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CHANGES IN THE VEGETATION OF THE DRIED ARAL SEA BED

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Abstract. The article investigates the distribution, species, and projective cover levels of vegetation that emerged in the sand dunes formed in place of the Aral Sea due to its desiccation. The changes in vegetation over the years, from 1981 to 2024, have been studied. According to the results, the projective cover level of vegetation on the dried Aral Sea bed has undergone significant changes. Specifically, from 1981 to 2024, the projective cover level increased by 31 %, reaching 55 %. Currently, dominant plant species such as *Haloxylon ammodendron (C.A. Mey.) Bunge ex Fenzl, Halostachys caspica (M. Bieb.) C.A. Mey., Halocnemum strobilaceum (Pall.) M.Bieb., Haloxylon persicum Bunge, and Caroxylon nitrarium (Pall.)* Akhani & Roalson are widespread. In the study area, factors such as increased soil salinity, changes in groundwater levels, low precipitation, and rising temperatures have had the most significant impact on the distribution and changes in vegetation. In the early years of the Aral Sea desiccation, approximately 10 plant species grew, with a projective cover level of 24 %. Over the course of 10 years, the number of species increased by 1–2 species. After 20 years, the number of species decreased to 7, but after another 20 years, the number of species increased again, reaching 11 species. The projective cover level increased from 24 % in 1981 to 55 % by 2024, showing a 31 % increase.

Keywords: vegetation, Aral Sea, degree of projective cover, salinization, sandy areas, soil

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ИЗМЕНЕНИЯ РАСТИТЕЛЬНОСТИ НА ОСУШЕННОМ ДНЕ АРАЛЬСКОГО МОРЯ

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Аннотация. Исследуются распространение, видовой состав и уровень проективного покрытия растительности, появившейся на песчаных дюнах, сформировавшихся на месте высохшего Аральского моря. Изучены изменения в растительности с 1981 по 2024 г. Согласно результатам, уровень проективного покрытия растительности на осушенном дне Аральского моря претерпел значительные изменения. В частности, с 1981 по 2024 г. уровень проективного покрытия увеличился на 31 %, достигнув 55 %. В настоящее время широко распространены такие доминирующие виды растений, как *Haloxylon ammodendron (C. A. Mey.) Bunge ex Fenzl, Halostachys caspica (M.Bieb.) C. A. Mey., Halocnemum strobilaceum (Pall.) M. Bieb., Haloxylon persicum Bunge и Caroxylon nitrarium (Pall.)* Akhani & Roalson. В изучаемом районе на распределение и изменения в растительности наибольшее влияние оказали такие факторы, как повышение засоленности почв, изменения уровня грунтовых вод, низкое количество осадков и повышение температуры. В первые годы после высыхания

Аральского моря произрастало около 10 видов растений, при уровне проективного покрытия 24 %. В течение следующих 10 лет количество видов увеличилось на 1–2. Через 20 лет число видов снизилось до 7, но спустя ещё 20 лет вновь увеличилось, достигнув 11 видов. Уровень проективного покрытия вырос с 24 % в 1981 г. до 55 % в 2024 г., что составляет увеличение на 31 %.

Ключевые слова: растительность, Аральское море, степень проективного покрытия, засоление, песчаные территории, почва

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Introduction

As a result of the Aral Sea's desiccation, sandy areas have formed in its former basin [4, 11] and the process of soil formation has begun [8]. In the result, these areas cover approximately 5.2 million hectares, of which 3.2 million hectares are located within the territory of Uzbekistan. The distribution of vegetation across the dried seabed of the Aral Sea varies by region – including the southern, eastern, western, northern, and central parts. In the southern part alone, 216 species of plants have been identified [1]. In the western part, 27 plant species belonging to 4 different genera have been identified [2]. Changes in vegetation on the dried seabed of the Aral Sea have been observed over the years. Notably, a significant transformation occurred within mesophytic plant communities due to the lowering of groundwater levels. Additionally, the movement of salts has contributed to the emergence of new plant species, while others have disappeared [3]. The primary factor influencing the progressive transformation of vegetation is soil salinization [5]. Furthermore, due to desertification, approximately 68 % of the dried seabed of the Aral Sea is currently experiencing degradation [6]. In the northern part of the dried Aral Sea basin, the dominant soil degradation processes include anthropogenic soil salinization, wind erosion, and soil alkalization [7]. Initially, the Aral Sea's water was fresh; however, over time it became highly saline, which led to severe soil salinization and the formation of solonchaks [9]. The dried seabed of the Aral Sea is now predominantly covered by halophytic and psammophytic plant species, whose projective cover fluctuates over time [10]. Ongoing climate change is further contributing to shifts in vegetation patterns [12]. Soil salinization has also intensified, which in turn has negatively affected plant growth and development [13–15]. Among the salt- and drought-tolerant plant species in the Aral Sea region is licorice (*Glycyrrhiza glabra*), which is considered resistant to various environmental stresses [16]. Another stress-tolerant plant found in different parts of the dried Aral Sea basin is *Chenopodium quinoa* Willd [17]. Studying the widespread plant species *Salicornia* L. around the Aral Sea and isolating bacteria from its rhizosphere for application to plants in other regions has shown promising results under stress conditions [18]. The desiccation of the Aral Sea has also negatively affected the growth, development, and yield of autumn wheat and cotton crops even in distant areas such as the Khorezm region [19]. One of the most adaptable and salt- and drought-tolerant species suitable for sandy soils in the dried seabed of the Aral Sea is black saxaul (*Haloxylon aphyllum*), which develops root systems specifically in response to sodium-induced salinity [20]. In the northern regions of the Aral Sea, plowing activities have significantly reduced naturally occurring vegetation, highlighting the urgent need for measures to restore native plant species [21]. Planting species such as *Elaeagnus angustifolia*, *Ulmus pumila*, *Morus alba*, and *Populus nivea × tremula* around the Aral Sea has been shown to reduce soil salinity and enhance biomass accumulation [22]. As evidenced by the analysis of the above-mentioned literature, changes in vegetation on the dried seabed of the Aral Sea are closely linked to soil salinization, climate change, and fluctuations in groundwater levels. Our research has also revealed patterns in the distribution of plant species in the eastern part of the dried Aral Sea, as well as inter-annual variations in their projective cover.

Methods

The research was conducted in the eastern part of the dried Aral Sea basin, specifically at the following coordinates: N43º 41.8157', E60º 18.1042'; N43º 43.7409', E60º 17.9305'; N43º 47.0546', E60º 15.9007'; N43º 59.3149', E60º 16.6137'; and N43º 67.4337', E60º 17.1723'. Geobotanical surveys were carried out based on the methodology outlined in

"Methodological Guidelines for Geobotanical Survey of Natural Forage Lands of Uzbekistan", while cartographic analyses were performed using the Inverse Distance Weighting (IDW) geostatistical interpolation method. The soils in the study area were characterized as moderately to highly saline, with widespread presence of solonchaks. The average annual precipitation is approximately 90–100 mm, with maximum summer temperatures reaching up to 42 °C. The groundwater table is located at depths ranging from 1.7 to over 3 meters.

Results

The plant world in the study area has undergone changes over the years, primarily due to alterations in the hydrological regime caused by the desiccation of the Aral Sea. This has led to the formation of automorphic soils, fluctuations in groundwater levels, a decrease in precipitation, and an increase in air temperatures. As a result, the vegetation has gradually undergone transformations.

The changes in the plant species composition around the Aral Sea and its dried basin have been extensively studied and analyzed by scientists. The changes in vegetation in the dried seabed of the Aral Sea from 1981 to 2001 revealed significant transformations in species composition and cover. During this period, the number of plant species decreased from 10 to 7, while the total projective cover increased from 24 % to 44 %. Although the number of species declined, their distribution cover increased, indicating that the plant world adapted and expanded as the Aral Sea dried up. The soil cover decreased slowly, and the groundwater level approached the surface. Over time, as the properties of the soil improved, conditions for plant growth were created, resulting in an increase in the cover level. Notable plants contributing to the increase in projective cover in the dried seabed include *Eremosparton aphyllum* (increased from 2 % to 15 %), *Lycium ruthenicum* (from 0.5 % to 7 %), *Calligonum crispatum* (from 0.5 % to 12 %), *Salsola paulsenii* and *Corispermum aralo-caspicum* (from 0.1 % to 0.5 %), *Chondrilla brevirostris* (from 0.1 % to 6 %), and *Anisantha tectorum* (from 0.1 % to 0.2 %). Conversely, some species showed a decline, such as *Stipagrostis pennata* (from 20 % to 3 %) and *Leymus racemosus* (from 0.5 % to 0.1 %) (Table 1).

Table 1

The changes in the species composition of vegetation on the dried seabed of the Aral Sea over the years (Dimeeva, 2007; *Jabbarov, 2024* [regarding the eastern region])

Indicators	Years of observation														
	1981	1982	1983	1984	1985	1986	1987	1989	1990	1992	1994	1998	1999	2001	2024*
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Succession year	17	18	19	20	21	22	23	25	26	28	30	34	35	37	38
Number of species	10	10	12	10	12	11	12	10	10	11	13	10	7	7	11
Total projective cover, %	24	24	26	26	26	27	33	33	32	32	35	21	21	44	55
Species projective cover, %															
Stipagrostis pennata	20	20	20	20	20	20	20	20	20	10	10	4.0	1.0	20	20
Eremosparton aphyllum	2.0	2.0	4.0	4.0	4.0	4.0	10	10	10	20	20	10	10	15	
Leymus racemosus	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.1	0.1				
Lycium ruthenicum	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.1	0.1	0.5	1.0	7.0	1.0
Calligonum crispatum	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.0	4.0	5.0	12	
Lactuca tatarica	0.1		0.1	0.1	0.1							0.2			
Salsola paulsenii	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5		1
Corispermum aralo-caspicum	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.0	0.1	1.0	0.5	1
C. hyssopifolium	0.1	0.1		0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.0	0.1			
Atriplex pratovii	0.1		0.1												
Convolvulus subsericeus		0.1													
Astragalus brachypus		0.1	0.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.1				
A. lehmannianus			0.1												
Chondrilla brevirostris			0.1		0.1	0.5	0.5	0.5	0.5		0.5	2.0	3.0	6.0	
Linaria dolichoceras					0.1		0.1								
Horaninovia ulicina										0.1					
Anisantha tectorum						0.1	0.1			0.1	0.1			0.2	
Lappula semiglabra											0.1				
Senecio noeanus											0.1				

End of Table 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Haloxylon ammodendron (C.A.Mey.) Bunge ex Fenzl															15
Alhagi pseudalhagi (M.Bieb.) Desv. ex Wangerin															15
Haloxylon persicum Bunge															55
Lepidium perfoliatum L.															1
Calligonum acanthopterum I.G.Borshch.															25
Ammodendron conollyi Bunge ex Boiss.															0.5
Phragmites australis (Cav.) Trin. ex Steud.															2
Astragalus villosissimus Bunge															5
Climacoptera lanata (Pall.) Botsch.															0.5
Caroxylon scleranthum (C.A.Mey.) Akhani & Roalson															0.5
Bassia eriophora (Schrad.) Asch.															0.5
Halostachys caspica (M.Bieb.) C.A.Mey															8
Tamarix hispida Willd.															10
Climacoptera aralensis (Iljin) Botsch.															1
Peganum harmala L.															0.5
Suaeda microsperma (C.A.Mey.) Fenzl															0.5
Eremopyrum triticeum (Gaertn.) Nevski															0.5
Atriplex fominii Iljin															1
Ephedra strobilacea Bunge															10
Xylosalsola richteri (Moq.) Akhani & Roalson															10
Stipagrostis karelinii (Trin. & Rupr.) H.Scholz															15

The plant world has undergone changes over the years, following a dynamic trajectory, with one of the main driving factors being the ongoing desiccation of the Aral Sea. The dynamic changes in vegetation are primarily influenced by continued soil salinization and desertification, driven by exogenous processes such as aeolian, halogeochemical, and hydromorphic processes. These changes are closely linked with soil formation processes. In the dried seabed of the Aral Sea within the territory of Kazakhstan, 342 plant species belonging to 43 families and 170 genera have been recorded (Dimeeva, 2008). Among them, the dominant families include: *Chenopodiaceae* (83 species), *Asteraceae* (45 species), *Polygonaceae* (36 species), *Brassicaceae* (32 species), *Fabaceae* (22 species), *Poaceae* (19 species), *Boraginaceae* (13 species), *Tamaricaceae* (9 species), *Ranunculaceae* (7 species), *Cyperaceae* (5 species), and *Apiaceae* (5 species). In terms of life forms, annual plants account for 41.5 %, perennial herbaceous plants 31.9 %, and shrubs 16.7 %, making them the dominant forms. The Aral Sea crisis is still ongoing; periodic inflows of water, as well as residual water from rivers and reservoirs, continue to extend the duration of this process.

In the dried seabed of the Aral Sea, the distribution of plant species and their projective cover values are highly variable. According to research findings, the composition of plant species has almost completely changed – species that were present in the 1980s are now either absent or occur very rarely, having been replaced by other species. Furthermore, the level of projective cover has increased, indicating that vegetation is expanding and progressively covering the soil surface. This phenomenon can be attributed to the ongoing hydrogeological processes and consistent progression of soil formation in the region (Fig. 1).

As shown in the figure, during the initial years of the Aral Seaɔ’s desiccation, approximately 10 plant species were predominantly present, with a projective cover of 24 %. Within the first 10 years, the number of species increased by 1–2. However, after 20 years, the number of species declined to 7, before increasing again to 11 after another 20 years. The projective cover, on the other hand, has shown a steady increase–from 24 % in 1981 to 55 % in 2024, marking a 31 % rise, which is considered a positive indicator. These findings suggest that the composition of vegetation changes naturally every 15–20 years. Therefore, it is important to consider the dynamic nature of species composition when developing recommendations. The distribution of vegetation is closely linked to the drying process of the Aral Sea and to soil formation over time, including the specific properties and characteristics of the soils. The figure below illustrates the distribution of vegetation from 1981 to 2025 and highlights the changes over this period (Fig. 2–4).

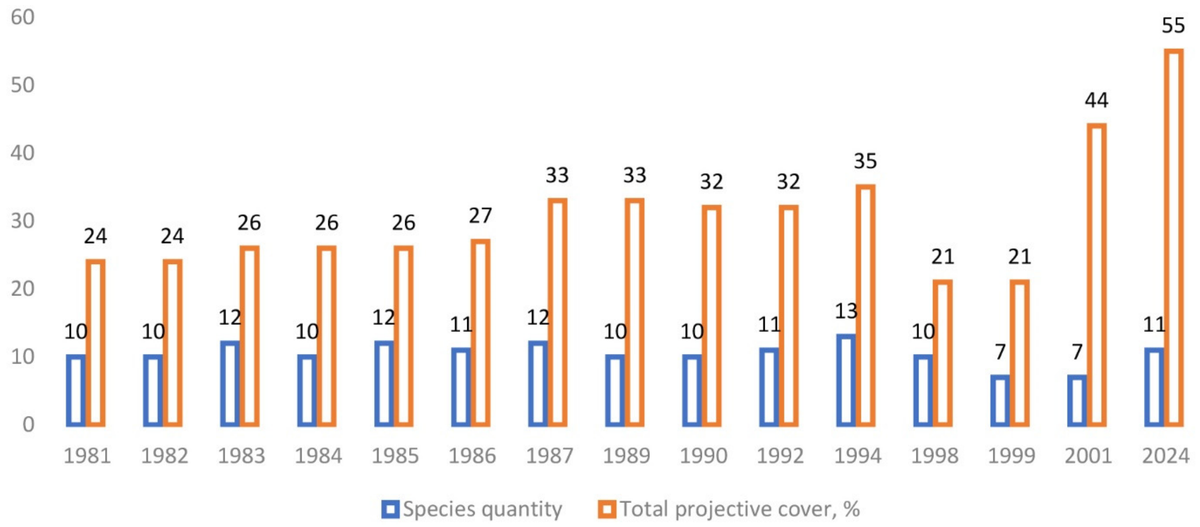

Fig. 1. Dynamic characteristics of plant species distribution
and their projective cover on the dried seabed of the Aral Sea

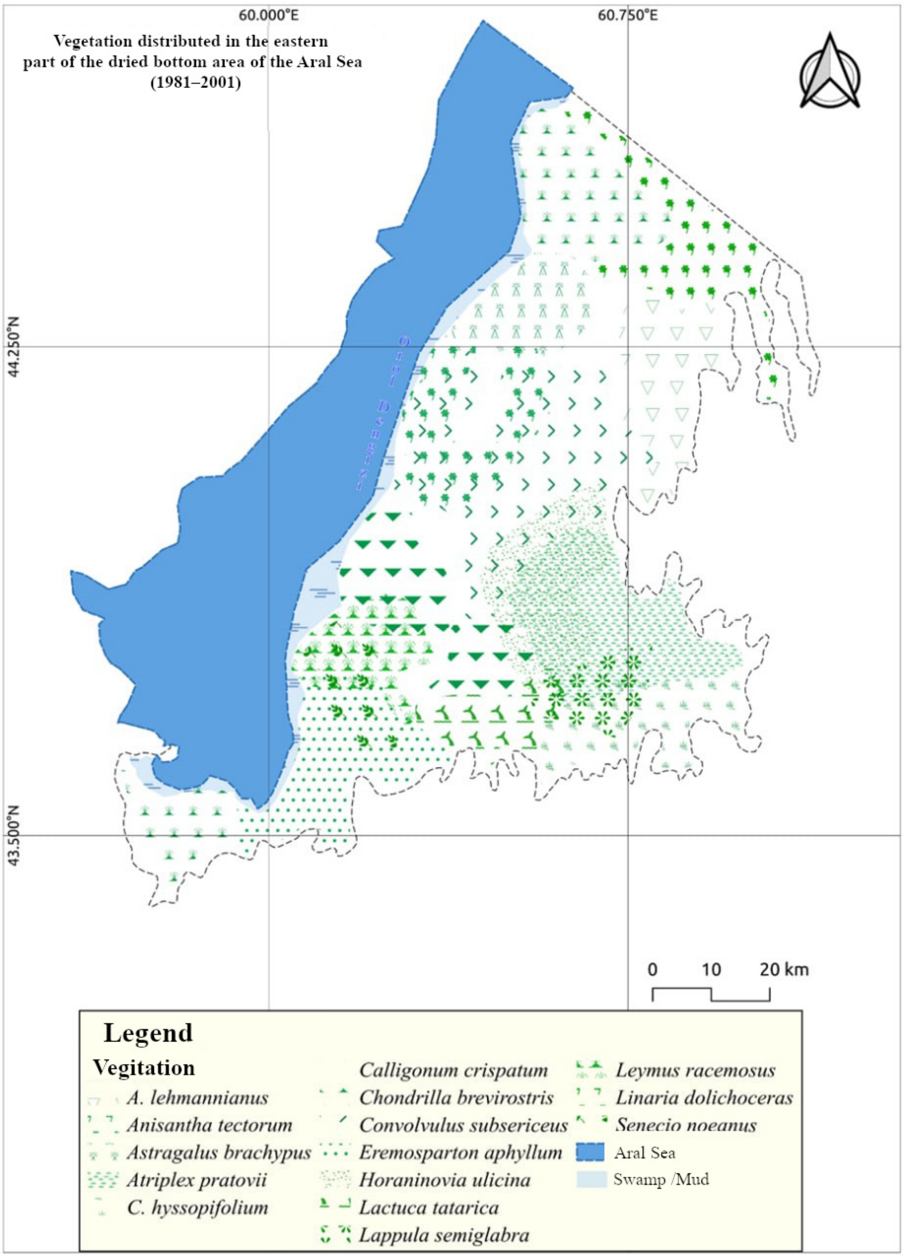

Fig. 2. Distribution of vegetation in the eastern part of the dried Aral Sea bed (1981–2001)

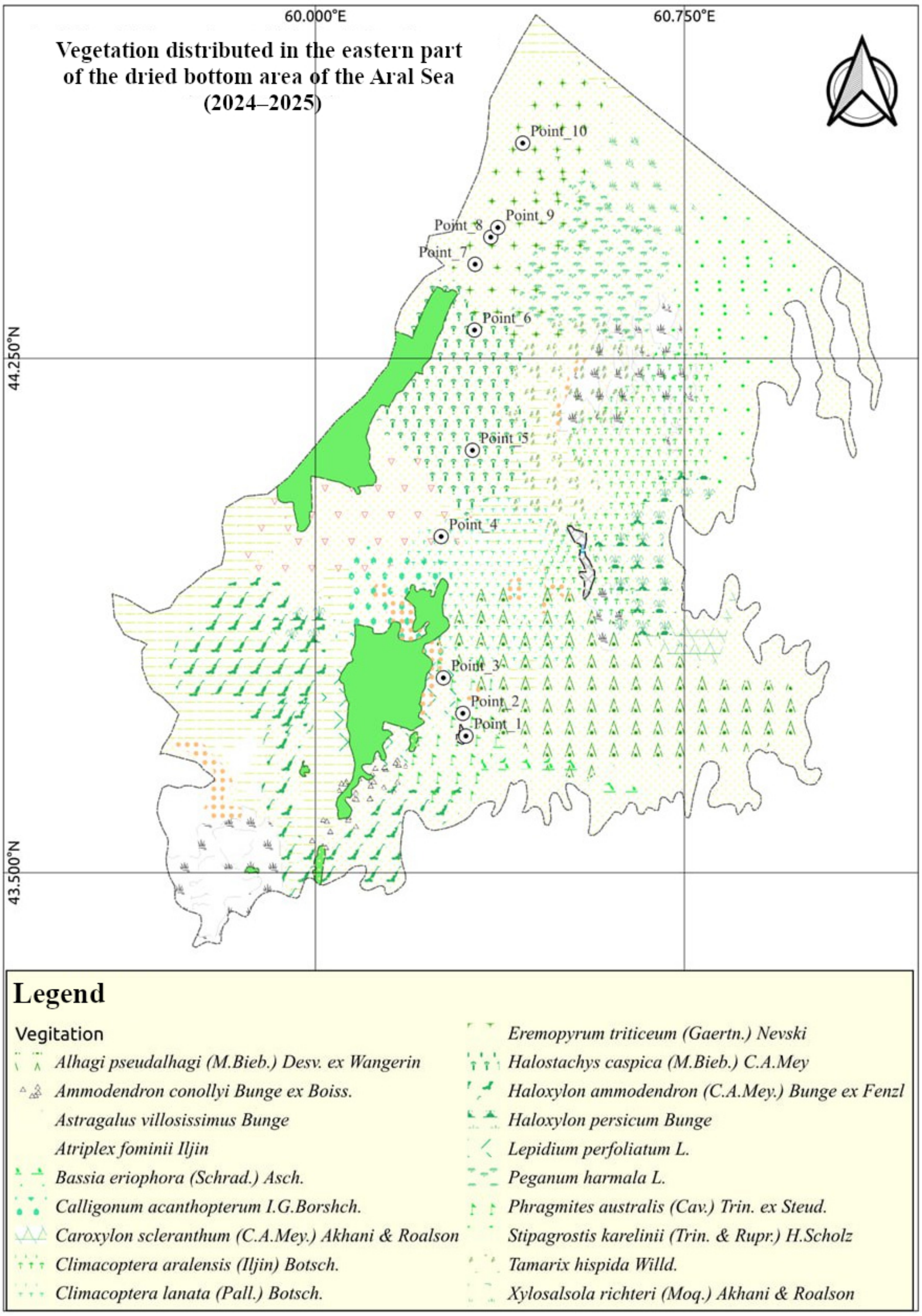

Fig. 3. Distribution of vegetation in the eastern part of the dried Aral Sea bed (2024–2025)

As shown in the fig. 4, 21 different plant species have been recorded in the eastern part of the dried Aral Sea bed, with projective cover levels ranging from 0.5 to 55 %. The distribution of these species is uneven across the area some species are absent in certain locations while others are found only in specific zones. Therefore, it is not feasible to recommend planting the most widespread species uniformly across the entire region. The distribution of each plant species is influenced by the local soil conditions, salinity levels, depth and mineralization of the groundwater table. Consequently, when proposing vegetation planting on the dried seabed of the Aral Sea, it is essential to base recommendations on the natural distribution areas of the plants and to consider the physical and chemical properties of the soils. Otherwise, the growth and development of the introduced species may be significantly limited.

During the first year of the project research, the distribution of vegetation, their projective cover levels, and dominant species on the dried seabed of the Aral Sea were studied. The findings are summarized as follows (Fig. 5).

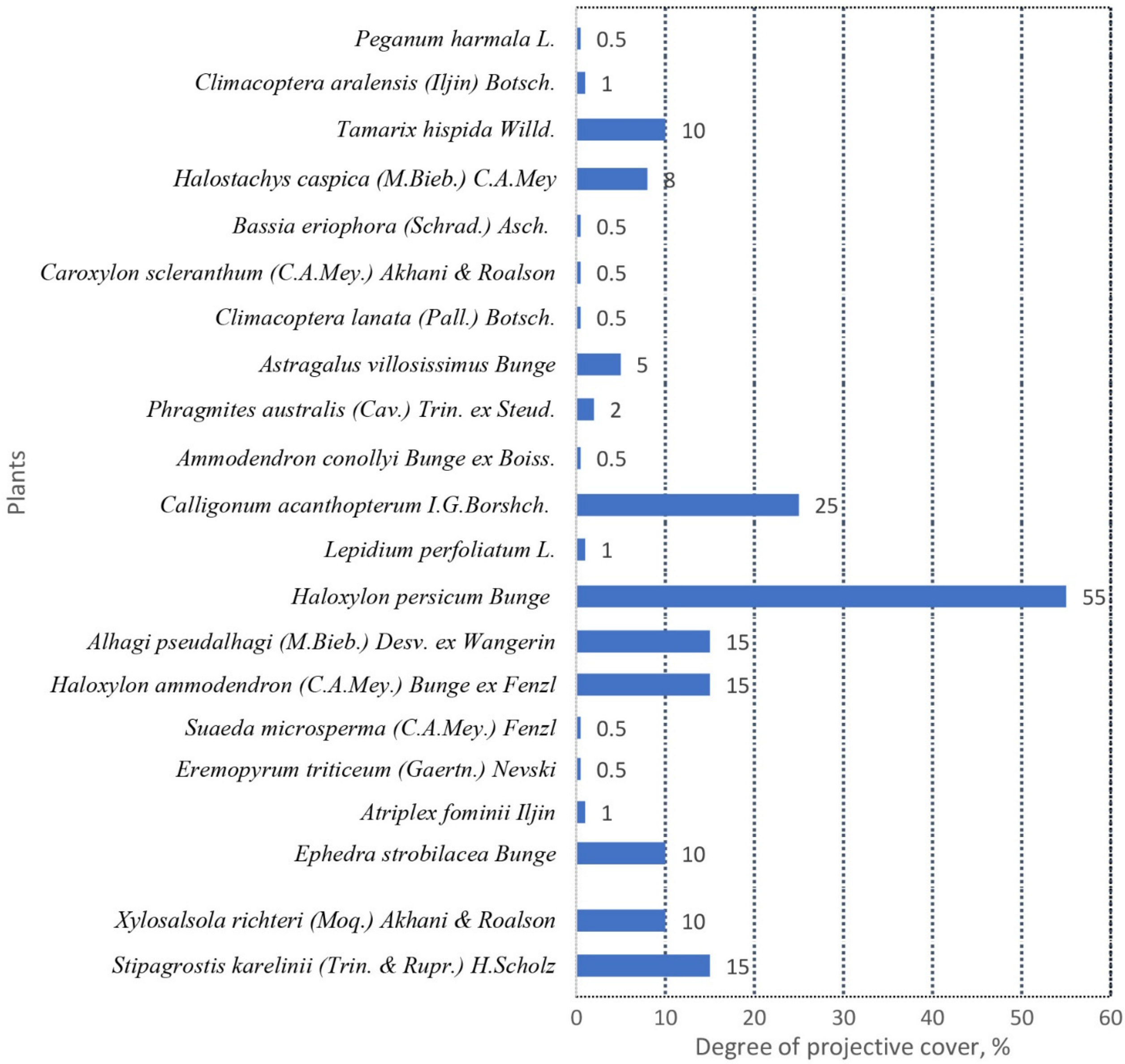

Fig. 4. Distribution of plant species and projective cover level (%) in the eastern region of the dried Aral Sea bed

Fig. 5. Distribution of vegetation in the eastern part of the dried Aral Sea bed (N43° 41.8157', E60° 18.1042')

The projective cover levels of plant species distributed in this area are as follows. According to the results, the vegetation community in the study area is characterized as a Haloxylon-mixed (saxaul-dominated) shrubland. The projective cover of the plant community (PCLC – Projective Cover Level of the Community) was 36 % (Table 2).

In the next area, vegetation distribution has noticeably decreased, and the projective cover level was found to be sparse (Fig. 6).

Table 2

Distribution of vegetation in the eastern part of the dried Aral Sea bed (N43° 41.8157', E60° 18.1042')

Species	PCLC, %
Haloxylon ammodendron (C.A.Mey.) Bunge ex Fenzl	15
Alhagi pseudalhagi (M.Bieb.) Desv. ex-Wangerin	15
Haloxylon persicum Bunge	5
Lepidium perfoliatum L.	1
Calligonum acanthopterum I.G.Borshch.	+
Ammodendron conollyi Bunge ex Boiss.	+
Phragmites australis (Cav.) Trin. ex Steud.	+
Astragalus villosissimus Bunge	+
Climacoptera lanata (Pall.) Botsch.	+
Caroxylon scleranthum (C.A.Mey.) Akhani & Roalson	+
Bassia eriophora (Schrad.) Asch.	+

Fig. 6. Distribution of vegetation in the eastern part of the dried Aral Sea Bed (N43° 43.7409', E60° 17.9305')

In this area, the number and abundance of plant species have decreased, and the morphological characteristics of the soil substrates have also changed. According to the results, the vegetation community is characterized as a saline-sarsazan-sand desert type, with the projective cover of the plant community (PCLC) being 16 % (Table 3).

In the next area, the species composition and number of plants further decreased and became sparser (Fig. 7).

Table 3

Projective cover level of vegetation in the eastern part of the dried Aral Sea bed (N43° 43.7409', E60° 17.9305')

Species	PCLC, %
Halostachys caspica (M.Bieb.) C.A.Mey.	8
Caroxylon scleranthum (C.A.Mey.) Akhani & Roalson	3
Halocnemum strobilaceum (Pall.) M.Bieb.	3
Tamarix hispida Willd.	1
Climacoptera aralensis (Iljin) Botsch.	1
Haloxylon ammodendron (C.A.Mey.) Bunge ex Fenzl	+
Lycium ruthenicum Murray	+
Peganum harmala L.	+
Bassia eriophora (Schrad.) Asch.	+

Fig. 7. Distribution of vegetation in the eastern part of the dried Aral Sea bed (N43° 47.0546', E60° 15.9007')

In this area, the vegetation community is characterized as a saline-sarsazan desert, with the projective cover of the plant community (PCLC) being 10 % (Table 4).

The next area, which was planted with saxaul between 2000 and 2002, was found to have a higher vegetation cover compared to other areas (Fig. 8).

Table 4

Projective cover level of vegetation in the eastern part of the dried Aral Sea bed (N43° 47.0546', E60° 15.9007')

Species	PCLC, %
Halocnemum strobilaceum (Pall.) M.Bieb.	5
Climacoptera lanata (Pall.) Botsch.	2
Caroxylon scleranthum (C.A.Mey.) Akhani & Roalson	2
Suaeda microsperma (C.A.Mey.) Fenzl	1
Calligonum sp.	+
Eremopyrum triticeum (Gaertn.) Nevski	+
Haloxylon ammodendron (C.A.Mey.) Bunge ex Fenzl	+
Atriplex fominii Iljin	+
Salsola paulsenii Litv.	+

Fig. 8. Distribution of vegetation in the eastern part of the dried Aral Sea bed (N43° 59.3149', E60° 16.6137')

In this area, the vegetation community is a mixture of Alhagi and saxaul-sarsazan-saxaul desert, with the projective cover of the plant community being 35 % (Table 5).

In the next area, Haloxylon species were also planted and maintained by the government between 2000 and 2002. After 22 years, the area has developed into a saxaul-dominated desert (Fig. 9).

Table 5

Projective cover level of vegetation in the eastern part of the dried Aral Sea bed (N43° 59.3149', E60° 16.6137')

Species	PCLC, %
Haloxylon ammodendron (C.A.Mey.) Bunge ex Fenzl	20
Halocnemum strobilaceum (Pall.) M.Bieb.	10
Halostachys caspica (M.Bieb.) C.A.Mey.	5
Tamarix ramosissima Ledeb.	1

Fig. 9. Distribution of vegetation in the eastern part of the dried Aral Sea bed (N43° 67.4337', E60° 17.1723')

In this planted area, the vegetation community is characterized as a *Haloxylon* desert, with the projective cover of the plant community (PCLC) being 55 % (Table 6).

Table 6

Projective cover level of vegetation in the eastern part of the dried Aral Sea bed (N43° 67.4337', E60° 17.1723')

Species	PCLC, %
Haloxylon persicum Bunge	55
Tamarix ramosissima Ledeb.	+

Conclusion

As a result of the desiccation of the Aral Sea, sand dunes have formed in its place, and various plant species have been observed to grow in these areas. Over time, changes in soil salinity, fluctuations in groundwater levels, as well as variations in temperature and precipitation, have resulted in shifts in plant species and their projective cover levels. The projective cover level of vegetation on the dried seabed of the Aral Sea has undergone significant changes. From 1981 to 2024, the projective cover level increased by 31 %, reaching 55 %. Currently, dominant plant species such as *Haloxylon ammodendron* (C. A. Mey.) Bunge ex Fenzl, *Halostachys caspica* (M. Bieb.) C. A. Mey., *Halocnemum strobilaceum* (Pall.) M. Bieb., *Haloxylon persicum* Bunge, and *Caroxylon nitrarium* (Pall.) Akhani & Roalson are widespread. Additionally, human activity has played a significant role in the changes in the vegetation. Various funds and international organizations, along with the Government of Uzbekistan, plant salt- and droughtresistant species every year across thousands of hectares of land, creating green areas and contributing to the changes in the vegetation. It is important to note that in areas where saxaul forests have grown, the rise in groundwater levels must be prevented. The groundwater table should be maintained at a critical depth of 2.5–3 meters; otherwise, the saxaul forests, which have been growing for the past 20 years, may be destroyed due to the rise in groundwater levels.

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