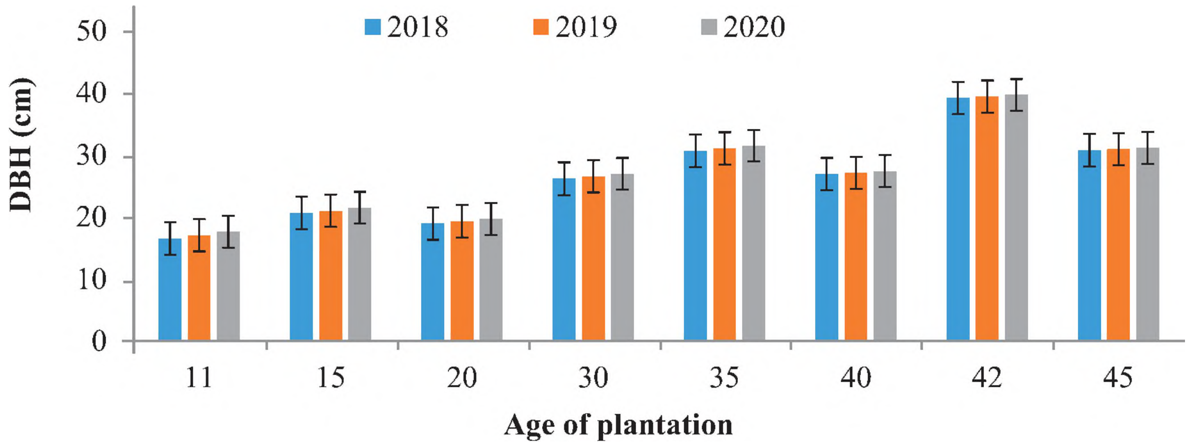


Figure 2. DBH of Keora at Char Kukri-Mukri area in three subsequent years.

found for the mean DBH growth rate after 1 year (2019) and 2 years (2020). The highest mean DBH growth rate was found at the age of 11 years (0.570cm), followed by 15 (0.482cm), 30 (0.415cm), 35 (0.407cm), 20 (0.340cm), 40 (0.282cm), 42 (0.280cm) and 45 (0.207cm) years plantation after 1 year measurement in 2019 (Table 1). On the other hand, in the same plantation, the highest mean DBH growth rate was found at the age of 11 years (1.085cm), followed by 15 (0.857cm), 35 (0.797cm), 30 (0.782cm), 20 (0.700cm), 42 (0.492cm), 40 (0.487cm) and 45 (0.360 cm) years after 2 years of measurement in 2020 (Table 1).

In the Rangabali area, the highest mean height was found at the age of 45, followed by the ages of 35, 50, 48, 44, 42, and 30 years of *S. apetala* plantation (Fig. 3). On the other hand, in the same area, the highest mean DBH was found at the age of 45, followed by 35, 30, 48, 42, 50, and 44 years (Fig. 4). A significant difference was found for the mean height growth rate after 1 year (2019) and 2

Table 1. Height and DBH growth of *S. apetala* at Char Kukri-Mukri area.

Age of the plantation (years)	Height growth (m)		DBH growth (cm)	
	After 1 year (2019)	After 2 years (2020)	After 1 year (2019)	After 2 years (2020)
11	0.357 ± 0.04 [a]	0.662 ± 0.09 [a]	0.570 ± 0.02 [a]	1.085 ± 0.02 [a]
15	0.255 ± 0.03 [ab]	0.525 ± 0.03 [ab]	0.482 ± 0.01 [ab]	0.857 ± 0.01 [ab]
20	0.197 ± 0.02 [bc]	0.412 ± 0.05 [b]	0.340 ± 0.02 [bcd]	0.700 ± 0.03 [bc]
30	0.160 ± 0.01 [bcd]	0.375 ± 0.02 [bc]	0.415 ± 0.01 [bc]	0.782 ± 0.06 [b]
35	0.100 ± 0.01 [cd]	0.180 ± 0.03 [cd]	0.407 ± 0.03 [bc]	0.797 ± 0.07 [b]
40	0.118 ± 0.02 [cd]	0.186 ± 0.03 [cd]	0.282 ± 0.03 [cd]	0.487 ± 0.03 [cd]
42	0.075 ± 0.01 [d]	0.150 ± 0.02 [d]	0.280 ± 0.01 [cd]	0.492 ± 0.01 [cd]
45	0.095 ± 0.01 [cd]	0.147 ± 0.01 [d]	0.207 ± 0.05 [d]	0.360 ± 0.09 [d]

Note: Treatment values followed by different letters (like a, b, c, etc.) significantly differ at the 5% significance level.

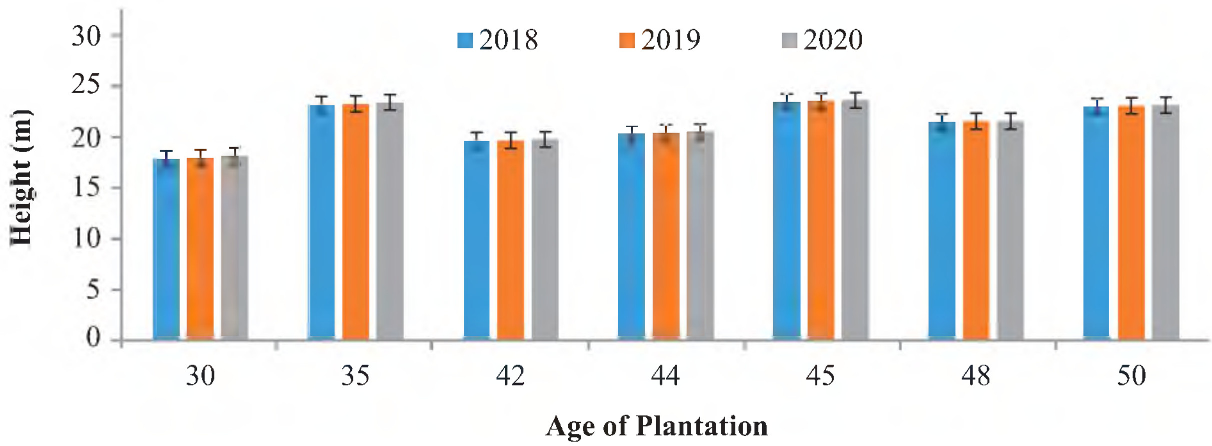


Figure 3. Height of Keora at Rangabali area in three subsequent years.

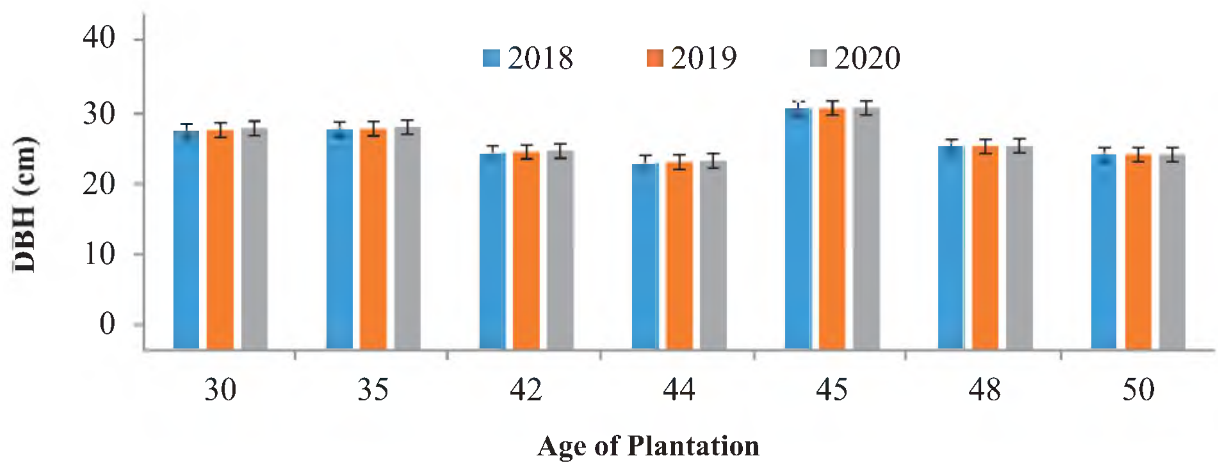


Figure 4. DBH of Keora at Rangabali area in three subsequent years.

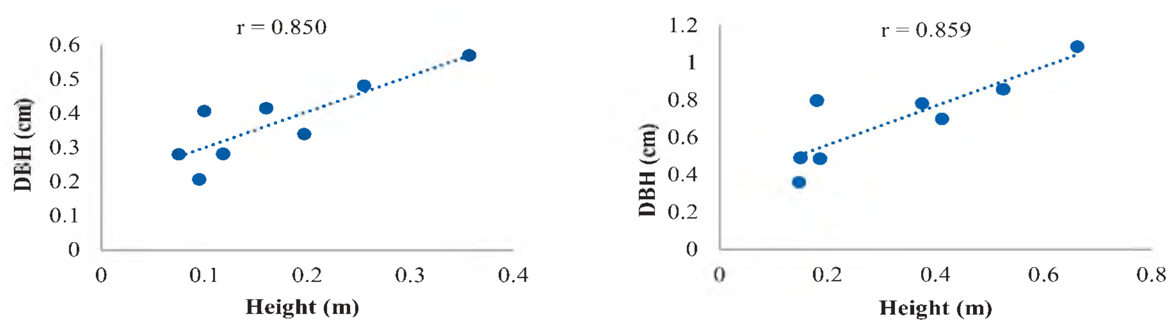
years (2020). The highest mean height growth rate was found at the age of 30 years (0.216m), followed by 35 (0.150m), 44 (0.136m), 42 (0.090m), 45 (0.086m), 50 (0.063m), and 48 (0.036m) years after 1 year in 2019 (Table 2). On the other hand, in the same plantation, the highest height growth rate was found at the age of 30 years (0.353 m), followed by 35 (0.243m), 44 (0.223m), 45 (0.173m), 42 (0.150m), 48 (0.103m), and 50 (0.093m) years after 2 years in 2020 (Table 2). In the same area, a significant difference was found for the mean DBH growth rate after 1 year (2019) and 2 years (2020). The highest mean DBH growth rate was found at the age of 30 years (0.246cm), followed by 44 (0.206cm), 35 (0.203cm), 42 (0.126cm), 45 (0.060 cm), 48 (0.036 cm) and 50 (0.023cm) years after 1 year in 2019 (Table 2). On the other hand, in the same plantation, the highest DBH growth rate was found at the age of 30 years (0.390cm), followed by 44 (0.300cm), 35 (0.283cm), 42 (0.240cm), 45 (0.123cm), 48 (0.083cm) and 50 (0.036cm) years after 2 years in 2020 (Table 2). Besides in the objectives,

Table 2. Height and DBH growth of *S. apetala* at Rangabali research station.

Age of the plantation (years)	Height growth (m)		DBH growth (cm)	
	After 1 year (2019)	After 2 years (2020)	After 1 year (2019)	After 2 years (2020)
11	0.357 ± 0.04 [a]	0.662 ± 0.09 [a]	0.570 ± 0.02 [a]	1.085 ± 0.02 [a]
15	0.255 ± 0.03 [ab]	0.525 ± 0.03 [ab]	0.482 ± 0.01 [ab]	0.857 ± 0.01 [ab]
20	0.197 ± 0.02 [bc]	0.412 ± 0.05 [b]	0.340 ± 0.02 [bcd]	0.700 ± 0.03 [bc]
30	0.160 ± 0.01 [bcd]	0.375 ± 0.02 [bc]	0.415 ± 0.01 [bc]	0.782 ± 0.06 [b]
35	0.100 ± 0.01 [cd]	0.180 ± 0.03 [cd]	0.407 ± 0.03 [bc]	0.797 ± 0.07 [b]
40	0.118 ± 0.02 [cd]	0.186 ± 0.03 [cd]	0.282 ± 0.03 [cd]	0.487 ± 0.03 [cd]
42	0.075 ± 0.01 [d]	0.150 ± 0.02 [d]	0.280 ± 0.01 [cd]	0.492 ± 0.01 [cd]
45	0.095 ± 0.01 [cd]	0.147 ± 0.01 [d]	0.207 ± 0.05 [d]	0.360 ± 0.09 [d]

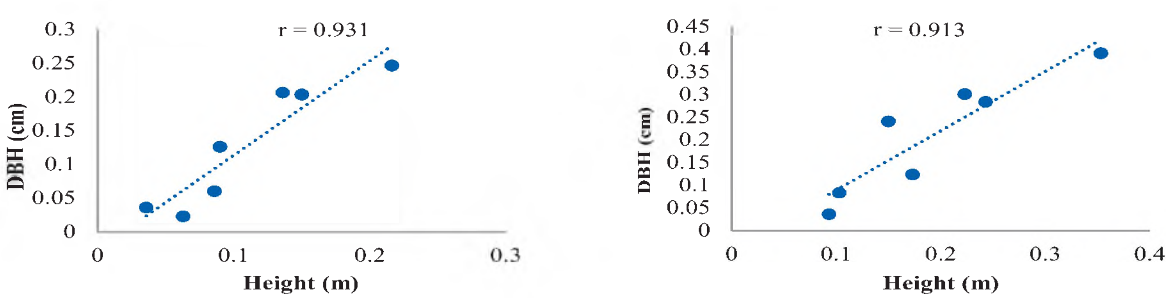
Note: Treatment values followed by different letters significantly differ at the 5% significance level.

there was found a positive and strong relationship between height and DBH growth (for both 1 and 2 years) in both the Char Kukri-Mukri and Rangabali areas (Fig. 5 & Fig. 6). In the Char Kukri-Mukri area, a positive, strong relationship was found between height and DBH growth rate after 1 year (r = 0.850) and 2 years (r = 0.859) (Fig. 5A & Fig.5B). On the other hand, in the Rangabali area, a positive and very strong relationship was found between height and DBH growth after 1 year (r = 0.931) and 2 years (r = 0.913) (Fig. 6A & Fig.6B).



(A) (B)

Figure 5. Relationship between height and DBH growth rate at Char Kukri-Mukri area after 1 year (A) and 2 years (B).



(A) (B)

Figure 6. Relationship between height (m) and DBH (cm) growth rate at Rangabali area after 1 year (A) and 2 years (B).

Discussion

In this research, a significant difference was found in the height growth rate among the different stand ages for 1 year (2019) and 2 years (2020) in both the Char Kukri-Mukri and Rangabali areas. However, the growth rate did not always follow the decreasing trend of the growth rate with increasing stand age in both Char Kukri-Mukri and Rangabali areas. In the Char Kukri-Mukri area, the annual height increment was found to decrease with increasing stand age, up to the age of 11 to 30 years. Then it broke the trend, and the annual height increment of 40 years of age was more (0.118m) than the 35 years growth (0.100m), and the growth of 45 years was more (0.095m) than the 42 years growth (0.075m). When the data were collected, after 2 years in the same plantation, the previous one followed without a height growth rate of 42, which was more (0.150m) than the 45 years growth rate (0.147m). On the other hand, in the Rangabali area, the annual (2019) height growth rate of 44 years was more (0.136m) than the 42 years growth rate (0.090m), and the 50 years growth rate was more (0.063m) than the 48 years growth rate (0.036m). Incase of height growth, the growth rate of DBH was not following the decreasing trend with increasing stand age in both the Char Kukri-Mukri and Rangabali areas. In the Char Kukri-Mukri area, the annual (2019) DBH growth rate of 30 years and 35 years was higher (0.415 and 0.407cm) than the 20 years growth rate (0.340cm). On the other hand, in the Rangabali area, the DBH growth rate of 44 years was higher (0.300cm) than the 35 years and 42 years growth rate (0.283 and 0.240cm) after 2 years of data collection (2020). Siddiqi (2001) found the maximum mean annual diameter increment (MAI) of *S. apetala* up to 11 years was 1.23cm and the height increment was 1.16m in the coastal area of Bangladesh. In addition, Siddiqi (1988) found that the annual DBH and height increment (MAI) were 1.33cm and 0.936cm, respectively, up to 10 years of *S. apetala* plantation in the Char Kukri-Mukri area of Bhola district. Moreover, *S. caseolaris*, a species near to *S. apetala,* showed the highest growth among all planted species, with an annual diameter increment (MAI) of 1.92cm and a height increment of 0.97m, which occurred in low saline areas (up to 16 ppt) (Siddiqi and Khan 1990). The height and DBH of different years stands showed variation, which means that in some cases, the lower year stand has more height and DBH than the older one. As well, variation happened between the locations at the same age. Like in the Char Kukri Mukri area, the height of 45 years was less than the heights of 30, 35, 40, and 42 years. On the other hand, in the Rangabali area, the DBH of a 45 years old plantation was higher than the 48 and 50 years old plantations. It was found that at 45 years old plantation (Kukri Mukri area), some big trees are dead, and it could be a possible case of reason to take the mean data (both height and DBH) of all the trees in the plots. Poor-quality seeds and planting stocks can be the reason for this low productivity, or grazing can happen after plantation that severely affects plantation establishment and affects the growth of the species (Shafi 1982; Kathirensan and Ravikumar 1993; Nandy *et al.* 2004). For the same age plantation, the height and DBH are greater in the Rangabali area than in the Char Kukri-Mukri area. *Sonneratia apetala* performs better on barren, muddy beaches, with higher survival and growth rates (Ren *et al.* 2009), which could be one reason for this. It grows best in thick and soft muddy soils from the middle to the low tidal zone with low salinity (0–15) (Huang and Zhang 2002; Chen *et al*. 2003; Liao *et al*. 2004), that can be the reason for variation. Siddiqi (2001) stated that growth was higher in places with lower salinity and declined in places with higher salinity. The depth, duration, and frequency of flooding are all important factors in the survival of mangrove seedlings and mature trees (Mitsch *et al*. 2002; Lewis 2005). All of the above-mentioned factors can be a possible factor in the different growth rates of different age groups, along with the age factor in both the same and other locations. The height-diameter relationship varies greatly between forest types and regions (Feldpausch *et al*. 2011). Dey *et al*. (2021b) found a strong positive relationship (r= 0.789) between DBH and height for *Acacia auriculiformis* at the Char Kukri-Mukri area in the Bhola district of Bangladesh, which was one of the study areas in this research. In the savanna zone of Nigeria, Arzai and Aliyu (2010) found a very strong linear relationship between DBH and height in *Khaya senegalensis*, *Parkia biglobosa* and *Eucalyptus species*.

Conclusion

A significant difference was found for the growth (height and DBH) of *S. apetala* among the different ages of plantations in the western coastal belt of Bangladesh. However, there is not always a decline in growth rate (height and DBH) as age increases. The findings will be helpful for managing *S. apetala* plantations on a sustainable basis and determining appropriate forest management methods to mitigate the negative effects of climate change. This was only examined the growth rates of different age groups of *S. apetala* stands, but the other climatic factor was not included; that could be another research study.

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