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RESEARCH ARTICLE

Experiences on Establishment of Scots Pine (*Pinus sylvestris* L.) Plantation in Ash Dump Sites of Reftinskaya Power Plant, Russia

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ABSTRACT

Since the middle of the last century in the Urals of Russia there has been a problem of environmental pollution by man-made emissions. The purpose of this investigation has been to summarize the recultivation experience of Reftinskaya power plant ash dump. The station was put into operation in 1970 and it is the largest one in Russia. Specific feature of the used coal is high content of ash (47%). Daily consumption of coal in winter period constitutes 48 thousand tons. Yearly emissions of the station constitute 400 thousand tons. The main components of the emissions are sulphureous anhydride (up to 40%) solid stuff (up to 50%) and nitric oxides. The Scots pine (*Pinus sylvestris* L.) plantations on ash dumps have shown good adaptation and growth. The plantations have formed 143 m^3/ha total volume at the age of 20 in 1st site index of the recultivation site of the ash dump with ash layer up to 7 m. Weakly alkaline reaction of the ash spread by wind promoted soil dioxidation that results in soil fertility increasing significantly on territory of adjacent stands. Recultivation process includes two main stages which are ash dump surface covering with 25-40 cm soil layer, planting with 2-year old Scots pine (*Pinus sylvestris* L.) seedling.

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Introduction

Extraction and processing of mineral resources is inseparably connected with soil withdrawal for sand pits overburden rock dump wastes of ores processing and enriching as well as routes communication (Stanturf, 2015; Martinyuk, 2016). In particular, solid fuel ashes, deposited near thermal power stations, are harmful to people living in nearby areas and the environment.

Natural regeneration of disturbed lands the most often lasts for many dozens and even hundred years that calls forth necessity of artificial recultivation. However, the latter requires significant labor and financial expenditures.

There are about 4.5 million km^2 of man-made landscapes in the world that require radical reclamation (Belyakova et al., 2003). Many studies have been carried out on technogenic pollutions, especially in Russia and the Urals (Zavyalov et al., 2018; Mohnachev et al., 2018; Makhniova et al., 2019; Menshikov et al., 2019; Potapenko et al., 2019). Regretfully, in spite of works significant number on artificial recultivation many problems of their carrying out are still remains to be debated. Among the destroyed lands there are ash dumps -

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places where ash is stored after burning coal. They are man-made terrains (hills) that rise above the surrounding surface.

Due to the high concentration of industrial production and insufficient waste treatment since the middle of the last century in the Urals and in some regions of Russia there has been a problem of environmental pollution by man-made emissions. Scientific and practical interest in the subject of remediation is determined by the extent of disturbed land, resulting in more than 300-year history of the development of metallurgy and the whole industry in Russia. Research on biological recultivation of territories in the Urals has a long history. Since the late 50-ies of the 20th century began to actively develop methods of biological reclamation of disturbed lands, which were more effective than technical reclamation. In the following years, institutes of technical and biological profiles have been developed and successfully implemented research and practical projects on land reclamation in Russia (Makhnev, 2002; Barannik, 2005; Martinyuk, 2006; Lukina, 2008; Androkhanov and Kurachev, 2010; Kapelkina, 2013; Zhukov, 2016).

In this study it was focused on effects of Reftinskaya power plant, thermal power plant working on coal, Sverdlovsk region in Ural Region. The investigation area is immediately to the disturbed lands of ash dumps. The purpose of the investigation was to summarize the recultivation experience of Reftinskaya power plant ash dump and present certain recommendations for improving rehabilitation works.

Materials and Methods

The investigation area of this research is the site of Reftinskaya power plant ash dump № 1 (Figure 1). The station was put into operation in 1970 and it is the largest one in Sverdlovsk region of the Russian Federation. Nowadays the ash dump № 1 covering the territory of 440 ha is fully filled up. The second ash dump on territory of 860 ha is being filled up, and the process of ash storing by dry method has been doing.

The fixed electric capacity of the station constitutes 3800 thousand kwt, thermal - 350 Hcal/hour. Republic of Kazakhstan Ekibastuzsky deposit coal serves as raw material for the station. Specific feature of this coal is high content of ash; it can constitute 47%. Daily consumption of coal in winter period constitutes 48 thousand tons; besides that, 150 tons of fuel-oil are also used by the station. Yearly emissions of the station constitute 400 thousand tons. The main components of the emissions are sulphureous anhydride (up to 40%) solid stuff (up to 50%) and nitric oxides.

The investigations carried out have shown that ash in the ash dump № 1 is characterized by heightened as compared with soil, content of microelements as well as available nutrition elements of plants (P_2O_5 and K_2O). Weak alkaline reaction of ash spread by wind promoted soil dioxidation that results in soil fertility increasing significantly on territory of adjacent stands. The forest management plans data of Sukholorhsky forest district testify to the fact that growth site index capacity in the forest district where Reftinskaya power plant is located has been changed from 1970 to 2000. If in 1970 the Scots pine (*Pinus sylvestris* L.) stand share of I^a and I classes of growth site index capacity constituted 17.9%, in 2000 the Scots pine plantations share in these growth site classes shows portion of 43.6% (Table 1).

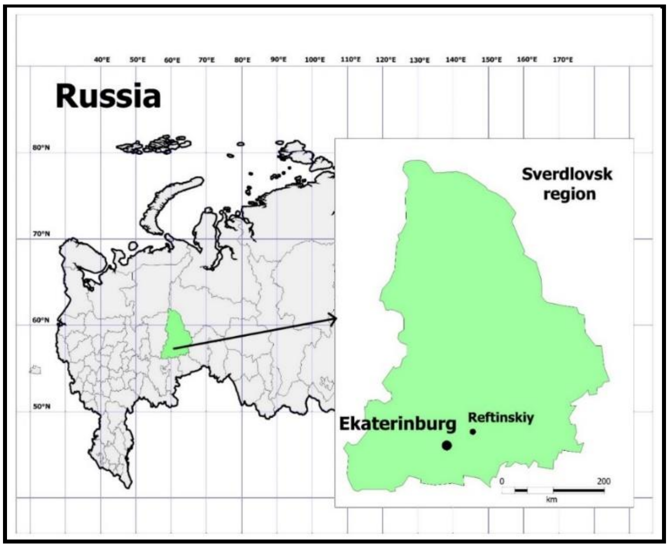

Figure 1. Map of the study area

Table 1. Scots pine plantations areas and percentages according to site indexes (bonitet index) in Sukholozhsky forest district

Year	Unit	Area of stands according to bonitet index (ha/%)								
		I^a	I	II	III	IV	V	V^a	V^6	Total
1970	ha	12	7906	23605	10210	819	1090	590	-	44232
	%	0.03	17.87	53.37	23.08	1.85	2.47	1.33	-	100
1990	ha	-	16527	17285	3626	605	956	540	79	39618
	%	-	41.72	43.63	9.15	1.53	2.41	1.36	0.20	100
2000	ha	402	17805	15749	5432	954	954	378	43	41717
	%	0.96	42.68	37.75	13.02	2.29	2.29	0.91	0.10	100

The Institute of Vegetation and Animal Ecology together with the Ural Forest Experimental Station expressed the typology of forest stands as shown in table 2 (Anonymous, 1984).

Table 2. Characteristic of forest type groups

№ of forest type groups	Forest type groups	Characteristics of the dominant living ground cover of forest types *Pinus sylvestris*
1	Pineta cladinosa	*Cladonia* spp Mountainous.
2	Pineta fruticulosa	Vaccinio vitis-idaeae
3	Pineta fruticuloso-hylocomiosa	*Vaccínium myrtíllus,* *Vaccinium myrtillus + Rubus saxatilis,* *Vaccinium myrtillus + Vaccinium vitis idaea*
4	Pineta composita (nemoro-boroherbosa)	*Tilia cordata + Oxalis acetosella + Carex rhyzina*
5	Pineta mesoxerophiloherbosa (multiherbal)	*Calamagrostis* spp. *Rubus saxatilis + Calamagrostis arundinacea*
6	Pineta parviherboso-hylocomiosa	*Oxalis acetosella + Rubus saxatilis,* *Pleurozium schreberi*
7	Pineta magnoherbosa	*Filipendula ulmaria*
8	Pineta eutropho- uliginosoherbosa	*Equisetum sylvaticum+ Sphagnum* spp.
9	Pineta sphagnosa	*Eriophorum vaginatum + Sphagnum* spp.; *Carex lasiocarpa + Sphagnum* spp.; *Sphagnum girgenzohnii + Sphagnum* spp.

From 1993 beginning the works on the ash dump № 1 on biologic recultivation are being carried out, the artificial forest stands (plantations, pine cultures) are supposed to be established on its surface. The research carried out showed that light recultivation effect is achieved only when a definite technic stage is achieved, the one that implicates covering ash by soil thick layer of 24-40 cm. Then the biologic stage of recultivation is carried out. In fact, 2-year old seedlings of Scots pine are being planted with the forest planting machine LMD-81.

Scots pine forest cultures planting has been carried out by blocks of 500 × 50 m. The blocks were arranged in chess board order and altered with blocks of analogous size sowed with herbaceous mixtures. The soil layer thickness for sowing constituted 10-15 cm, and for forest cultures 30-40 cm.

In the process of investigations, we have succeeded in analyzing the history of artificial stands establishment of the ash dump № 1. The method of permanent quadrates (pq) has been laid into the base of the investigations. All the permanent quadrates have been laid and processed according to approved methods being used nowadays (Dancheva and Zalesov, 2015). In addition, the woody species composition and terrestrial biomass of live ground vegetation have been studied.

The process of the establishment of plantation on the ash disposal area № 1 at Reftinskaya power plant is pointed-out in brief, as follows (Menshikov et al., 2019):

- In 1992, 1.3 ha - planting of Scots pine in trenches filled with a mixture of peat and soil (1:1), depth of trenches 0.25; 0.40 and 0. 65 m.
- In 1993, 3.7 ha - planting of Scots pine, Siberian larch spruce (*Larix sibirica* Ledeb.), birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.), as well as balsam poplar (*Populus balsamifera* L.) 2-year-old seedlings produced in wide bulk bands, the thickness of which was 0.25; 0.40 and 0.65 m. In addition, these bands were planted with unrooted cuttings of balsam poplar and native species of willows (*Salix viminalis* L. and *Salix dasyclados* Wimm. Syn. *Salix gmelinii* Pall.), and a collection of ornamental woody and fruit species.
- In 1994, 1.1 ha of plantations of Scots pine, spruce, larch and white birch (*Betula pubescens* Ehrh.) trees on an artificial strip with a width of 3-4 m and the wide bulk of the strip, spread a drainage layer.

Results and Discussion

Forest management works carried out in Sukholozhsky forest district as concerns the above mentioned typology have shown that 30 years after the station was put into operation unprecedented changing of forest growing conditions has taken place. The latter became apparent in berry live ground cover decreasing and multi herbal layer of forest types increasing (Table 3). In other words, in field-layer (herb and small shrub layer) cover (forest type group 3) - the share of berry undershrub has decreased and the share of forest small reeds and some other kinds of cereals has increased (forest type group 5).

Table 3. Scots pine stands distribution according to forest type groups in Sukholozhsky

Year	Unit	Pine stands area according to forest type groups, ha/%							
		2	3	4	5	6	7	8	Total
1970	ha	806.0	24489	66	16366	129	-	2376	44232
	%	1.82	55.37	0.15	37.00	0.29	-	5.37	100
1990	ha	636.3	5360.9	18.8	31130.1	134.1	144.1	2193.6	39617.9
	%	1.61	13.53	0.05	78.58	0.34	0.36	5.53	100
2000	ha	1269	15297	63	22895	45	10	2138	41717
	%	3.04	36.67	0.15	54.88	0.11	0.02	5.13	100

Stands' share of multi-herb group of forest type increasing has complicated reforestation process and imposed wildfire risk in autumn and spring seasons. Due to these reasons, on the account of podzol soils deoxidation their fertility has increased and furthermore, volume increment for every square unit has also increased. Zavyalov et al. (2019) emphasized that the annual growth rings of Scots pine on fertile soils were significantly higher than those of on poor soils. Also, soil fertility allows better adaptation of Scots pine to low temperatures, and more actively grow on sites with increasing precipitation in technogenic areas. However, Makhniova et al. (2019) stated that the level of soil technogenic pollution predominantly contributes to the formation and growth of sprouts and seedlings i.e. their morphometric characteristics. Most likely, under natural conditions, the level of soil technogenic pollution is a particularly strong factor in restricting plant seed reproduction.

Recultivation experiments on the first ash dump were started in 1992, due to the process of air dusting. Ash from the ash dump was spread by wind to adjacent territories.

In the process of the first experiments carrying out on the ash dump the tranches of 0.7 m width and 0.25 depth; 0.45 and 0.65 cm have been laid, followed by filling with sandy soils and turf mixture (1:1), and then with the process of Scots pine and Sukhacheva larch (*Larix sukaczewii* Dylis Syn. *Larix sibirica* Ledep.) planting. The space between the tranches to prevent dusting has been covered with the soil layer of 0.1 m thickness. Unfortunately, the results of recultivation were unsatisfactory and most of the plant layer has been lost.

In 1993 recultivation experiments were kept on under direction of Makhnev. Namely, 4 ha square has been covered with soil layer of 25, 40, and 60 cm (Makhnev, 2002). The process was followed by 3-year old seedlings of Scots pine, Siberian spruce (*Picea obovate* Ledeb.), Sukhacheva larch, silver birch (*Betula pendula* Roth.) and white birch, balsam poplar, as well as Russian broom (*Salix rossina* Nas.), willow branched (*Salix viminalis* L.), willow woolly sprouted (*Salix dasyclados* Wimm.) planting. This carried out research made it possible to start reclamations in industrial scale.

During 1996 – 2001, an area of 172 ha of Scots pine cultures have been established. Research carried out in 2001 showed that the forest cultures planted on ash dumps are characterized by good adaptation and mean increment in height as well as by high preservation (Table 4). Zavyalov et al. (2018) and Mohnachev et al. (2018) stated that despite the pollution in the technogenic soils, the success of natural regeneration is effected by the stand density and the occurrence of undergrowth of Scots pine. Soil remediation can positively affect the natural regeneration process. Moreover, seed supplementation can play a major role in successful natural regeneration.

Table 4. Scots pine growth on the ash dump after planting

The year of planting	Area (ha)	Number of trees (psc)	Height (m)	Diameter at root collar (cm)	Current increment (cm)	Capacity for survival (%)
1996	0.8	100	1.69±0.03	4.03±0.09	48±1.0	86.2
1996	3.2	100	1.76±0.05	4.10±0.13	44±1.0	79.4
1996	0.1	100	1.18±0.06	2.74±0.13	33±3.0	73.0
1997	19.9	200	1.32±0.05	3.19±0.12	41±1.0	89.7
1998	30.7	150	0.63±0.03	1.72±0.07	26±6.0	64.3
1999	4.2	100	0.76±0.03	2.11±0.09	26±7.0	72.5
1999	23.1	300	0.75±0.03	2.16± 0.11	24.3±1.3	89.3
2000	20.0	150	0.47±0.02	1.38±0.07	6.0±0.1	73.0
2000	28.0	200	0.81±0.03	2.11±0.07	22.0±0.1	96.2
2001	10.0	100	0.47±.02	1.30±0.05	8.5±0.1	91.7
2001	10.0	100	0.48±0.02	1.42±0.06	11.0±0.1	91.7
2001	22.0	100	0.45±0.01	1.19±0.09	7.0±0.0	84.0

High preservation and growth in height indices, as well as possibility of mechanized planting, favors Scots pine as main species for establishment of forest stands on the ash dump.

In 2011, Reftinskaya power plant ash dump № 1 recultivation was entirely completed. On its territory, a total of 360.2 ha of pine stands have been established (Figure 2, 3).

Figure 2. Establishment of Scots pine plantation on the ash dump of Reftinskaya power plant (Photo by: S. Zalesov)

We have made inventory of artificial stands planted on the ash dump and have established permanent quadrates to determine the main inventory indices and subsequent monitoring according to their growth and development. The main taxation indices of the Scots pine plantations established on ash dump are shown in table 5.

Our results testify to the fact that if at the age of up to 8 years' artificial stands are characterized by II class of forest capacity site then at the age of more than 10 years by the first (1) class. The latter, to our opinion, is explained by competition from field-layer during the first years after forest cultures are being planted.

At the age of 20 artificial stands are characterized by 143 m^3/ha stem volume that corresponds to yearly increment of 7.15 m^3/ha. In other words, artificial stands established on the ash dump exceed the stands of analogous age established on felled sites of the most productive forest types (Table 6). In addition, it can be seen that the stand volume, diameter and height change according to plantation age (Figure 4).

Figure 3. 20-years old Scots pine plantations on the ash dump of Reftinskaya power plant (Photo by: A. Opletaev)

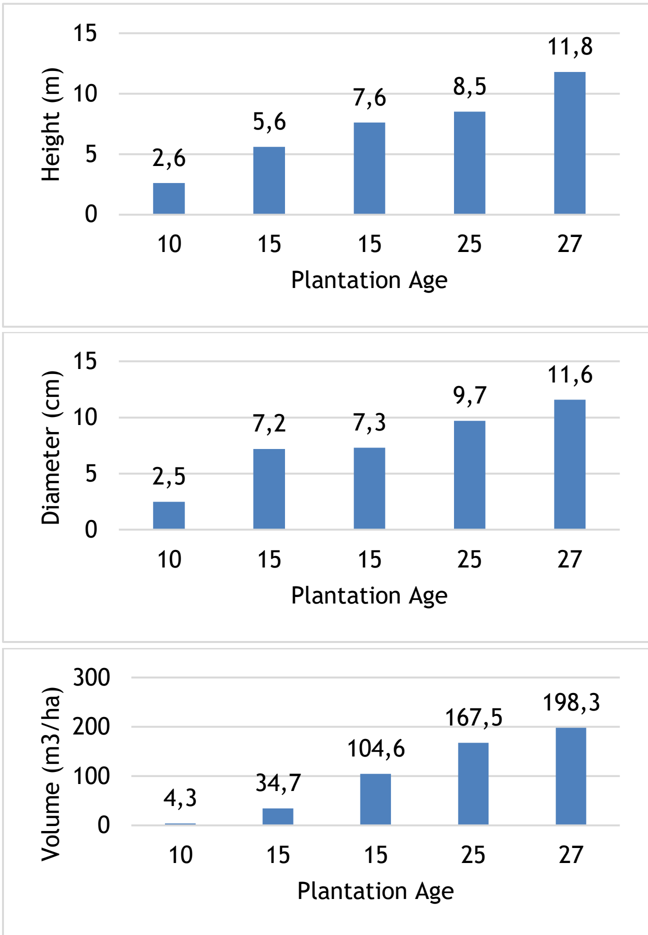

Figure 4. The stand volume, diameter and height change according to plantation age

Table 5. The main fixation indices of artificial pine stands established on Reftinskaya power plant ash dump

№ of order	Composition (%)	Thickness, p/ha	Biologic age, years	Average Height (m)	Average $d_{1,30}$ (cm)	Basal area (m^2/ha)	Volume (m^3/ha)	Site Index
7	100 C	3016	7	2.4	2.4	1.423	3.36	II
6	99.8 C	3675	8	2.5	2.5	1.884	4.58	II
	0.2Oc	13	6	2	2	0.004	0.01	
	Total	3688				1.888	4.59	
5	99.8 C	2142	10	5.4	5.4	4.85	18.67	I[a]
	0.2Oc	53	8	1.6	2	0.016	0.03	
	Total	2195				4.866	18.7	
4	100 C	4377	13	6.4	6.4	14.069	61.51	I[a]
	-Oc	23	11	2	2	0.007	0.01	
	Total	4400				14.076	61.52	
3	99.9C	3632	15	7.8	7.9	17.821	88.15	I[a]
	0.1Oc	72	13	2	2.3	0.03	0.05	
	Total	3704				17.851	88.2	
2	99.2 C	2149	16	8.8	9	13.739	75.16	I[a]
	0.8 Oc	104	14	4.5	4.5	0.171	0.61	
	Total	2253				13.91	75.77	
1	98.5C	3390	20	11.5	9.1	22.113	140.74	I[a]
	1.3 Б	133		9	5.6	0.337	1.79	
	0.2Лц	29		8.5	4.9	0.053	0.29	
	- Oc	19		4	2	0.006	0.02	
	Total	3571				22.509	142.84	

C: Scots pine (*Pinus sylvestris* L.), Oc: Aspen (*Populus tremula* L.), Б: Silver birch (*Betula pendula* Roth.), Лц: Siberian larch (*Larix sibirica* Ledeb.)

Table 6. The main taxation indices of Scots pine plantations created on the felled sites

№ of order	Composition (%)	Age, years	Average Height (m)	Average $d_{1.30}$ (cm)	Thickness (p/ha)	Basal area (m^2/ha)	Volume (m^3/ha)	Site Index
1/12	100C	10	2,6	2,5	3420	1,67	4,3	II
2/12	100C	15	5,6	7,2	2604	10,56	34,7	I
3/12	100C	15	7,6	7,3	5989	25,91	104,6	I
4/12	100C	25	8,5	9,7	3405	26,66	167,5	II
5/12	100C	27	11,8	11,6	2650	30,48	198,3	I

C: Scots pine (*Pinus sylvestris* L.)

In addition, beside the woody vegetation planted on the recultivated ash dump thrives herbaceous (grassy) vegetation. In the process of investigations, it has been established that 43 species of field-layer grow on the territory. With artificial stands age increasing species of field-layer are decreasing (Figure 5).

If in the first years after planting forest crops, the above-ground phytomass of living soil cover amounted to 415.9 kg/ha. After 20 years it did not exceed 12.8 kg/ha in absolutely dry condition

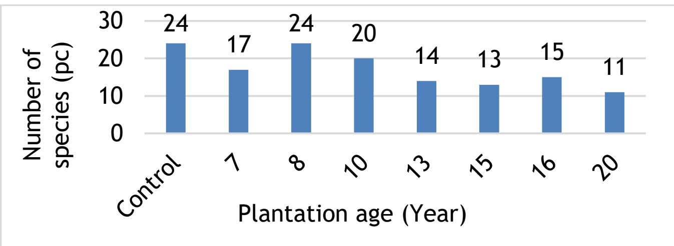

Figure 5. Change of herbaceous vegetation species composition on the recultivated ash dump according to plantation age

Protective measures against forest fire on the recultivated ash dump are very important. To stop forest cover fires during the first years after establishing plantations, it is recommended to make flat field-layer in spaces between rows in rainy weather or immediately after rainfall. The established plantation strips should be planned in a manner that delays fire progress and facilitates firefighting. To decrease fire risk, some counter fire measures should be taken. Particularly, to prevent forest cover fires developing into crown fires, it is recommended low pruning of tree branches up to 2,5 m height to be carried out (Figure 6).

The state of the path network, the removal of living ground cover and trimming of the lower branches excludes the possibility of the transfer of grassroots ground fire to the tree crowns.

Figure 6. 20-years old Scots pine plantation with trimmed branches (Photo by: S. Zalesov)

Conclusion

The station emissions during the period of its exploitation brought to unprecedented change on forest growing conditions that results in forest type changing on more than 40 thousand ha of adjacent territories. Scots pine plantations has formed 143 m^3/ha volume at the age of 20 in 1st site index of the recultivation area of the ash dump with ash layer up to 7 m.

Experiences with the Scots pine plantations established at the ash dump site are as follows: 1) On the ash dumps obtained from burning coal, the most promising species is the Scots pine plantations, 2) Recultivation process includes 2 main stages: The 1st stage consists of ash dump surface covering with soil layer of 25-40 cm thickness; The 2nd is establishment of plantation with 2-year old Scots pine seedling, 3) The establishing of artificial pine stands eliminates the spread of ash dust, which improves the environmental state; Also, the pine plantations on ash dumps are superior in productivity i.e. Scots pine stands growing in natural conditions, 4) The weed growth is short-term and, 20 years after planting Scots pine plantations, the aboveground phytomass of the weed does not exceed 13 kg/ha; In addition, depending on the age of the plantation and the crown closure (canopy), the number of weed species gradually decreases, 5) Taking into account potentially high fire risk in the establishment of the plantations on the ash dump, effective counter fire measures are necessary on recultivation areas, 6) On the territory of the ash dump, in addition to planting, it is of high importance to conserve the self-regenerating process of the vegetation in successional dynamics, which can be effectively used to level-up into uneven-aged plantations that are much more stable concerning wildfires and forest protection.

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