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Carbon sequestration capacity of Casuarina equisetifolia in the coastal areas of Cox's Bazar, Bangladesh

Mohammed Mukhlesur Rahman

Bangladesh Forest Research Institute, P. O. Box, 273, Chittagong-4000, Bangladesh

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ABSTRACT
Casuarina equisetifolia is mainly planted in the coastal regions of Bangladesh due to the reduction of natural calamities and climate change mitigation.Establishment of a green-belt of Casuarina equisetifolia appeared as the most suitable device to reduce the losses and damages of the natural disasters. A total of 415 ha plantation were established in three coastal Forest rangesalong the sea beach under Cox's Bazar Sadar, Ukhiya and Teknaf during 1997-2020.A systematic sampling process and non-destructive method were used to determine the total carbon. The survival percentage was varied from 65 to 92% at different ages. The maximum diameter and height 23.54 cm, 20.33 m werefound in 20 years-oldplantations respectively. The highest carbon stock was 52.28 t ha^{-1}in 20 years old and the lowest carbon stock was15.40 t ha^{-1} in4years old plantation. The average carbon stock and mean annual increment carbon were35.41t ha^{-1} and 6.73 t $ha^{-1}yr^{-1}$respectively.The statistical analysis showed that total biomass and carbon differed significantly ($p<0.05$) among different ages. The correlation indicated that a strongly positive relationships were found among ages,biomass and carbon. The results also focused that Casuarina equisetifolia was more capable of storing carbon than other coastal forest tree species.The results of this study will provide important information on the plantation of Casuarina equisetifolia, which will be utilized in afforestation and reforestation programmes implementation in the coastal regions of Bangladesh.

Keywords: Coastal, growth, survival, biomass, carbon, vegetation, Cox's Bazar

I. INTRODUCTION

Bangladesh is one of the most coastal marginal countries in the world. Bangladesh has a total of 47,211 km^2 coastal areas, which represent about 32% of country's area and 28 % of the total people live in the vast coastal areas (Islam, 2007; Hossain et al., 2008).The tidal floodplains are less than 1 m above the mean sea level (MSL) and the main river and estuarine flood plains are 1- 4m above MSL (Rashid, 1991). About 710 km long coastline in Bangladesh is divided into three distinct geomorphological regions, viz., western zone, central zone, and eastern zone (Siddiqi, 1993).The western and central zones are very flat and low, whereas the eastern coastal zone boasts the beautiful tourist spot of Cox's Bazar, which is world famous for its uninterrupted longest sandy sea beaches (Banglapedia, 2006). The main attraction of Cox's Bazar is the long sandy beach which is one of the most-visited tourist destinations in Bangladesh. Bangladesh is one of the most vulnerable countries to the impacts of global climate change and these impacts are becoming ever more visible (IPCC, 2007).The sandy beaches of Cox's Bazar are becoming susceptible to a variety of natural hazards including floods, cyclones, storm surges, sea- level rise, coastal erosion and landslides (Hossain, 2010). Recent studies reveal that an annual increase of 7.8 mm sea level rise was recorded from Cox's Bazar coastal station (Alam, 2003). A total of 14 super cyclones along with tidal surges have attacked the coast of Bangladesh since 1960 (Al-Hossaini et al., 2005). After the 1960 cyclone, the Forest Department has taken massive initiatives for planting and managing both the mangrove and non-mangrove plantation on newly accreted char land in the coastal beaches of Bangladesh and a total of 192,395 ha coastal plantations have been established (Hasan, 2013).

Sonneratia apetala and Avicennia officinalisare the main species for coastal plantation in the newly accreted muddy charlands (Siddiqi, 1993); whereas Casuarina equisetifoliahas proved to be the only suitable, climate resilient and promising species in the coastal sandy beaches of the open coast and off-shore islands (Hossain et al., 2008; Hossain, 2010). Casuarina equisetifolia is thought to be indigenous in the coasts of Bangladesh (Troup, 1921; Parrotta, 1993a) and also a priority plantation species in the sandy beaches, off-shore islands, roadside and coastal homesteads (Serajuddoula et al., 1995; Nandy et al., 2002; Islam, 2003; Jashimuddin et al., 2006). The species is also suitable for industrial raw material and fuel wood production, conservation of coastal ecosystems and the environment, protection of wildlife and aquatic resources, agricultural land protection against salinity intrusion and attracting the tourists (Hossain et al., 1998; Bhuiyan et al., 2000; Chowdhury et al., 2009). Established Casuarina equisetifolia plantations in the sandy beaches are able to halt and reduce these climate change. Casuarina equisetifolia is highly resistant to wind damage and young trees can resist hurricane-force winds with little or no damage (Parrotta 1993a). Many plantations are established in the coastal areas with the help of the government and private sectors and these plantation act as protection belts during the natural calamities in Bangladesh.Casuarina equisetifoliais suitable, sustainable and it has the ability of more growth than other species. The demand of this species is increasing day by day in the coastal forests plantation of Bangladesh. But research paper on the estimation of carbon sequestration of Casuarina equisetifolia has yet to publish. So it is the urgent need to estimate the biomass and carbon stock of Casuarina equisetifolia plantation for the carbon trading facilities.On this background, the present study was carried out with the objectives of estimating the carbon of Casuarina equisetifolia in the coastal areas of Cox's Bazar.

II. MATERIALS AND METHOD

Study areas

The study area lies at 20^{0}.20' to 20^{0}.50' N latitudes and 91^{0}.54' to 92^{0}.28’ E longitudes.It is located at Cox's Bazar Sadar, Inani and Teknaf Ranges of Chittagong Coastal Forest Division. The total study area was 415ha under three Forest Ranges and seven Beats.The land surface of the area is flat to gentle slope and sandy in nature. The whole study area was under coastal area and south east parts of Bangladesh. All regions of the area were saline zone and inundated by saline water. The elevation of the study area ranged between 1meter and 4 meter mean sea level.

Climatic condition

The climate is tropical in nature. The climate is pleasant and balanced. Winter begins in the middle of November and lasts until the end of February. The summer comes from March and continues up to the end of May. The rainy season starts in June and continues up to October. About 85% of rainfall occurs during this season. The main rainfall starts in the middle of June and continues up to the middle of July and an average 3000 mm rainfall occurs during this time. From October to February the weather is mild with low rainfall. The minimum and maximum mean temperature vary from16.80° to 28.20° C in December and May respectively (Cox’s Bazar Weather Station, 2019**)**. The humidity in the whole area is high throughout the year. In June, the highest humidity is 91%, while the minimum humidity is 70% in February (Rahman, 2009).

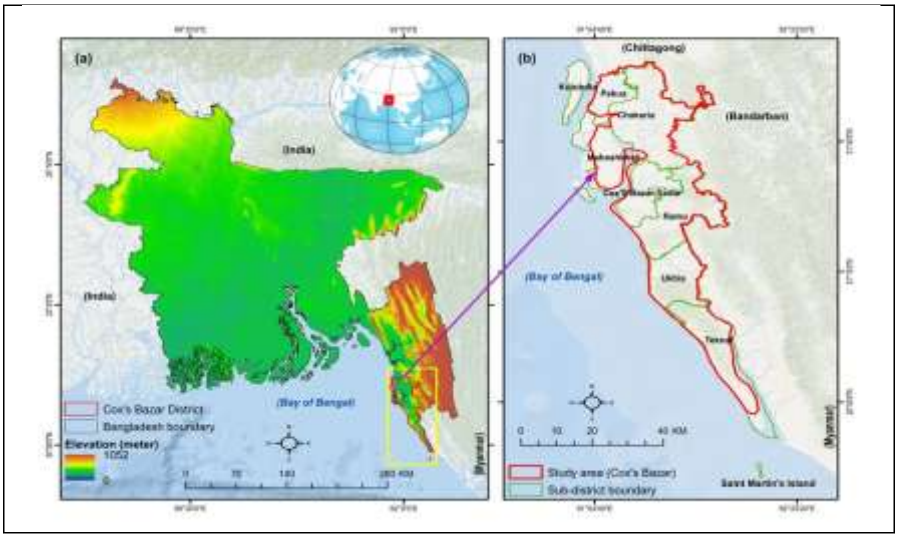

Figure 1. Map showing the location of the study area

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Selection of plots

The study was conducted on the basis of the field data collection, observation and laboratory analysis during January 2020 to December 2020. Plots of the present study were selected using Global Positioning Systems (GPS). A systematic sampling method was used for the selection of each plot with the help of global positioning system which is recognized all over the world (Pearson et al., 2007). For the convenience of the study, a total of 627 plots were selected from the whole study area and each plot was 100 m apart from each other. Although the minimum sampling intensity (number of plots per hectare) required for such studies was suggested to be 1 % by Rana et al. (2012).

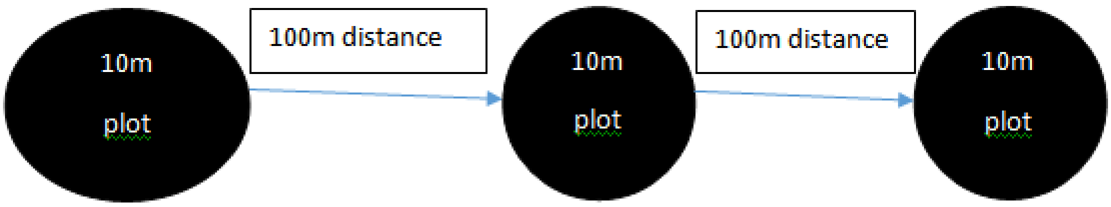

Figure2. Schematic representation of the arrangement of sampling plots.

Growth and biomass measurement of tree

After laying out of the plots, the number of trees in each plot were counted and recorded. The trees were measured for height and diameter at breast height (DBH). Each tree was marked and numbered to prevent double counting. A diameter tape was used to measure the DBH (1.30 m above from the ground level) of all the trees in each plot. Height of the trees having DBH equal or greater than 5 cm was measured with a Hega- altimeter. Trees on the border was included in a plot if > 50 % of their basal area fell within the plots and excluded if < 50 % of their basal area fell outside the plot. Trees overhanging to the plots were excluded, but with their trunk inside of the sampling plots, and branches out were included. Care was taken to ensure that the diameter tape is put around the stem exactly at the point of measurement.

Estimation of tree biomass

A non-destructive method was used to measure the aboveground biomass of an individual tree. The model of Brown et al. (1989) was used to determine the aboveground biomass (AGB) of each tree from its height and DBH values. This method is taken to be one of the most suitable methods for biomass estimation in tropical forests (Alves et al., 1997; Brown, 1997; Schroeder et al., 1997).

The model for aboveground biomass is as follows.

$$AGB=\exp.\{-2.4090+0.9522\ln(D^2HS)\}$$

Where,

AGB is the aboveground biomass (kg), H is the height of the trees (m),

D is the diameter at breast height (cm), S is the wood density (kg /m^3) for specific species.

Wood density values of the species of the present study were obtained from Sattar et al. (1999).

Aboveground biomass per plot and per hectare were calculated by the following formulas:

AGB per plot = Summation of the AGB values of all the trees in a plot.

$$\text{AGB per hectare} = \frac{\text{Sum of AGB values of all the plots}}{\text{Total area of all the plots}} \times 10{,}000$$

BGB was considered to be 20 % of the aboveground biomass as suggested by Mac Dicken (1997). The formula is given below:

BGB= AGB× (15 / 100)

The aboveground and belowground biomass was added to get the total biomass of a tree.

Carbon stock in trees

The carbon stock of a tree was estimated by assuming that biomass contained 50 % carbon (Brown et al., 1989). Carbon stocks per plots and per hectare were also calculated.

$$\text{Carbon stock per hectare} = \frac{\text{Sum of biomass of all the plots}}{\text{Area of a track}, m^2 \times \text{total number of plots}} \times 10{,}000 \times 0.50$$

Data analysis

All data were analyzed with computer software IBM SPSS ver. 21 to conduct Analysis of variance(ANVA) and Duncan Multiple Range Test (DMRT) in order to the significant ($p \leq 0.05$) variations among different parameters.

III. RESULTS

The total biomass and carbon was measured on the basis of the diameter at breast height, height and specific gravity ofCasuarina equisetifolia. The study indicated that the diameter at breast height and biomass growth was uneven in the coastal areas. The highest diameter at breast height and the lowest diameter at breast height were 23.54 and 12.30 cm in 20 yearsand 4 years old Casuarina equisetifolia plantation respectively (Figure 3). The study focused that an average diameter at breast height and mean annual increment were17.44cm and1.84 cm year^{-1}(Table 1).The growth of diameter at breast height wasfast in the early stages of the plantation and then slowed down as the plantation aged. More growth rate was observed in 5–8 years old stages in the present study areas.

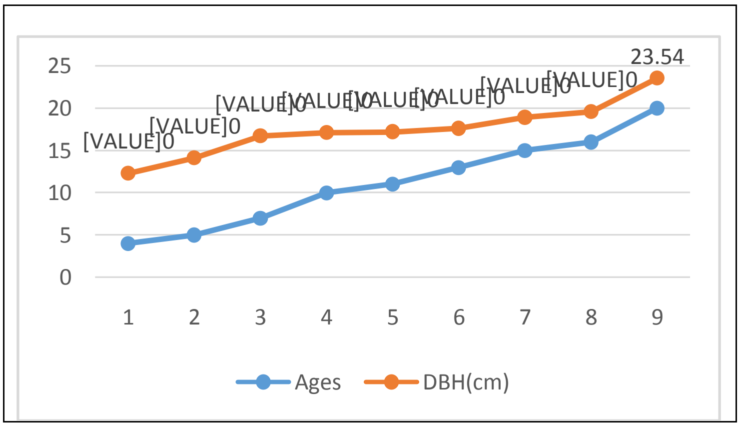

Figure 3.Variation of diameter at breast height (DBH) in different ages.

The height is a major part in the estimation of biomass and carbon.The highest and the lowest height were 20.33m and 11.50m in 20 yearsand 4 old plantation respectively (Figure 4). The study focused that an average height and mean annual increment were16.57m and 1.73m year^{-1}(Table 1). The growth of height wasfast in the early stages of the plantation and then slowed down as the plantation aged. More height rate was observed in 4 years old stage and then slowed down as the plantation aged which was observed in the present study areas.

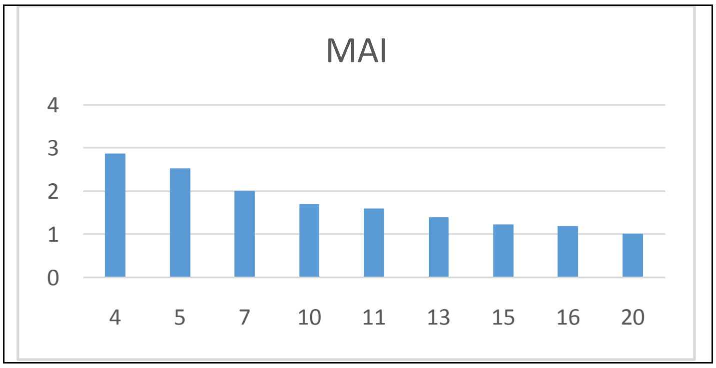

Figure 4.Variation of height (H) in different ages.

The highest biomass was found in the 7th year old plantation (9.11 t ha^{-1}). The growth of biomass in 4 years,5 years,7 years,10 years,11 years ,13 years,15 years,16 years and 20 years plantations were 7.70 t ha^{-1} yr^{-1},7.91 t ha^{-1} yr^{-1},9.11 t ha^{-1} yr^{-1},6.99 t ha^{-1} yr^{-1},6.78 t ha^{-1} yr^{-1},6.25 t ha^{-1}yr^{-1},5.84 t ha^{-1} yr^{-1},5.77 t ha^{-1} yr^{-1},5.23 t ha^{-1} yr^{-1}respectively (Figure 5).The mean annual increment growth rate was 6.73t ha^{-1} yr^{-1}. The mean annual increment growth rate was decreased slowly with increasing ages.

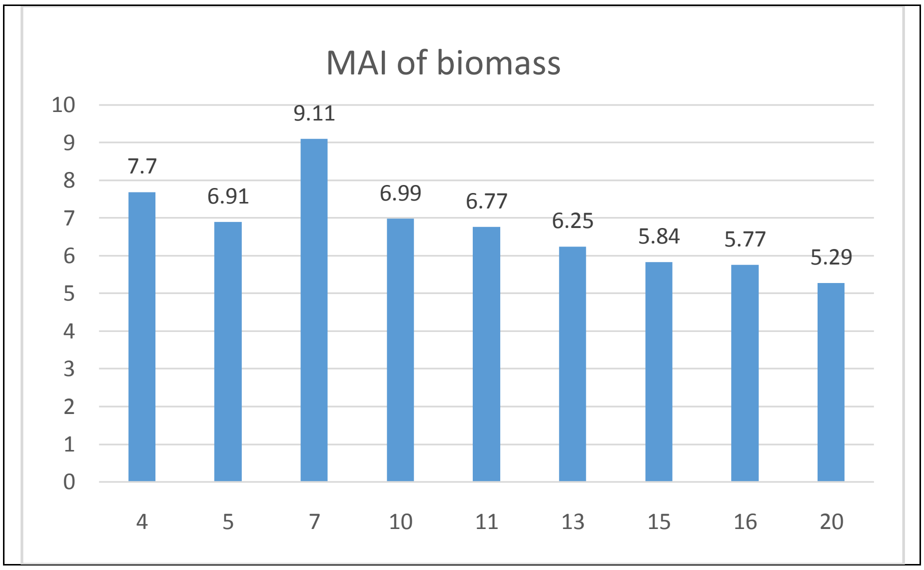

Figure 5. Variation of biomass in different ages

Survival, biomass and carbon stocks

The survival percentage was decreasing with increasing of ages, which was found in the present study. Survival percentage was varied from 65 % to 92 % among all the plantation areas. The highest survival percentage was 92% found in 4 years old plantation areas whereas, 20 years old plantation showed the lowest survival rate only 65% (Table1).

Table1. Age, DBH,MAI of DBH, height,MAI of height and survival of Casuarina equisetifolia

Age (yrs.)	DBH (cm)	MAI of DBH	Height (m)	MAI of Height	Survival (%)
4	12.30±0.29	3.08±0.09	11.50±0.05	2.88±0.05	92
5	14.10±0.21	2.82±0.04	12.70±0.09	2.54±0.07	91
7	16.70±0.27	2.39±0.07	14.10±0.10	2.01±0.04	89
10	17.10±0.35	1.71±0.05	17.10±0.07	1.71±0.06	88
11	17.20±0.41	1.56±0.03	17.60±0.21	1.6±0.08	85
13	17.60±0.21	1.35±0.08	18.20±0.27	1.4±0.02	82
15	18.90±0.11	1.26±0.03	18.40±0.20	1.23±0.07	76
16	19.60±0.19	1.23±0.09	19.20±0.19	1.20±0.5	67
20	23.54±0.21	1.17±0.07	20.33±0.29	1.02±0.02	65
	Av.,=17.44	1.84	Av.,=16.57	1.73	

DBH=Diameter at breast height, MAI=Mean annual increment,

The present study revealed that the carbon storage of Casuarina equisetifolia was variable in different stages. This species had a rapid early growth rate, which was focused in the study. The results revealed that average biomass and carbon were found 70.82 t ha^{-1} and 35.41t ha^{-1} respectively (Table 2).

Table 2.Aboveground biomass(AGB), belowground biomass(BGB), total biomass(TB), total carbon (t ha^{-1}) andmean annual increment (MAI) of Casuarina equisetifolia

Years	AGB (t/tree)	BGB (t/tree)	TB (t/tree)	TB (t/ha)	TC (t/ha)	MAI (t $ha^{-1}yr-^{1}$)
4	0.09	0.02	0.11	30.80	15.40	7.70
5	0.13	0.03	0.16	34.56	17.28	6.91
7	0.20	0.04	0.24	63.80	31.90	9.11
10	0.25	0.05	0.30	69.87	34.94	6.98
10	0.26	0.05	0.31	74.55	37.28	6.78
13	0.28	0.07	0.35	81.21	39.61	6.25
15	0.33	0.07	0.40	87.62	43.81	5.84
16	0.36	0.07	0.43	92.35	46.18	5.77
20	0.39	0.08	0.47	104.56	52.29	5.62
				Av.=70.82	Av.=35.41	Av.=6.73

The study also indicated that total biomass and carbon were increased with increasing ages and mean annual increment rate an average was6.73 t $ha^{-1}{}_{y}r^{-1}$(Table2). The total biomass was mainly depended on diameter at breast height, height and density of species. There was a positive correlation between ages and biomass growth. The value of correlation between ages and biomass were strongly positive correlated (r=0.96) and total carbon varied significantly at different ages ($p <0.05$) in the present study.

IV. DISCUSSION

Many coastal areas were planted by Casuarina equisetifolia tree species in Bangladesh. A total of 765 km^2 areas were planted from 1966 to1996 under Chittagong coastal Forest Division. Among them 32.38 ha areas planted of Casuarina shelterbelt in the Parki beach during 1992-1992.A study was conducted on the Parki sea beach under Anwara upzila of Chittagong district by Danesh et al. (2013) and they reported that the average density of Casuarina equisetifolia in the plantation was found 966.72 ha^1, which showed a comparatively higher survival rate in comparison with the present plantations.They also reported that the total biomass was 162.58 t $ha^{-1}$and the mean annual increment of 3.85 t $ha^{-1}yr^{-1}$which were higher than the present value. The annual increment rate was lower than the findings of the present study, but the density of trees was so much higher.A study was conducted in the Sundarbans by Ahmed and Kamruzzaman (2021) and they reported that biomass accumulation rate for Heritiera fomes, Bruguiera sexangula, Excoecaria agallocha, and Xylocarpus mekongensis were 2.10, 1.49, 0.59, and 1.28t $ha^{-1}yr^{-1}$, respectively. Their values were lower than the results of the present investigation.

Thousands of kilometers of shelterbelt plantation of Casuarina equisetifolia have been planted to protect the southeast coastline of China. These plantation also play an important role in the regional carbon cycling. A study was conducted on four different aged Casuarina equisetifolia plantations in sandy beaches in South China (Wang et al., 2013). The carbon accumulated in the Casuarina equisetifolia plant biomass increased markedly with stand age. The carbon storage in the plant biomass averaged 6.3, 28.8, 55.9, and 59.7 t ha^{-1} in the 3, 6,13, and 18 years old plantations respectively. The annual rate of carbon accumulation in the Casuarina equisetifolia plant biomass during 0–3, 3–6, 6–13 and 13–18 years stage was 2.90, 8.20, 4.20 and 1.00 t $ha^{-1}yr^{-1}$respectively.

Many scientists suggested that Casuarina equisetifolia biomass and carbon storage increased quickly with plantation age in both aboveground and belowground parts(Hughes et al., 1999; Usuga et al., 2010). Moreover, the accumulation rate was fast in the early stages of the plantation and then slowed down as the plantation aged. The highest accumulation rate was observed in the 5–8 years old stage in the coastal areas of the tropical forests. These results were consistent with other studies, which found the largest fine root biomass in the fast-growth stagestand (Borja et al., 2008: Makkonen et al., 2001). Casuarina equisetifolia plantation also accumulated more biomass than many other secondary tropical forests. Harmand et al. (2004) reported that total biomass in the 7 years old Eucalyptus camaldulensis and 6 years old Senna siamea was 62.35 and 45.39 t ha^{-1}respectively. A study was conducted by Miao et al. (1998) in China on thebiomass of different mangrove forests in South China and found that total forest biomass in the 5 years old Aegiceras corniculatum, Avicennia marina and Kandelia candel forests was 5.5, 16.4, and 62.6 t ha^{-1}respectively. Their values were smaller than the present study. Cheng et al. (2011) mentioned that the annual carbon accumulation rate of Casuarina equisetifolia was higher than A.crassicarpa (6.5 t ha^{-1}) in tropical forests of China.Yang and Guan (2006)also reported that annualbiomass carbon accumulation rate was higher than Pinus elliottii(4.8t ha^{-1}), Acacia(4.7t ha^{-1}) and broadleaf(6.5 t ha^{-1}) plantation in various forests of Pearl RiverDelta regions in China.The above discussions indicate that Casuarina equisetifolia is sustainable, adapted and highly capable of storing carbon than other coastal forest tree species in the coastal belt of home and abroad.

V. CONCLUSION

The study concluded that Casuarina equisetifolia plantations could rapidly accumulate large quantities of biomass. The total plant biomass of Casuarina equisetifolia plantation at different ages were greater than many other tropical forests of similar ages. The study suggested that these plantations have a greater potential to sequestrate carbon despite poorsoil conditions. The expansion ofCasuarina equisetifolia plantation in the South coastal areas can play important roles in the regional carbon budget and coastal protection. Long-term monitoring and research are needed to further explore the ecological and social-economic factors that affect the carbon sequestration and ecosystem health of these shelterbelt forests.

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