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State of Saxaul Plantations in Kazakhstan's Section of the Aral Sea Region

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Abstract
The article aims to assess the survival rate of saxaul plantations on the dry seabed of the Aral Sea (DSAS) and these close to the villages along the original seacoast. Protective black saxaul (Haloxylon ammodendron) plantations on the DSAS were established in the course of 2009-2019 with the grant support of the International Fund for Saving the Aral Sea (IFAS), Japan's environmental funds, UNDP Kazakhstan, as well as under the Grass-Roots Program of the Embassy of Japan in Kazakhstan. During September 1-14, 2020, the target plantation plots at 24 sites adjacent to the villages of Aralkum and Karateren underwent examination, including forest surveying, projected species cover determination, as well as seed regeneration and survival rate assessment. The findings of 2020 revealed the varying condition of target saxaul plantations. Thus, the survival rate of saxaul inside forest plantations ranged between 0.12 and 78.0%. The actual number of saxaul trees varied from 1 (one) to 1,000 per ha on the DSAS and from 888 to 2,633 per ha in Aralkum village. The novelty of the obtained results is due to the fact that they clearly demonstrate that the survival rate and development of forest plantations, as well as saxaul seed self-renewal, above all, depend on the overall ecological conditions at specific sites. Saxaul demonstrated the best survival rate and growth at the sites with sandy loam and saline light loamy soils with sandy cover, and the worst – at the sites with crusty and takyr (dry-type playa) saline soils.

Keywords: dry seabed of the Aral Sea, forest reclamation, saxaul plantations, state, survival rate.

1. Introduction

The Aral Sea began to dry in the early '60s of the 20th century due to the irrational use of water resources of the Amudarya and Syrdarya rivers feeding it. The drop in the sea level and seabed drying had triggered multiple adverse environmental processes. The wind has been spreading dust, sand and the remains of agricultural chemicals – lifted from the dry seabed of the Aral Sea (DSAS) – over the adjacent settlements, thereby negatively affecting the living conditions of their residents. The surveyed protective plantations were set up with the aim of addressing this problem, with black saxaul (*Haloxylon ammodendron*) as the planting material (nomenclature as per The Plant List (2013).

Protective plantations positively affect the overall ecological state of the environment. Firstly, they restrain sand transfer and reduce the blowing of salt and dust from DSAS. The studies by Uzbekistan scientists have shown that in 1-year saxaul-saltwort (*Haloxylon ammodendron*, *Salsola richteri*) plantations, the wind speed decreases by 20.5%, in 2-year plantations – by 34.6%, and with plantations reaching the age of 7 years, the wind speed may reduce to zero. Thus, the most active movement of sand and transfer of chemicals occur on forestless dunes, and the least active – in protective plantations (Bakirov et al., 2020a). Saxaul likewise improves the local microclimate and helps reducing GHG emissions. One hectare of saxaul woods of 13 years old absorbs 4.95 tons of carbon and releases 3.78 tons of oxygen (Mukanov, Kaverin, 2014). Vegetation also reduces deflation. Along with fixing sand, root systems firmly hold plants in the soil and strengthen its wind resilience (Vilps, Novitsky, 2007).

In Kazakhstan, phyto-reclamation efforts in the Aral Sea Region launched in the mid-80's of the 20th century. At the same time, the recommendations were developed describing the assortment and main planting methods (Kurochkina, Makulbekova, 1984; Yerimbetov et al., 1985; Dimeyeva, 1990). The first mass saxaul planting at the dry Aral Sea bed was done by the Kazalinsk Forestry Department in the fall of 1988 in the eastern seacoast sections near the village of Kaukei (Mukanov, Kaverin, 2014).

This article aims to assess the survival rate (integrity) of saxaul plantations in DSAS close to the villages of Karateren and Aralkum 25 km away from the coastline of the '60s.

2. International phyto-reclamation experience: review

Uzbekistan possesses the experience of creating forest plantations in DSAS (southern section of the Aral Sea Region) (Kuzmina et al., 2004; 2006; Kuzmina, Treshkin, 2007; Bakirov et al., 2020a; Novitsky, 2018; Novitsky, 2012; Ashirbekov, 2013). Several foreign countries have also accumulated an extensive experience of combating shifting sands using phyto-reclamation (Aiban, 1994; Orencio, Herrmann, 2006; Li et al., 2010).

The Great Green Wall Project deserves mention as one of the world's largest phyto-reclama-tion efforts aimed at stopping the penetration of the Sahara Desert into southern Africa – launched in 2007, it involves 20 African countries. Its scope includes planting trees along the entire Sahara's southern border. The length of the 15 km wide forest strip from Senegal to Djibouti is about 8,000 km (Goffner et al., 2019). The afforestation methodology is based on the local planting technology called "zai" developed by Yatenga Province farmers. Combined with soil and water preservation activities, this technology has allowed turning vast areas of barren desert turn into forests. According to statistics, of the 2 mln seedlings planted annually, up to 70-75% survive (Colin Thor West et al., 2020).

Satellite imagery studies have allowed detecting a clear boundary of enhanced vegetation. The already created part (15%) of the green wall prevents wind-induced soil drying and restores the microclimate (Colin Thor West et al., 2020).

In China, sand fixing represents one of the important tasks while addressing the challenge of steppe zone desertification. Chinese scientists have found that, depending on the composition, diversity and functional types of plant species, dune fixing takes place differently. Plant functionality pre-determines the strategies applicable in different local conditions. The already obtained research and planting results undergo application in northern China to secure permanent shifting sand foci (Dong et al., 2012).

3. Research area

3.1. Physical and geographical conditions

The research area is located in Aral District of Kyzylorda Region – DSAS section also known as the Aralkum Desert – and close to the village of Aralkum 25 km away from the seacoast as it was in the '60s of the last century (Fig. 1.). Overall, the territory's relief is plain-like.

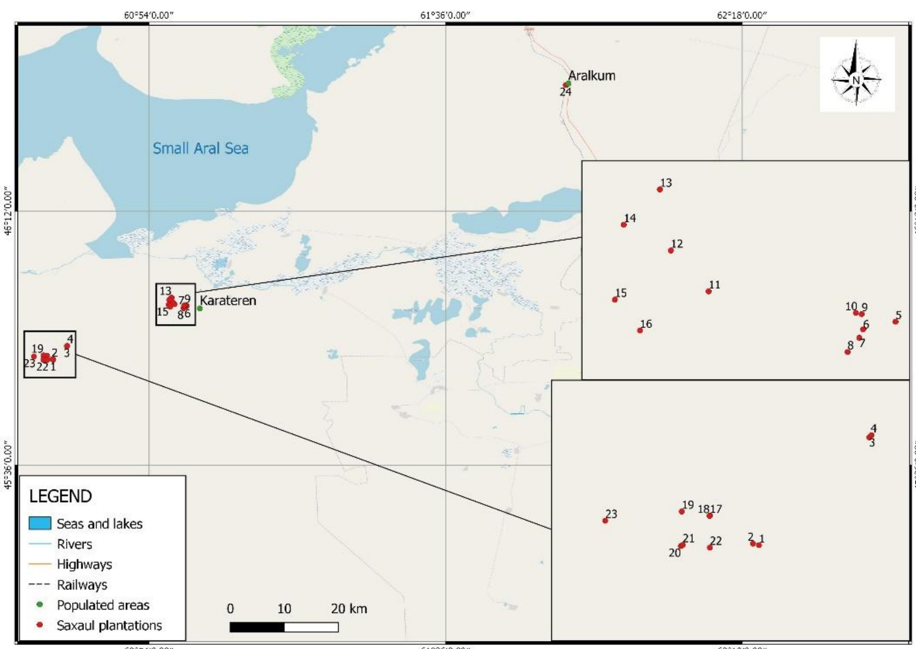

Figure 1. Position of protective plantation monitoring plots.

Climate. Aral District is located in the temperate desert zone, including two subzones: northern and true deserts (sagebrush-saltwort and ephemeral-sagebrush). The local climate is sharp continental with significant temperature fluctuations, short spring transition from winter to summer, and low precipitation. The mean temperature in January is -11.5°C; and +27.5°C in

July. The annual precipitation amounts to approx. 130 mm. The mean annual relative humidity is about 60% making the air dry to an extent (Baisholanov, 2016).

Wind. The mean annual wind speed in the town of Aralsk is 4.7 m/s. Northern and northeastern winds prevail in January and October; in April – northeastern, in July – northern (Baisholanov, 2016).

Water resources. The area's current hydrographic network includes the Small (Northern) Aral Sea and current delta channels of the Syrdarya, as well as delta lake systems – Kamystybas, Akshatau, Primorsky Right-Bank, Primorsky Left-Bank, and Aidarkul. The area is rich in groundwater, both subsoil and artesian, at the depths of 1-6 down to 10-20 m, which may be both brackish (3-10 g/L) and highly mineralized (10-50 g/L). Depending on the distance from the shoreline, the groundwater table in the dried sea bottom section varies between 0.5 and 2.5 m with water mainly saline (mineralization of 30 g/L or more) (Akiyanova, Yegemberdiyeva, 2016).

Soils. In the system of soil latitudinal zonality, Aral District's soil cover corresponds to the subzones of brown and gray-brown desert soils and their varieties. The weak ruggedness of relief and salinity of soil-forming bedrock determine the predominance of soil cover complexity with the soil profile varying between zonal and azonal desert soils of varying salinity. Among zonal soils – both in complexes and in combinations – sandy, takyr-like, dry-type playa soils and salt marshes of various geneses are widespread (Yerokhina, 2016).

DSAS soils in the eastern coastline section, within 43-48 m of the absolute sea level, are relatively young (early formation phase). Depending on the time of exposure to sunlight and groundwater level drop, coastal soils demonstrate salt migration and solonetz formation processes (Dimeyeva, Permitina, 2006).

Along the original coast, sandy massifs are observed, occupying the most significant territory close to Tokpan and Uzynkair. The sands are fine-dune and medium-ridge-tuberous, both overgrown and devoid of vegetation. Soil salinity in inter-dune depressions remains quite significant. Sand massifs manifest the sources of sand and fine-grained earth transfer.

Vegetation. By botanical-geographical zoning, the area belongs to the North Turan Province of the West-North Turan Sub-Province, Iran-Turan Sub-Region of the Sahara-Gobi Desert Area, and is located within the northern and mid-latitude desert sub-zones.

In the Northern Aral Sea, the leading role in the vegetation cover belongs to sagebrush (*Artemisia semiarida*, *A. terrae-albae*) deserts, in some places combined with communities of *Artemisia pauciflora*, *Anabasis salsa*, *Salsola* spp., and *Climacoptera* spp. Psammophytic deserts on hummocky poorly fixed sands are represented by psammophytic shrub (*Calligonum aphyllum*, *Ammodendron bifolium*, *Astragalus brachypus*), and psammophytic wormwood (*Artemisia arenaria*, *A. quinqeloba, A. santolina, A. tomentella*) communities. Shallow sands feature black saxaul (*Haloxylon ammodendron*) desert woodlands (Botanical geography..., 2003). The DSAS is likewise distinguished by the distribution of salt wastelands without any vegetation or with sporadic groups of ephemeral saltwort species (*Climacoptera aralensis*, *Petrosimonia triandra*, *Bassia hyssopifolia*), and halophyte shrubbery (*Tamarix spp.*, *Halostachys belangeriana*, *Nitraria schoberi*) (Dimeyeva et al., 2013).

DSAS flora includes 368 species of vascular plants belonging to 43 families and 178 genera. The leading families include Amaranthaceae (Chenopodiaceae), Asteraceae, Polygonaceae, Brassicaceae, and Poaceae. The largest genera include *Calligonum* (35 species), *Artemisia* (14), *Salsola* (13), *Atriplex* (12), *Astragalus* (11), *Tamarix* (10), *Suaeda* (9), *Climacoptera* (5), and *Corispermum* (5) (Dimeyeva et al., 2012).

3.2. Review of international phyto-reclamation projects in the Northern Aral Sea Region

Experimental phyto-reclamation studies in the Aral Sea Region were initiated in 1997 under the corresponding UNESCO project (Dimeyeva et al., 2000; Geldyeva et al., 2001; Meirman et al., 2001a), and continued during 1998-2000 thanks to the BMBF (Meirman et al., 2001b) and BMBF-GTZ/CCD projects in 2002-2004 (Wucherer et al., 2012).

In 2007, the Forestry and Wildlife Committee of the Ministry of Agriculture of the Republic of Kazakhstan (RK) embarked on implementing the joint Government of the RK/World Bank Forest Protection and Afforestation Project, whose pilot sites included saxaul plantations in Kyzylorda Region. Under the project (2008-2014), approx. 56.5 thous. ha of plantations were established in DSAS, with the survival rate ranging from 5 to 40% (Mukanov, Kaverin, 2014; Dimeyeva et al., 2017).

In the course of 2009-2019, under the grants of international funds such as the International Fund for Saving the Aral Sea (IFAS), Japan’s environmental organizations (Environmental Restoration and Conversion Agency, National Land Afforestation Promotion Organization, AEON Environmental Foundation, Green Fund, Risona Fund) and Japan’s Embassy in Kazakhstan, protective forest plantations were created in Aral Sea Region’s northeast. The experience gained laid the foundation for the recommendations on establishing protective forest plantations consisting of black saxaul on the salt marshes of the Aral Sea bottom (Dimeyeva et al., 2013).

In 2016-2017, under the UNDP Kazakhstan Grant “Demonstration and implementation of mechanical and phyto-reclamation methods of fixing shifting sands”, phyto-reclamation efforts were carried out in the village of Aralkum. The combination of phyto-reclamation and mechanical approaches showed good results – in 2017, the plantation survival rate at the pilot site ranged between 32 and 57% (Alimbetova et al., 2020).

3.3. Examined plantations

Twenty-four (24) protective plantation plots at DSAS were selected for examination under this research, created mainly during 2009-2019 near the village of Karateren with the support of IFAS, Japan’s environmental funds (Plots 1-4, 17-23), and under the Grass Roots Program of Japan’s Embassy in Kazakhstan (Plots 5-16). Plot 24 (in the village of Aralkum) was planted under the UNDP Kazakhstan grant (Fig. 1.).

The plots around Karateren Village are located in two clusters – at a distance of 5 km (these established under the Grass Roots Program), and over 30 km away from the settlement. The plot in Aralkum Village is located on its western outskirts.

For most plots, the survival rate of the planting material was identified in the year of planting (Table I.). Certain sites were surveyed several years after planting to determine the plantations' survival rate: namely, after 2 years (Plot 24), and after 5 years (Plot 1). Some of the data resulting from those surveys are presented in this article.

Planting at the sites in question was carried out by the following methods. Phyto-reclamation of the first twenty-three plots involved several steps. Tilling was first done in the salt marsh wasteland zones (1-5 ha) with furrows perpendicular to predominant winds. The distance between rows was 10 m, between seedlings in a row – 1.5-2 m.

To plant seedlings immediately after tilling, sand application is necessary. At least one year after tilling, sand accumulates naturally in the furrows. Seedlings are planted in spring, and saxaul seeds are sown in autumn. After planting, moisture-charging watering is carried out. Forest plantations undergo watering three times during the first growing season (Dimeyeva et al., 2013).

The last – Plot 24 in the village of Aralkum – was established to fix shifting sands by combining phyto-reclamation with a mechanical anti-blowing installation. Prior to phyto-reclamation works, the area was fenced off to protect it against livestock. To fix the sand and protect the plants, 3x3 m cell barriers from reeds were installed. For this, 30 cm deep trenches were dug to install reed mats. To enhance sand fixing the "tops" of moving dunes underwent claying. Planting was carried out in early spring closer to the reed fencing to prevent root system denudation. The plots were watered twice a month (Alimbetova et al., 2020).

Table I. Description of monitoring plots.

Plot №	Planting year	Site geographic coordinates	Area, ha	Survival rate, %	Donor/Project
1	2008 2010*	N 45º50′57.0′′ E 60º40′25.1′′	1	0 72	Japanese environmental agencies (National Land Afforestation Promotion Organization of Japan), Afforestation Project
2	2009 2010*	N 45º50′58.7′′ E 60º40′18.7′′	2	33 55	
3	2011	N 45º52′51.3′′ E 60º42′21.8′′	2	0	
4	2013	N 45°52′53.7′′ E 60°42′24.3′′	1	1.3	

Table I. (continued).

Plot №	Planting year	Site geographic coordinates	Area, ha	Survival rate, %	Donor/Project
5-10**	2012	N 45°58´31.1´´ E 60°59´19.6´´ N 45°58´26.9´´ E 60°59´01.9´´ N 45°58´22.3´´ E 60°58´59.8´´ N 45°58´14.5´´ E 60°58´53.4´´ N 45°58´35.3´´ E 60°59´01.1´´	27	9.2	Grass Roots Program, Japan’s Embassy in Kazakhstan
11-16**	2014	N 45º58.795´ E 60º57.623´ N 45º59.167´ E 60º57.279´ N 45º59.723´ E 60º57.179´ N 45º59.402´ E 60º56.850´ N45º58.720´ E 60º56.769´ N 45º58.438´ E 60º56.998´	30	5	Grass Roots Program, Japan’s Embassy in Kazakhstan
17	2016	N 45º51´28.5´´ E 60º39´33.2´´	2	–	IFAS, Phyto-Reclamation of Absolute Wasteland in the North-Eastern Section of the Aral Sea Coast Project (Project Report…, 2016)
18	2017	N 45º51´28.1´´ E 60º39´32.7´´	1	90	Risona Fund (Japan), Afforestation Project
19	2017	N 45º51´32.7´´ E 60º39´03.3´´	1	–	AEON (Japanese fund), Afforestation Project
20	2018	N 45º50´56.1´´ E 60º39´02.3´´	1	11	Risona Fund (Japan), Afforestation Project
21	2018	N 45º50´57.3´´ E 60º39´04.2´´	1	5	AEON (Japanese fund), Afforestation Project
22	2018	N 45º50´54.5´´ E 60º39´33.0´´	1	15,2	Risona Fund (Japan), Afforestation Project
23	2019	N 45º51´23.0´´ E 60º37´42.2´´	1	46	Risona Fund (Japan), Afforestation Project

Table I. (continued).

Plot №	Planting year	Site geographic coordinates	Area, ha	Survival rate, %	Donor/Project
24	2017	N 46º29´50´´ E 61º53´00´´	2	44,7	UNDP/Kazakhstan Project "Demonstration and Implementation of Mechanical and Phyto-Reclamation Methods of Fixing Shifting Sands in Aralkum Settlement in the Aral-Syrdarya Project Site" (Alimbetova et al., 2020)

* Note 1. Re-planting year.
* * Note 2. Adjacent site(s).

4. Research methods

The works under this research were carried out during September 1-14, 2020 as per Forest Species Inventory Rules (On Approval of Rules..., 2012). Black saxaul taxational measurements were done at each target plot (Bayzakov et al., 2007). 100 sq. m (10x10 or 5x20 m) plots were marked to assess the taxational indicators – number and height of saxaul trees, crown width, and root collar of each plant. Between the rows, 5x5 m pads were laid out for seed renewal inventory. Saxaul projective cover was calculated based on crown area.

Geobotanical descriptions were also done for each plot (Bykov, 1978) based on special templates to record the main landscape components: relief, soils, vegetation, and their condition. Special attention was paid to examining the spatial profile of plant communities and their correlation with relief, soils, and hydration.

While describing plant communities, the following parameters were logged: 1) floristic profile (composition); 2) overall projective cover; 3) phenophase; 4) abundance of species (Drude scale); 5) nature of species distribution. For each species, the following parameters were registered: a) plant height, b) layerage, c) life state (Grossheim scale). The factors affecting vegetation (natural or anthropogenic) were taken into account as well.

Plantations' integrity (survival rate) was estimated as the percentage of seedlings that took root to their initial number.

Herbarium collection was done in the course of describing plant communities. Identification of unfamiliar plant species was carried out during the laboratory processing of the collected material using the "Illustrated Plant Indicator of Kazakhstan" in 2 volumes (1969, 1972) and "Flora of Kazakhstan" in 9 volumes (1956-1966) (Illustrated Plant Indicator..., 1969, 1972; Flora of Kazakhstan, 1956-1966).

The species nomenclature herein is provided as per the latest taxonomic changes adopted by the botanical community (The Plant List, 2013; Plantarium, 2007-2021).

5. Results

Plot 1. Site soils are coastal saltmarsh middle loamy. Disturbance signs: camel dung, rodent burrows. Vegetation cover: annual saltwort-saxaul community (Fig. 2.). Total projective cover (TPC) of the plant community is 40.5%. Species diversity: *Haloxylon ammodendron*, *Petrosimonia squarrosa* (sp), *Climacoptera aralensis* (sol).

Figure 2. Saxaul plantation (planting in 2010) at Plot 1.

Overall condition – satisfactory. Projective cover of saxaul is 40% (17% of the planting in 2010, 23% - uneven undergrowth).

The age of saxaul is 11-12 years with sporadic 2- and 3-year-old seedlings. The average height is 195 cm (from 150 to 250 cm). The average crown area is 1.7 sq. m, and the largest – 5.5 sq. m. The average root collar diameter is 8.7 cm, and the largest – 12 cm. Quantity of saxaul trees is 1,000 pcs/ha. The number of 2-year-old saxaul seedlings is 18 pcs, and 3-year-old – 40 pcs on the area of 100 sq. m.

The plantation survival rate is 64.5. The saxaul has spread in eastern and northeastern directions for 438 m, and 39 m to the northwest. Fifteen (15) oases of saxaul distribution from the mother plantation were detected (Fig. 3.).

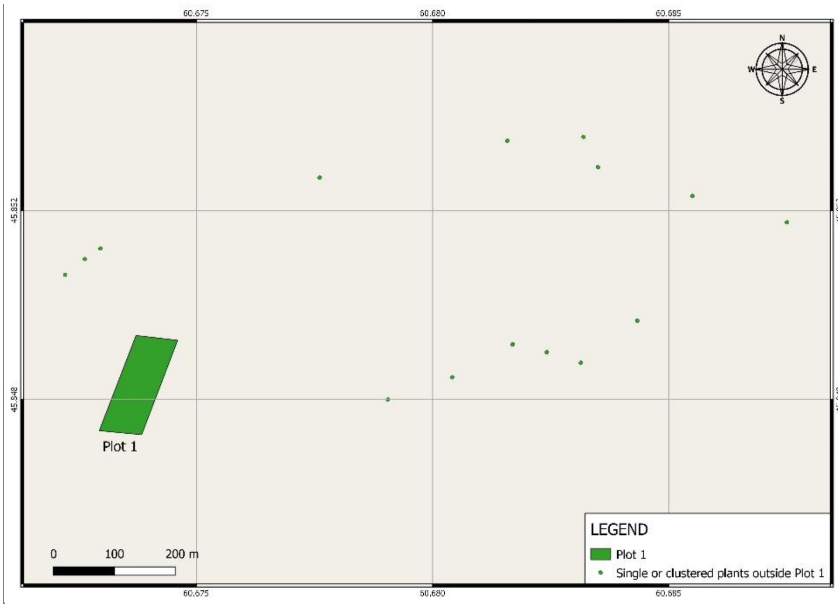

Figure 3. Saxaul distribution from mother plantation at Plot 1.

Plot 2. The soils are dry-type playa salt marsh (takyr-like solonchak). Disturbance signs: camel dung, goitered gazelle tracks. Last year seedlings are present. Vegetation cover: annual saltwort-saxaul community (Fig. 4.).

Figure 4. Saxaul plantation (planting in 2009-2010) at Plot 2.

Species diversity: *Haloxylon ammodendron*, *Anabasis aphylla* (sol), *Petrosimonia squarrosa* (sol-sp), *Salsola nitraria* (sp-cop$_1$), *Halostachys belangeriana* (sol), *Phragmites australis* (sol). TPC – 27%. Saxaul protective cover is 21.5%.

The age of saxaul is 11-12 years with 3-6-year-old saxaul undergrowth. The average height is 190.4 cm (from 120 to 220 cm). The average crown area is 2.8 sq. m, and the largest – 6.6 sq. m. The average root collar diameter is 11.2 cm, and the largest – 16 cm. The quantity of saxaul trees is 80/ha. The number of 3-year-old saxaul seedlings is 16 pcs, 4-year-old undergrowth – 11 pcs, and 6-year-old – 4 pcs on the area of 10x100 m. The plantation survival rate is 9.4%.

Plots 3-4. The soils are dry-type playa salt marsh (takyr-like solonchak); previously, it was crust salt marsh. With time, the site got covered with fine-grained earth kept in place by saxaul and orach, due to which a pit-and-mound surface formed. Disturbance signs: camel dung, goitered gazelle tracks. Last year seedlings are present. Vegetation cover: saxaul community with orach (Fig. 5.). Species diversity: *Haloxylon ammodendron*, *Atriplex pratovii* (sol-sp), and *Salsola nitraria* (sol). TPC – 30%. The saxaul projective cover is 25%.

Figure 5. 3-5-year-old saxaul at Plots 3 and 4.

The age of saxaul is 7-9 years with 3-5-year-old saxaul undergrowth. The average height is 200 cm (160 to 230 cm). The average crown area is 5.1 sq. m, and the largest – 8.4 sq. m. The root collar diameter could not be determined due to being covered with fine-grained earth. The quantity of saxaul trees is 500 pcs/ha. The number of 3-year-old saxaul plants is 7 pcs, and 5-year-old – 3 pcs on the area of 100 sq. m.

Plot 5. The soils are emerging desert sandy shallow with blue clay coming to the surface in some places. Vegetation cover: psammophytic shrub community with saxaul (Fig. 6.). Species diversity: *Calligonum aphyllum* (sp), *Haloxylon ammodendron*, *Eremosparton aphyllum* (sp), *Astragalus brachypus* (sp), *Stipagrostis pennata* (sp), *Salsola paulsenii* (sp), *Heliotropium arguzioides* (sol). TPC – 25-30%, and saxaul projective cover – roughly 8%.

Figure 6. General view of Plot 5.

The saxaul at the plot is 10 years old with 3-4-year-old undergrowth and 1-year seedlings present. The average height is 76 cm (from 30 to 200 cm). The average crown area is 1 sq. m, and the largest – 5.9 sq. m. The number of saxaul trees is 100 pcs/ha. The plantation survival rate is 20%.

Plot 6. The soils are salt marsh turning into dry-type playa (takyr-like solonchak). Disturbance signs: hoof tracks, horse dung. Vegetation cover: sparse clusters of saxaul, tamarix, boxthorn, and petrosimonia (Fig. 7.). Species diversity: *Haloxylon ammodendron*, *Tamarix hispida* (sol), *Lycium ruthenicum* (sol), *Petrosimonia squarrosa* (sol), *Karelinia caspia* (sol), *Tamarix laxa* (sol). TPC – 5-7%; saxaul projective cover – 0.1%.

Figure 7. General view of Plot 6.

The saxaul is 10 years old. The average height is 80 cm (75-85 cm). The average crown area is 0.5 sq. m, and the largest – 1.6 sq. m. The average root collar diameter is 3.8 cm, and the largest – 5 cm. The quantity of saxaul trees is 10 pcs/ha. The plantation survival rate is 2%.

Plot 7. The soils are salt marsh turning into dry-type playa (takyr-like solonchak). Disturbance signs: horse dung, rodent burrows. Vegetation cover: sparse petrosimonia-saxaul aggregations with boxthorn microcenoses (Fig. 8.). Species diversity: *Haloxylon ammodendron*, *Petrosimonia squarrosa* (sol), *Zygophyllum oxianum* (sol-un), *Lycium ruthenicum* (sol). TPC – 7-10%; saxaul projective cover – 5%.

Figure 8. Saxaul plantation at Plot 7.

The saxaul at the plot is 10 years old. The average height is 133.3 cm (ranging between 100 and 160 cm). The average crown area is 3.1 sq. m, and the largest – 5.8 sq. m. The average root collar diameter is 5.3 cm, and the largest – 6 cm. The quantity of saxaul trees is 95 pcs/ha. The plantation survival rate is 19%.

Plot 8. The soils are salt marsh turning into dry-type playa (takyr-like solonchak). Disturbance signs: ungulate tracks, dung and paths. Vegetation cover: clusters of saxaul with singular nitrebush, boxthorn and annual saltwort (Fig. 9.). Species diversity: *Haloxylon ammodendron*, *Climacoptera aralensis* (sp), *Limonium otolepis* (sp), *Nitraria schoberi* (sp), *Halostachys belangeriana* (sp), *Tamarix hispida* (sp), *T. elongata* (sp). TPC – 10-15%; saxaul projective cover – 2%.

Figure 9. Saxaul plantation at Plot 8.

The saxaul is 10 years old. The average height is 118.3 cm (70 to 160 cm). The average crown area is 2.9 sq. m, and the largest – 4.6 sq. m. The average root collar diameter is 4.7 cm, and the largest – 6 cm. The quantity of saxaul trees is 44 pcs/ha. The plantation survival rate is 9%.

Plots 9-10. The soils are dry-type playa (takyr-like) with polygonal cracks. Disturbance signs: cow and camel dung. Vegetation cover: sparse boxthorn and saltwort clusters with sporadic saxaul (Fig. 10.). Species diversity: *Haloxylon ammodendron*, *Halocnemum strobilaceum* (sol), *Lycium ruthenicum* (sp), *Tamarix elongata* (sol), *Petrosimonia brachiata* (sol-sp), *P. squarrosa* (sol-sp), *Halostachys belangeriana* (sol), *Climacoptera aralensis* (sol), *Tamarix elongata* (sp), *Karelinia caspia* (sol). TPC – 5%; saxaul projective cover – 0.04%.

***Figure 10**. General view of Plots 9 and 10.*

The saxaul is 10 years old. The average tree height is 61.7 cm (50 to 80 cm). The average crown area is 0.3 sq. m, and the largest – 0.9 sq. m. The average root collar diameter is 2.8 cm, and the largest – 4 cm. The quantity of saxaul trees is 11 pcs/ha. The plantation survival rate is 2.2%.

Plot 11. The soils are crust salt marsh. Disturbance signs: camel tracks. Vegetation cover: saxaul, perennial seablite, halostachys and saltwort clusters (Fig. 11.). Species diversity: *Haloxylon ammodendron*, *Suaeda microphylla* (sp), *Climacoptera aralensis* (sp), *Petrosimonia squarrosa* (sol), *Halostachys belangeriana* (sol), *Anabasis aphylla* (sol), *Halocnemum strobilaceum* (sol), *Limonium otolepis* (sol), *Kalidium foliatum* (sol). TPC – 5-7%; saxaul projective cover – 1.1%.

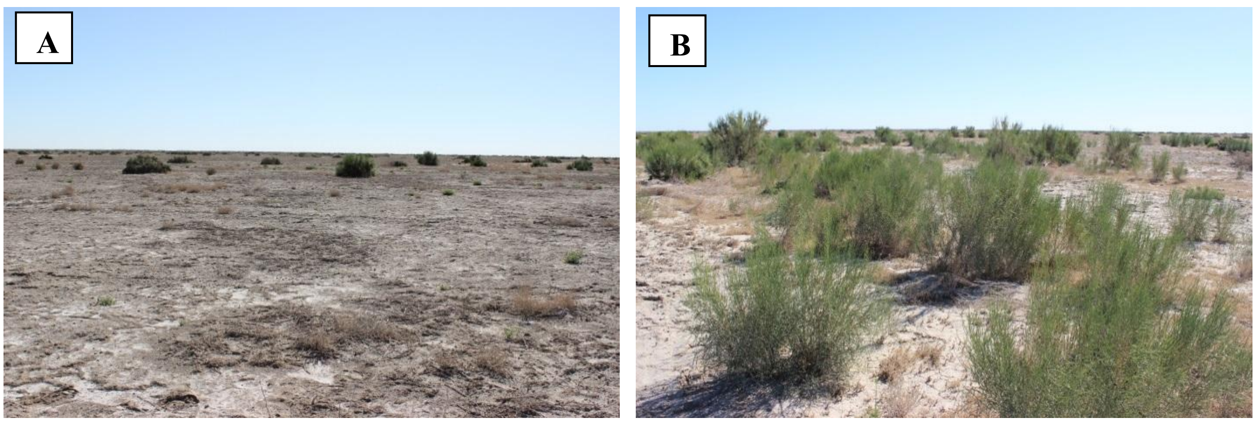

Figure 11. Plot 11 (A – general view; B – saxaul cluster up close).

At the plot, the saxaul is 8 years old with last-year seedlings present; this year's (2020) seedlings are not present; 50% of trees have broken tips. One-year undergrowth is present. The average tree height is 220 cm. The average crown area is 2.4 sq. m, and the largest – 5.9 sq. m. The average root collar diameter is 15 cm. The quantity of saxaul trees is 20 pcs/ha. The plantation survival rate is 4%.

Plot 12. The soils are crust salt marsh. Single high-vitality saxaul bushes are present. Vegetation cover: clusters of saxaul, perennial and annual saltworts (Fig. 12.). Species diversity: *Haloxylon ammodendron*, *Climacoptera aralensis* (sp-sol), *Petrosimonia squarrosa* (sp-sol), *Halostachys belangeriana* (sol). TPC – 2-3%; saxaul projective cover – 0.1%.

Figure 12. Salt-covered soil surface.

The saxaul is 8 years old. The average tree height is 220 cm. The average crown area is 5 sq. m. The average root collar diameter is 9 cm. The quantity of saxaul trees is 2 pcs/ha. The plantation survival rate is 0.3%.

Plot 13. The soils are crust salt marsh. Vegetation cover: sparse clusters of nitrebush, karelinia, halostachys and saltwort (Fig. 13.). Species diversity: *Nitraria schoberi* (sol), *Karelinia caspia* (sol), *Halostachys belangeriana* (sol). TPC – 1-2%. The plantation survival rate is 0%; saxaul is absent.

Figure 13. Crust solonchak (salt marsh) at Plot 13.

Plot 14. The soils are crust salt marsh. Vegetation cover: single clusters of anabasis (Fig. 14.). Species diversity: *Haloxylon ammodendron*, *Anabasis aphylla* (sol). TPC – >1%. The quantity of saxaul trees is 1 pc/ha. The plantation survival rate is 0.12%.

Figure 14. General view of Plot 14.

Plot 15. The soils are crust-puffed salt marsh turning into dry-type playa (takyr-like solonchak). Vegetation cover: sparse clusters of halostacys, nitrebush, limonium (Fig. 15.). Species diversity: *Haloxylon ammodendron*, *Limonium otolepis* (sol-sp), *Frankenia hirsuta* (sol), *Halostachys belangeriana* (sol), *Nitraria schoberi* (sol). TPC – 3-5%; saxaul projective cover – 0.1%.

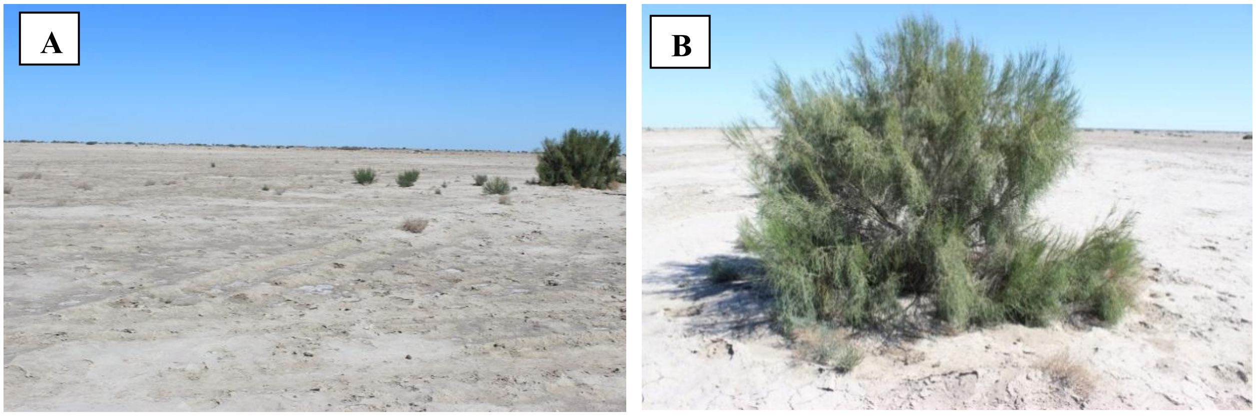

Figure 15. Plot 15 (A – general view; B – saxaul tree).

The saxaul is 8 years old with one-year undergrowth. The average tree height is 220 cm. The average crown area is 8.1 sq. m. The quantity of saxaul trees is 2 pcs/ha. The plantation survival rate is 0.24%.

Plot 16. The soils are crust-puffed salt marsh. Vegetation cover: sparse clusters of perennial and annual saltwort (Fig. 16.). Species diversity: *Haloxylon ammodendron*, *Limonium otolepis* (sol), *Phragmites australis* (sol), *Climacoptera aralensis* (sp-sol), *Halostachys belangeriana* (sol), *Anabasis aphylla* (sol), *Nitraria schoberi* (sol). TPC – 3%; saxaul projective cover – 0.06%.

Figure 16. A furrow with dead saxaul.

At the plot, the Saxaul is 8 years old with one-year undergrowth. The average tree height is 175 cm (ranging between 170 and 180 cm). The average crown area is 7.5 sq. m. The quantity of saxaul trees is 1 pc/ha. The plantation survival rate is 0.2%.

Plot 17. The soils are coastal sandy loam. Disturbance signs: rodent burrows. Vegetation cover: sparse saxaul aggregations (Fig. 17.). Species diversity: *Haloxylon ammodendron*, *Climacoptera aralensis* (sp). TPC – 10%; saxaul projective cover – 4.2%.

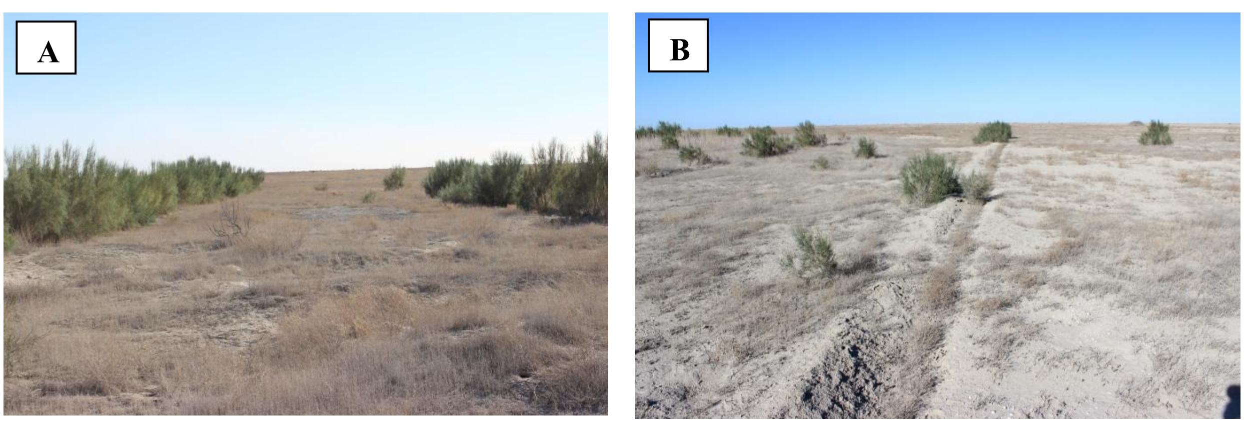

Figure 17. Plot 17 (A – general view; B – saxaul trees in rows).

The saxaul is 6 years old with one-year undergrowth. The average tree height is 136 cm (60-180 cm). The average crown area is 0.6 sq. m. The average root collar diameter is 3.4 cm, and the largest – 6 cm. The quantity of saxaul trees is 700 pcs/ha. The number of one-year saxaul seedlings is 11 pcs (per 100 sq. m). The plantation survival rate is 78%.

Plot 18. The soils are coastal saline light loamy with wind-drifted sandy cover. Vegetation cover: saxaul woodland. Species diversity: *Haloxylon ammodendron*, *Climacoptera aralensis* (sol-sp), *Salsola nitraria* (sol-sp). TPC – 20%; saxaul projective cover – 18%.

The saxaul is 5 years old with the tree height averaging 112 cm (70-160 cm). The average crown area is 0.9 sq. m, and the largest – 1.5 sq. m. The average root collar diameter is 4.9 cm, and the largest – 7 cm. The quantity of saxaul trees is 700 pcs/ha. The plantation survival rate is 72.4%.

Plot 19. The soils are coastal sandy loam. Vegetation cover: sparse saxaul woodland with annual saltwort. Species diversity: *Haloxylon ammodendron*, *Climacoptera aralensis* (sol-sp), *Salsola nitraria* (sol-sp). TPC – 15%; saxaul projective cover – 12.6%.

The age of the saxaul is 3 years (grown from seeds). The average tree height is 176.7 cm (ranging between 140 and 190 cm). The average crown area is 1.4 sq. m, and the largest – 2.3 sq. m. The average root collar diameter is 6.5 cm, and the largest – 8 cm. The condition of saxaul is excellent. The quantity of saxaul trees is 900 pcs/ha.

Plot 20. The soils are coastal middle loamy. Vegetation cover: clusters of saxaul with saltwort (Fig. 18.). Species diversity: *Haloxylon ammodendron*, *Kalidium foliatum* (sol), *Salsola nitraria* (sol). TPC – 5-7%; saxaul projective cover – 2.1%.

Figure 18. Saxaul plantation at Plot 20.

The age of saxaul is 4 years. The average tree height is 73.7 cm (from 50 to 120 cm); average crown area is 0.2 sq. m, and the largest – 1.1 sq. m; average root collar diameter is 2.4 cm, and the largest – 3 cm. The quantity of saxaul trees is 200 pcs/ha. The plantation survival rate is 20%.

Plot 21. The soils are crust salt marsh. Vegetation cover: sparse clusters of saxaul with saltwort (Fig. 19.). Species diversity: *Haloxylon ammodendron*, *Climacoptera aralensis* (sol), *Kalidium foliatum* (sol), *Halostachys belangeriana* (sol). TPC – >1%; saxaul projective cover – 0.2%.

Figure 19. Survived saxaul saplings at Plot 21.

The age of saxaul is 4 years. The average tree height is 60 cm. The average crown area is 0.2 sq. m. The quantity of saxaul trees is 60/ha. The plantation survival rate is 6%.

Plot 22. Soils are crust salt marsh. Vegetation cover: sparse clusters of saxaul with tamarisk (Fig. 20.). Species diversity: *Haloxylon ammodendron*, *Tamarix hispida* (sp), *Salsola nitraria* (sp-sol). TPC – 5%; saxaul projective cover – 0.3%. The age of saxaul is 4 years. The average tree height is 75 cm (from 70 to 80 cm). The average crown area is 0.6 sq. m. The quantity of saxaul trees is 45/ha. The plantation survival rate is 4.5%.

Figure 20. General view of Plot 22 (Salsola nitraria at forefront).

Plot 23. Soils are coastal salt marsh with wind-drifted sandy cover. Vegetation cover: sparse clusters of saxaul with annual saltwort (Fig. 21.). Species diversity: *Haloxylon ammodendron*, *Salsola nitraria* (sp), *Atriplex pratovii* (sp), *Climacoptera ferganica* (sol-sp). TPC – 10%; last year's dry orach – 40%; saxaul projective cover – 6.3%.

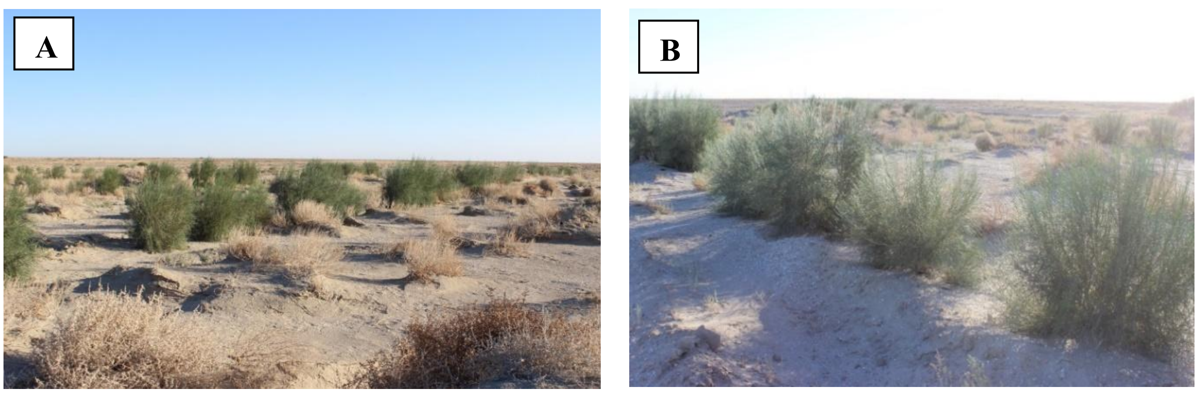

Figure 21. A – saxaul plantation at Plot 23; B – saxaul trees in rows.

The age of saxaul is 3 years, with the average tree height of 89 cm (50-170 cm). The average crown area is 0.9 sq. m, and the largest – 1.9 sq. m. The average root collar diameter is 3.3 cm, and the largest – 7 cm. The quantity of saxaul trees is 700 pcs/ha. The plantation survival rate is 70%.

Plot 24. Initially, the plot was divided into two 1 ha sections: the 1st section (in the north of the area) was characterized by shifting sand beds; the 2nd (in the south) was located in a relief depression (Fig. 22.). The observations in 2019 showed that the saxaul survival ranged between

35 and 53%, depending on the geomorphological conditions of specific zones (Alimbetova et al., 2020).

Monitoring Plot Section 1. The soils are low hummocky sands. Vegetation cover: saxaul community. The saxaul projective cover is 24%. Species diversity: *Haloxylon ammodendron*, *Salsola australis* (sol), *S. paulsenii* (sol), *S. orientalis* (sol-sp), *Anabasis aphylla* (un-sol), *Artemisia santolina* (sol), *A. scoparia* (sol), *Heliotropium arguzioides* (sol), *Ammodendron bifolium*, *Krascheninnikovia ceratoides* (sol-sp), *Kochia prostrata* (sol-sp). The age of saxaul is 4-5 years, with the average tree height of 133 cm (from 90 to 160 cm). The average crown area is 2.7 sq. m, and the largest – 5.5 sq. m. The average root collar diameter is 1.5 cm, and the largest – 2.5 cm. The quantity of saxaul trees is 888 pcs/ha. The section survival rate is 13.6%.

Monitoring Plot Section 2. The soils are low hummocky sands. Vegetation cover: saxaul community. The saxaul projective cover is 66%. Species diversity: *Corispermum aralo-caspicum*, *Salsola australis* (sol), *S. paulsenii* (sol), *Calligonum* spp. (sol-sp), *Krascheninnikovia ceratoides* (sol-sp), *Artemisia santolina* (sol), *A. arenaria* (sol), *A. tomentella* (sol), *Agriophyllum squarrosum* (sol), *Heliotropium arguzioides* (sol), *Peganum harmala* (sol), *Astragalus lehmannianus* (sol), *Aeluropus littoralis* (sol), *Secale sylvestre* (sol), *Bromus tectorum* (sol). The age of saxaul is 4-5 years. The average tree height is 111.8 cm (40-280 cm). The average crown area is 1.2 sq. m, and the largest – 2.0 sq. m. The average root collar diameter is 1.5 cm, and the largest – 4.5 cm. The quantity of saxaul trees is 2,633 pcs/ha. The section survival rate is 40.5%.

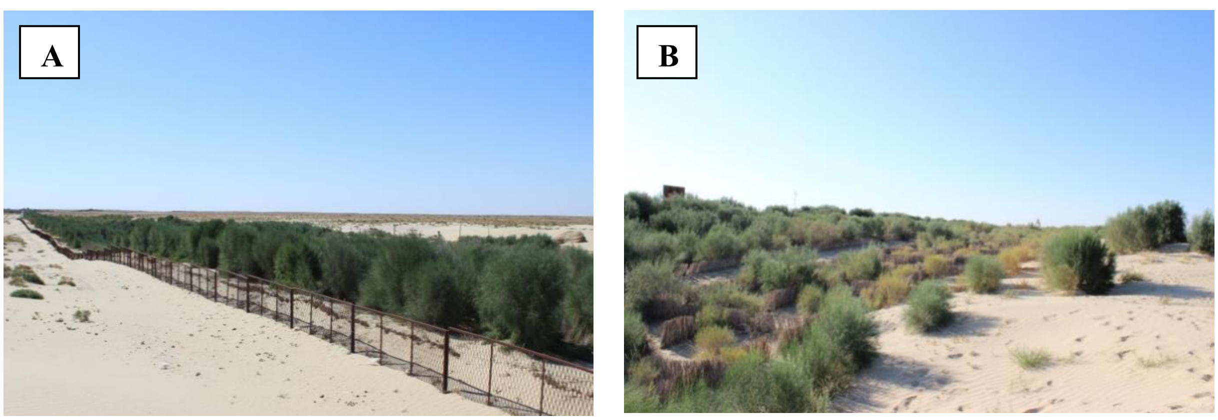

Figure 22. Fixing of shifting sands with saxaul at the village of Aralkum
(A – general view; B – saxaul plantation).

6. Discussion

6.1. *Factors affecting planation condition*

Plot 1 represents the most successful example of phyto-reclamation in the dry seabed. The plantation monitoring showed its satisfactory condition. The high number of trees (1,550 pcs/ha) did not prevent natural development and achieving the reproductive state in 4-5 years, due to which multiple seedlings of different age are currently developing on the plot; after 5 years of growing, their projective cover has reached 23%. Most of the seedlings germinate between the furrows, yet the process of seed transfer over significant distances from mother plants is also taking place. Whereas in the prevailing wind direction saxaul has spread for as far as 438 m from the first plantation section to the northeast, it has spread for no more than 39 m to the northwest. Nonetheless, the process of degradation of 10-year-old plantations is likewise observed, due to initial high plant density, plant gall development, rodent and camel activity. The decreased projective cover of saxaul from 40 to 17% over 5 years (compared to the monitoring data of 2015) indicates the ongoing degradation (Dimeyeva et al., 2017). Thus, at Plot 1 as to their formation saxaul plantations have gone from the most favorable phase (5 years after planting) to the onset of degradation registered on the 10th year.

At Plots 3 and 4, an increase in the quantity of saxaul trees compared to their number that took root originally is observed. This is due to good reproduction and presence of different-age saxaul plants of seed origin.

The plots planed under the Grass Roots Program – funded by Japan's Embassy in Kazakhstan – are located less than 5 km away from the village of Karateren. Due to this fact, they have been exposed to heavy anthropogenic pressure associated with animal grazing and timber logging. This has led to their lower survival rate.

Saxaul was completely absent at Plot 13. The initially low survival rate (5%) was due to the proximity to the Syrdarya bed in the ebb side of the Kokaral Dam (Fig. 1.) and high groundwater mineralization during spring flooding. High moisture content in this area does not correspond to saxaul ecology.

At Plots 20, 21, 23, an increase in the number of plants that had taken root compared to the first year after planting is observed due to the fact that initially not all seedlings had commenced to grow but were at rest waiting for sufficient moisture.

At Plot 24 – aimed to fix the shifting sands – near the village of Aralkum, plantation loss was observed, specifically 21.3% in Monitoring Plot Section 1, and 12.2% in Monitoring Plot Section 2. These differing indicators are associated with the geomorphological conditions at each of the sections (Alimbetova et al., 2020). Section 1 is located in close proximity to shifting dunes with active eolic activity. Section 2 is located in a depression; initially it was flat, and the plantations changed its relief to hummocky type stopping sand transfer. Saxaul seedlings are developing well, which is associated with the installation of sand-holding mechanical reed protective fencing. Uzbekistan colleagues are using the same method in the Southern Aral Sea area. The experiments in areas with reed protection have demonstrated 59% survival rate of the saxaul in the Southern Aral Sea Region (Bakirov et al., 2020b), and in Aralkum (Plot 24) the survival rate at the end of the first vegetation season ranged from 32 to 57% (Alimbetova et al., 2020).

6.2. Rating scale

Based on the data on saxaul survival and vitality at the surveyed plots, the following 5-score soil favorability scale for saxaul germination and growth was developed: 1 – crust salt marsh; 2 – salt marsh turning into dry-type playa (takyr-like solonchak); 3 – light loamy salt marsh; 4 – salt marsh with wind-drifted sand cover; 5 – sands.

In accordance with the developed scoring scale, the most favorable conditions have evolved on coastal sandy loam and salt marsh light loamy soils with wind-drifted sandy cover. It is well-known that the high content of sand fraction in the soil contributes to better moisture supply of seedling root system. For example, at Plot 17 with sandy loam soils, saxaul plantation survival has reached 78%, and the trees are developing extremely well. On dry-type playa (takyr-like) and crust salt marsh soils with salt effusions, the condition of saxaul is poor, and the survival rate in some sections drops down to 0%.

The scale proposed by the authors of this research is based on the classification of V.S. Kaverin et al. developed in 1989-1992. The classification includes 4 categories of forest-growing conditions: 1) good forest growing conditions – plains with sandy and sandy loam deposits; 2) satisfactory forest-growing conditions – coastal sandy loam and loamy soils of the plains with wind-drifted sandy cover; 3) conditionally forest-suitable soils – plains with heavy lithology deposits (loam and clay); 4) sandy soils (shifting dunes) (Kaverin et al., 1994; Kaverin, Salimov, 2000).

7. Conclusion

The survey of saxaul plantations at the dry seabed of the Aral sea showed different outcomes and efficiency of forest reclamation efforts. In total, 24 pilot plots with the area of 1-5 ha were examined occupied by 2-12-year-old plantations. The number of saxaul trees ranged from 1 to 1,000 pcs/ha on the dry seabed, and from 888 to 2,633 pcs/ha in the village of Aralkum. The survival rate of the plantations at the time of field research in 2020 ranged between 0 and 78% on the dry seabed, and between 13.6 and 40.5% in Aralkum Village. The average height of saxaul plants ranged from 60 to 220 cm; average crown area of one bush – between 0.2 and 7.5 sq. m; and average projective cover of saxaul in plantations – from 0 to 66%.

On the one hand, the survey has revealed the loss of plants that took root in the year of planting. The loss was predetermined by climatic conditions, salinization and soil texture, as well as anthropogenic and zoogenic impacts. On the other hand, the active process of increasing number of saxaul trees due to natural seeding is observed also.

The monitoring under this research has demonstrated that the main tasks of phyto-reclamation at DSAS – form obstacles to salt and dust transfer, and contribute to natural saxaul spreading – have been fulfilled to varying degrees of success. The example of Plot 1 shows that the best development of saxaul plantations is achieved by the 5th year, when the plants go into the generative phase. The same plot proves the efficiency of fixing shifting sands with the aim of protecting settlements using the combination of phyto-reclamation and mechanical methods.

For the purpose of executing further phyto-reclamation activities, it appears necessary to take account of forest-growing suitability of target areas, soil favorability scale, and phyto-indicators (Dimeyeva et al., 2017).

8. Recommendations

Thus far, a series of recommendations for phyto-reclamation at DSAS have been developed and practically tested (Kaverin et al., 1994; 2008a; 2008b). Recommendations for creating protective forest plantations on salt-marsh wasteland (Dimeyeva et al., 2013) and fixing shifting sand (Satekeyev, Dimeyeva, 2017; Tlepbergenov, 2015) have been elaborated as well.

Based on the finding of this research, the authors propose the following recommendations for monitoring plant loss and saxaul development directly at plantations:

- Monitor saxaul plantations during the 1st year of planting to detect root-taking of planting material;
- Conduct follow-up monitoring after 3-5 years, since by this time saxaul reaches the generative phase (seed regeneration). Plant communities and clusters form with the participation of salt-tolerant plant species, and should undergo geobotanical and reclamation assessment;
- Preferably, conduct monitoring in and around settlements as anthropogenic impacts can be extremely destructive and may be timely prevented.

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