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Current state of vegetation of the dried bottom of the Aral Sea

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Abstract. The rate of regression of the coastal line of Aral Sea has been revealed for the period from 1965 to 2019 with 5-year intervals. The primary communities and their succession determined by the landform, lithology, depth and salinity of groundwater have been studied. According to the TSAVI index, the dried bottom of the Aral Sea is classified as follows: the water surface, swamps, salt marshes, puffed solonchaks, areas suitable for vegetation, areas with very low, low, medium, high and very high aboveground biomass territories. The correlation between the shrinking of the sea and the formation of vegetation with very low, low, medium and high biomass territories are revealed. A map of the vegetation of the western part of dried bottom of the Aral Sea has been created with 27 plant communities belonging to 4 types of vegetation. Six salt-tolerant species perspective for the fixation of shifting sands of dried bottom of the Aral Sea were selected from the native flora. A high tolerance to sand deflation was revealed in *Salsola richterii* and *Calligonum caput-medusae*.

1. Introduction

The Aral Problem is a complex issue that covers a wide range of questions. As a result of the extensive irrigation, one of the largest inland seas in the world has been desiccating constantly since the 1960s. The desiccation of the Aral Sea led to the disastrous changes of the entire environmental and socio-economic situation of the Aral region. Over the last 50 years, the water volume was reduced by more than 90% and the sea surface area shrank more than 80%, the salinity of water of the the southern part of the former Aral Sea was increased by more than 1000% [1, 2]. At the end of 2009, the level of the Aral Sea has decreased by more than 26 m, and water salinity has reached more than 200 g/l [3]. As a result of the desiccation of the Aral Sea, the area of the Kysylkum Desert has increased by 4 mln. hectares. The Aral Sea was divided into several parts and has ceased to exist as a single water body.

The study of dynamics of the vegetation and landscapes is a part of environmental monitoring in the Aral Region. This research requires the creation of a network of permanent monitoring plots and profiles. Vegetation is one of the most sensitive indicators of environmental changes. Regular field botanical surveys combined with the analysis of up-to-date satellite imagery can be a good basis for monitoring of the natural ecosystems.

Different specialists [4-15] mapped the vegetation and landscapes of the dried bottom of the Aral Sea and studied processes of their formation and succession. The mapping of vegetation was carried out mainly in the northern part of the dried bottom of the Aral Sea and in certain sites on the south.

Z.B. Novitsky (1997) [16], as a result of long-term research, identified and mapped 18 groups of plant associations on the dried bottom of the Aral Sea (in accordance with dominant species). He found that the largest area cover lands without vegetation and Tamarix, Haloxylon, Salicornia-Suaeda and Atriplex-Salsola communities (31.7%).

Sh. Kamalov et al. (2001) [17] studied the vegetation of the dried bottom of Rybachie bay of the Aral Sea and created a large-scale map. On the territory of 162,000 hectares, authors distinguished 43 associations belonging to 11 formations and 4 types of vegetation.

W. Wucherer and Z.V. Breckle (2003) [10] described following 4 stages of primary succession in the south-eastern shore of Aral Sea: a stage of the annual halo-psammophytes, or *Atriplex fominii*-stage; *Haloxylon aphyllum* and *Nitraria schoberi*-stage on littoral saline areas with superficial sandy cover; stage of grasses (*Stipagrostis pennata*); stage of psammophilous shrubs. On sandy areas, the authors distinguished 3 stages of succession – a stage of the annual halo-psammophytes, stage of grasses and stage of psammophilous shrubs. Discussing the mechanisms of succession, the authors stated that the stages of succession can be different and have a stochastic character. However, intensification of aeolian processes and increasing of the relief-forming role of plants determine the dynamics of ecosystems in the later stages of succession.

At the same time with the mapping of vegetation, studies devoted on the fixation of the moving sands were conducted on the drained bottom of the Aral Sea. The processes of the soil blowing and the carryover of salts, formation of moving sands depend on the level of substrate fixing. The phyto-reclamation in the Aral Sea region, especially in the sandy areas, takyr and residue saline marshlands in the former seabed, is extremely important. For creation of artificial phytocenoses in the dried bottom of Aral Sea, native drought- and salt resistant species, well adapted to the local soil-climatic conditions, should be used. Many projects have been devoted to the fixation of moving sands formed on the dried bed of the Aral Sea [6, 16, 17]. The authors studied issues of the creation of protective forest stands and phyto-reclamation of saline marshlands on the bottom of the Aral Sea. The introduction of halophytes into culture and creation of plantations of these plants in saline lands can provide an additional source of fodder, oil-bearing and medicinal plants.

Our research was focused on the analysis of the rate of regression of the coastal line and on the study of the succession of vegetation in the western part of Aral Sea (Uzbek part). We also mapped the vegetation along several profiles and selected some perspective phytomeliorants for fixing the moving sands on the drained bottom of the Aral Sea.

2. Materials and methods

In the past, the Aral Sea was a huge closed saline lake lying in the Central Asia, and the fourth largest inland water body in the world (figure 1). Its volume, size, and quality of water are depended critically on the flow of two major rivers, the Amudarya (2,600 km in length and draining 692,300 km^2), and the Syrdarya (2,212 km in length and draining 493,000 km^2). Like other drainless water bodies, the surface and volume of the Aral Sea is determined by the balance between the inflow of water and evaporation [2].

As a result the Aral Sea water balance was disrupted and irreversible alterations in the sea regime appeared that later escalated into one of the "largest ecological disasters of the twentieth century". During the last 50 years we have observed a progressive degradation of the Aral Sea and its environment. During this time period the sea shrunk in size from 66,100 km^2 (in 1961) to 10,400 km^2 (in 2008), its volume decreased from 1,066 to 110 km^3, the sea level dropped by 24 m, and its salinity (mineralization) rose from 10 to 116 ppt and about 160 ppt in the western and eastern Large Aral Sea, respectively. The decrease in area of the Large Sea occurred mainly through its shallow eastern part, the area of which in 2008 (3,200 km^2) became for the first time less than that of the western part (4,000 km^2) (figure 1) [18].

The climate of the Aral region is moderate and strong continental with great amplitudes of seasonal and daily fluctuations of air temperature and precipitation. The region has a flat terrain and therefore it is opened to the intrusion of cold air from the north and northeast through Western Siberia. The region is located in the ''heart'' of Eurasia, quite far from the oceans and this factor results in the lower concentration of water vapor in the atmosphere and, consequently, less precipitation. Because of the aridity of the climate the prevailing landscape forms around the Aral are semideserts and deserts [19].

In the formation of the Aral region climate the radiation factor plays a key role. This refers especially to the warm period when, thanks to clear weather, the incoming solar radiation flux is so strong, that the other important climate-forming factor – atmospheric circulation – makes only a minor contribution. The annual duration of sunshine here is as high as 3,000 h, which is 65-70% of that possible. This factor in the Aral region is greater than in the Mediterranean and California which are located on the same latitude [18].

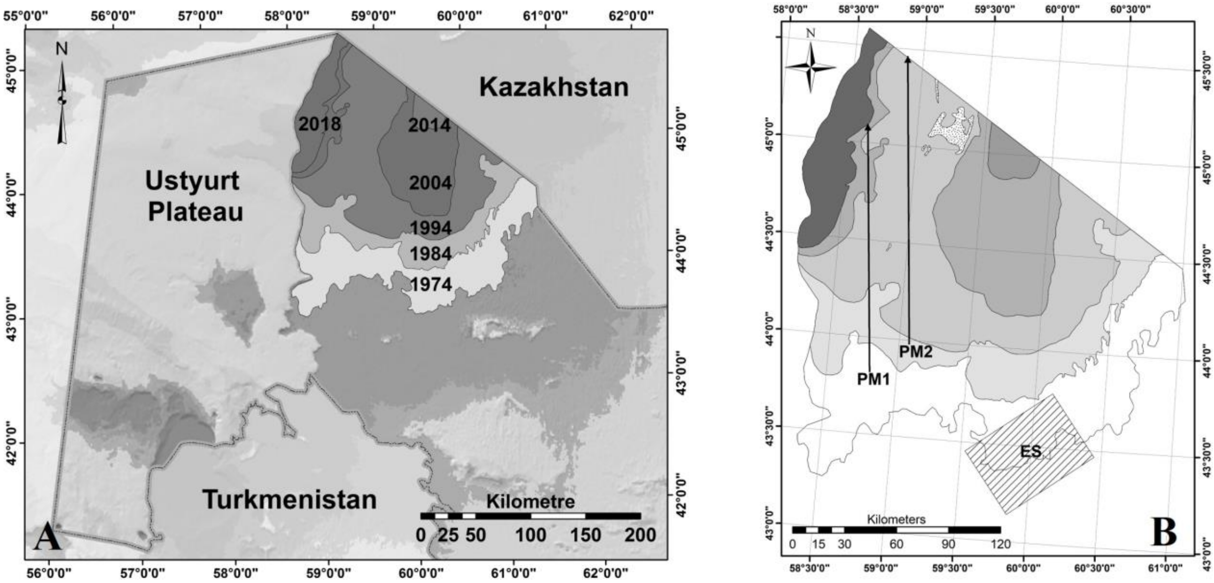

Figure 1. Study area: A – The Uzbek part of the Aral region; B – Location profiles PM1, PM2 and field experiments site (ES).

The rise of the air mean daily temperature above 0°C occurs in the late decade of March over the whole Aral Sea coast. In the north the return of negative temperatures is marked in the first decade of November, in the south in the first decade of December. In spring the rise of the air daily temperature above 5°C occurs everywhere in late March–early April. In autumn this temperature barrier (5°C) is overcome in late September in the northern part of the sea and in the second decade of December on the southern coast. The frost-free period lasts 220 days in the north and 260 days in the south of the Aral Sea coast. Thanks to high values of the radiation balance and the slightly cloudy weather, the cold air becomes heated rather quickly. This time the spatial contrasts of the temperature over the sea are smoothed and its mean monthly values are equal to 26-28°C over the whole seashore. In autumn the weather in the Aral region may remain warm for rather a long time period due to prevailing anticyclonic processes. Quite often the winter comes very quickly and this is accompanied by a sharp temperature drop. The mean annual air temperature is positive varying from +7°C in the north to +10° C in the south of the Aral Sea [18].

The Aral Sea coast is characterized by very scanty atmospheric precipitation. The Atlantic air masses, being the main humidifying factor, become desiccated while moving inside the continent or they fail to reach the Aral Sea at all. The cold season is rather dry. During this time the intrusion of cold and dry Arctic air masses or the air masses formed over the continent prevails. In summer the condensation level in the heated air is so high that convectional precipitation is not formed. Atmospheric fronts are the main reason for precipitation in this region. In this context the characteristics of monthly sums of various probability become very important. The annual precipitation in the Aral region reaches 90-120 mm. Over the Aral Sea basin as well as in the middle and upper streams of the Amudarya and Syrdarya rivers the precipitation tends to increase to 150-200 mm per year and more in mountainous regions [18].

The Uzbek part of the Aral region is bounded by the Ustyurt plateau in the west, the national border of the Republic of Kazakhstan in the north, the Kyzylkum Desert in the east, and the border of the Republic of Turkmenistan in the south.

The site selected for field experiments is situated to the east of the settlement Kazakhdarya (55-60 km) beyond Lake Zhiltirbas, on the bed of the former bay Zhiltirbas of the Aral Sea (the Aralkum desert), in Muynak district of the Republic of Karakalpakstan. The territory is a plain with a general inclination from the south to the north. This open territory is covered with sands, silt and clayey marine sediments. These sediments are currently overlaid aeolian marine sands formed under the effect of north-eastern winds.

The climate is continental arid with a wide range of seasonal and daily temperatures, low precipitation (11 mm) per year and a significant dryness in summer. Winters (December-February) are moderately soft, with little snow. The air temperature is -2-5ºC in the day time and -7-13ºC at night (the lowest temperature was recorded at -34ºC). The total number of days with snow is below 30 per season. In spring (March-April), the air temperature is 7-16ºC in the daytime and 3-9ºC at night. Precipitations consist of short pouring rain. The weather is unstable and warm days may be replaced by cold ones. The summer (May-September) is dry and hot. There are no precipitations from July to September. The air temperature is 25-30ºC in the daytime (maximum 43-45ºC); 12-18ºC at night. Autumn (October-November) is dry, mainly with clear weather. The temperature in the daytime is 7-16ºC; +4-3ºC at night. Eastern and north-eastern winds prevail during the year; their velocity usually reaches 3-5 m/s [20].

The map of the vegetation of the dried bottom of the Aral Sea has been created using the data of the traditional geobotanical field survey and remote sensing techniques. Descriptions of plant communities have been performed on the sample plots of 100 m^2 with the standard method used in CIS countries [21, 22]. The vegetation mapping process was organized in three stages, in accordance with the standard procedure: initial analysis of satellite data and compilation of draft map, field research, and compilation of final map based on the precise field data [23].

Two profiles (or transects) designated as PM1 and PM2 have been laid in the western pard of the dried bottom of the Aral Sea from the Tiger Tail Cape to the current shore line for the study of succession (figure 1).

For the analysis of the long-term dynamics of vegetation indexes, we used satellite images from Landsat 4, 5, 7 and 8 taken in July of 1970–2019 (earthexplorer.usgs.gov). Transformed Soil-Adjusted Vegetation Index (TSAVI) has been calculated:

$$TSAVI= (s*(NIR - s*RED - a)/(a*NIR+RED - a*s+X (1+s^2))$$

where NIR – pixel values from the near-infrared band, RED – pixel values from the red band, s the soil line slope (0,08), a – the soil line intercept, X – an adjustment coefficient that is set to minimize soil noise [24].

Classification of satellite images has been performed using ArcGIS 10.5 and SAGA 7.3 software. Statistical analyses were done using the program PAST ver. 3.2.

The following native species were selected for the moving sand fixing experiment: *Nitraria schoberii* L., *Salsola richteri* (Moq.) Kar. ex Litv., *Krascheninnikovia ewersmanniana* (Stschegl. ex Losinks.) Grubov, *Artemisia ferganensis* Krasch., *Calligonium caput-medusae* Schrenk. Seeds of these plants have been collected from the natural populations in the Kyzylkum Desert. Seedlings of these species for further transplantation to the experimental site were grown in plastic containers with sand in the greenhouse of the Tashkent Botanical Garden.

3. Results

As a result of the field survey and the interpretation of satellite images, following ecotopes have been identified along the profile PM1: massifs of hilly sands on the saline depressions along the indigenous shores, saline wavy-hilly sands, saline hilly aeolian sands, barkhan dunes (crescent-shaped dunes), crusted solonchaks, puffed solonchaks, exposed relict bedrock hills, flattened wet saline sandy coastal banks along the seashore, areas flooded with waste water. The largest area in the northern part of the profile is occupied by the crusted and puffed solonchaks with solitary individuals of *Atriplex fominii, Bassia hyssopifolia, Climacoptera aralensis, Suaeda crassifolia*. *Tamarix hispida, Eremosparton aphyllum, Phragmites australis* occur only on aeolian sandy hills.

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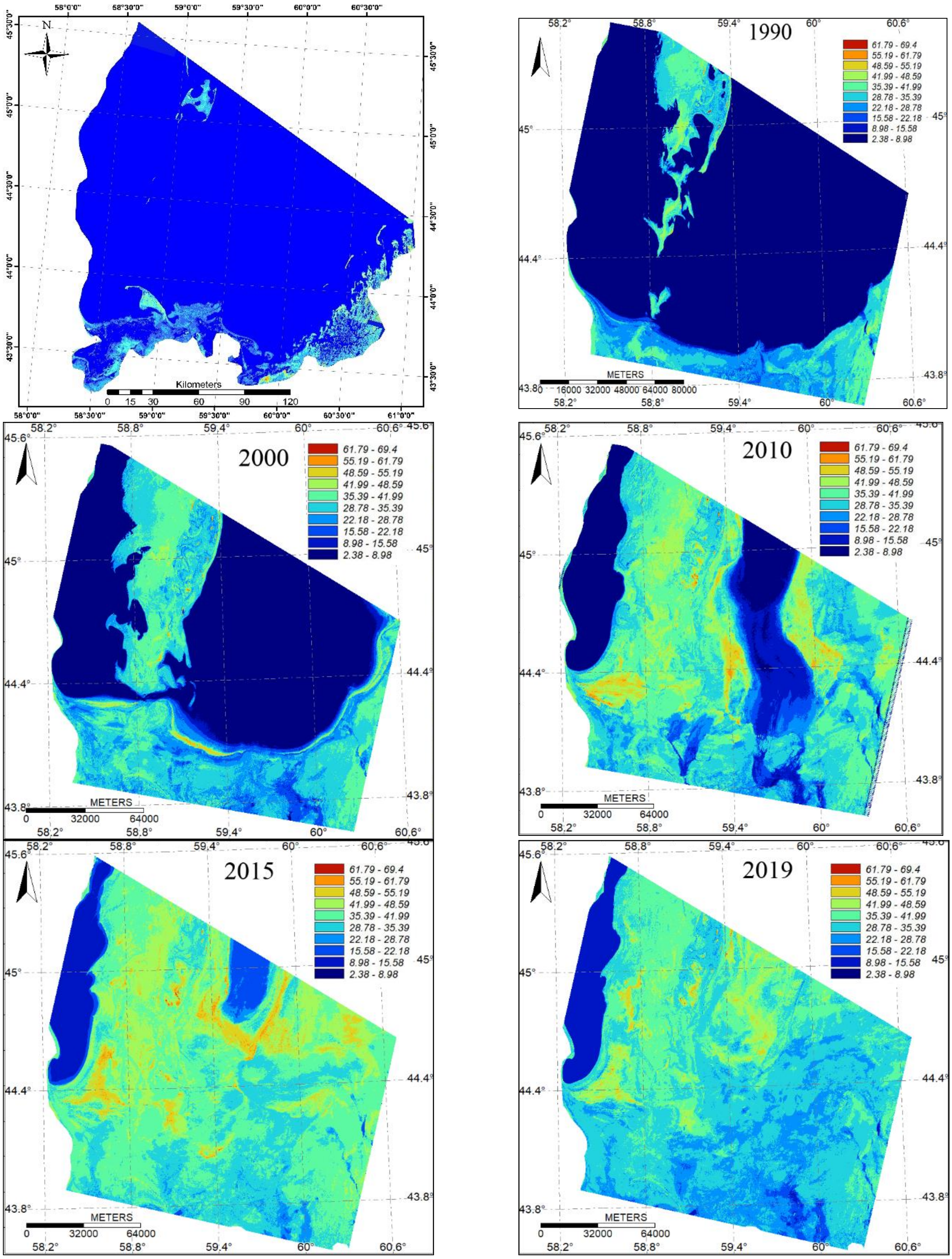

Figure 2. The dynamics of the formation of plant biomass on the dried bottom of the Aral Sea (1970-2019). Top left: the state of the Aral Sea in 1970-1973. Degree of classification of the scale (from dark blue to red): 1 – water surface; 2 – swamps; 3 – salt marshes; 4 – puffed solonchaks; 5 – areas suitable for vegetation; 6 – areas with very low biomass; 7 – areas with low biomass; 8 – areas with medium biomass; 9 – areas with high biomass; 10 – areas with very high biomass.

Analyzing the primary succession process of 1990-2019, we calculated TSAVI index and recognized following 10 classes which distinguish by spectral features: the water surface (1), swamps (2), salt marshes (3), puffed solonchaks (4), areas suitable for vegetation (5), areas with very low (6), low (7), medium (8), high (9) and very high aboveground biomass (10) (figure 2). The areas with different biomass density and their temporal dynamics are summarized in Table 1.

Table 1. Areas with with different biomass density on the dried bottom of the Aral Sea (thousand hectares).

Years	Areas suitable for vegetation	Areas with very low biomass	Areas with low biomass	Areas with medium biomass	Areas with high biomass	Areas with very high biomass
1990	369477	234398	22322	1398	341	257
2000	822301	517026	48642	10687	1506	173
2010	1005706	1119994	433832	102307	7751	413
2015	1115867	1699999	773850	188361	15162	459
2019	1747504	1009852	256314	35309	1925	560

Along the profile PM2, we identified 8 ecotopes. The difference from the first transect is that the barkhan dunes and bedrock hills are absent, but there is 4–5 km wide strip of swamps along the seashore. Large areas along the indigenous shores are covered with forest plantations. Plantations of *Haloxylon aphyllum, Salsola richteri, Calligonium caput-medusae* occupy 530 hectares on the left side of the profile PM2, and 4200 hectares on the right side are covered with plantations of these species created in 2003. These areas were plowed and the coastline was broken, the natural process of development of all components of the biotope and the course of vegetation succession were disrupted here.

Using the satellite imagery, we evaluated the rate of regression of the coastal line of Aral Sea along the profiles PM1 and PM2 from 1965 to the present time with 5-year intervals. In 1965-2005, the coastline retreated along the profile PM1 at a rate of 2.5 to 20 km. Maximum rates of 4-5 km per year were observed in 1980-1985.

Along both profiles, 66 species of vascular plants from 12 families and 42 genera have been recorded. Among them prevail *Chenopodiaceae* (20 species), *Poaceae* (9), *Asteraceae* (7), *Polygonaceae* and *Fabaceae* (by 5 species). The remaining families are represented by less than 5 species. In the flora of study area, 26 species are perennials, 21 are shrubs, and 19 – annuals.

4. Discussion

4.1. The dynamics of the formation of plant biomass on the dried bottom of the Aral Sea

According to the data of Dimeeva (2015) [15], the desiccation of the Aral Sea is accompanied by the restructurisation of all ecosystems and the formation of vegetation (table 1, figure 3). The main trend is continuous increase of the areas suitable for vegetation. At the present, these areas occupy about 1,800,000 thousand hectares.

We revealed the correlation between the shrinking of the sea and the formation of vegetation with very low (*k=0.9*), low (*0.8*), medium (*0.7*) and high (*0.6*) biomass. The *k* index is high for swamps (*0.9*) and low for the areas with very high biomass (*0.2*). This indicates that in recent years the retreat of the Aral Sea coastline has slowed down and the formation of woody vegetation is gradually progressing. The main areas with very high biomass are located in sand massifs covered with psammophilous vegetation with the domination of *Haloxylon aphyllum, Calligonum caput-medusa, C. junceum, C. eriopodum, Salsola richteri,* etc.

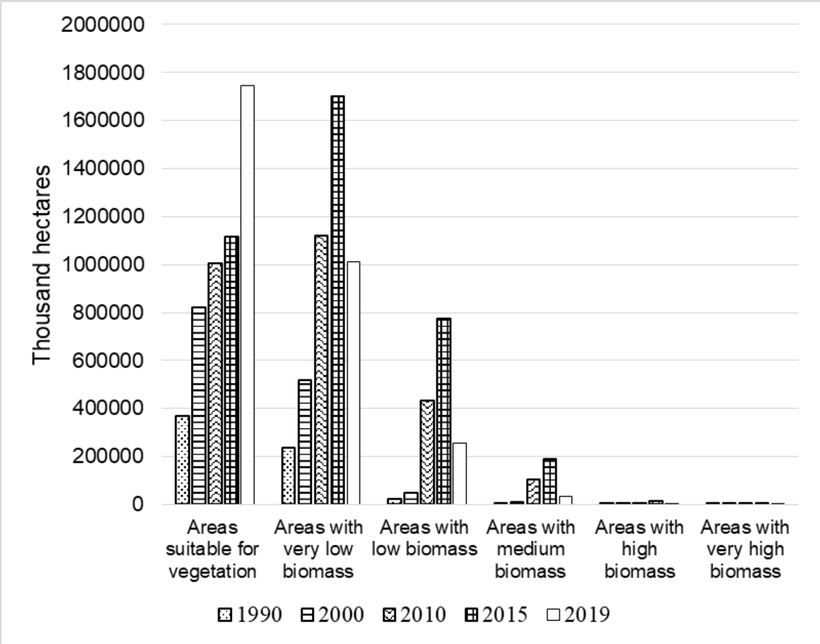

Figure 3. Change in areas of different biomass containing territories of the dried bottom of the Aral Sea on the period of 1990-2019.

4.2. Mapping of vegetation of the dried bottom of the Aral Sea

The Aral Crisis induced succession of the vegetation of the Aral region. Shrinking of the sea was accompanied by autogenous succession on the dried bottom directed to the formation of climax vegetation [25-28, 11, 15]. Vegetation changes run in three directions (psammoseries, haloseries and potamoseries) with different environmental conditions, dynamics, species diversity and succession stages [15].

During the first years, the exposed bottom of the sea is a lifeless wet rugged plain covered with crust of salt with shells of dead mollusks and the remains of algae. According to our observations, the continuous growth of annual halophytes (*Atriplex fominii, Salsola paulsenii, Bassia hyssopifolia*) do not always form on the dried bottom of the sea, as is shown in some sources [17]. Usually, communities of annual saltworts are developed in small contours separated by salt marshes without any vegetation. Probably, annual communities die through a sharp increase in salinization of sea water and soils. This very negatively affects the overall environment, leading to activation of wind deflation of unfixed bottom sands and sandy loams [19, 29].

It should be noted that sands and solonchaks without vegetation dominate in the areas dried in 1980-2019, sometimes with sparse *Tamarix hispida* and *T. ramosissima*. On the areas dried in 1970-80, there occur saltwort-shrub vegetation with significantly more dense cover: saltwort-Tamarix communities with reed (*Tamarix hispida, T. ramosissima, Halostachys belangeriana, Atriplex fominii, Bassia hyssopifolia, Phragmites australis*); reed communities with saltworts and Tamarix on mounds, and with bared plantless spots (*Phragmites australis, Bassia hyssopifolia, Climacoptera aralensis, Tamarix hispida, T. ramosissima*); saltwort communities on saline micro-depressions, sometimes with sparse psammophilous shrubs on sandy hills (*Bassia hyssopifolia, Atriplex fominii, Climacoptera aralensis, C. olgae, Haloxylon aphyllum, Salsola richteri*).

On the part of sea bed dried in 1960-1970, a relatively stable vegetation cover with the domination of *Haloxylon aphyllum* and species of *Tamarix* has already formed. The rate of regression of the coastal line along profile PM2 in that period was 7.5 km. Apart from saltwort-Tamarix vegetation, the following communities were observed here: *Haloxylon aphyllum* + *Salsola richteri* (*Haloxylon aphyllum, Salsola richteri, Tamarix hispida, Peganum harmala, Alhagi pseudalhagi, Phragmites australis*); *Phragmites australis* + annual halophytes (*Bassia hyssopifolia, Climacoptera aralensis, C. crassa, Atriplex fominii, Phragmites australis, Tamarix hispida, Haloxylon aphyllum*), plantations of

Haloxylon aphyllum. In some areas, there are sands, solonchaks and takyrs without vegetation.

During the last 45 years, the coastal line along profile PM2 has retreated on 65 km. On the initial stage of sea shrinking (1960-1965) the regression of the coastal line along profile PM2 near the Muynak Peninsula was 5 km. Maximal rate of regression (20 km) has been observed in 1980-1985.

Large areas dried in 1990-2005 were covered by puffed solonchaks and sometimes with aeolian sands almost without vegetation. Solitary specimens of *Bassia hyssopifolia, Climacoptera aralensis, C. crassa, Suaeda crassifolia, Atriplex fominii* and *Halostachys belangeriana* can be found sporadically on the solonchaks, *Phragmites australis, Tamarix hispida, T. ramosissima* and sometimes *Eremosparton aphyllum* – on the sands.

On the areas dried in 1970-2019, apart of above mentioned vegetation, communities of annual halophytes grow in saline micro-depressions, sometimes on the sandy hills with sparse *Haloxylon aphyllum* and *Salsola richteri* (*Bassia hyssopifolia, Atriplex fominii, Climacoptera aralensis, C. olgae, Phragmites australis, Tamarix hispida, T. ramosissima, Haloxylon aphyllum, Salsola richteri*). Territories dried in 1960–1970 well fixed by perennial plants and shrubs, but plantless plots of solonchaks, sands and takyrs can be found evet here. On the saline hilly sands have been recorded: *Haloxylon aphyllum+Salsola richteri* community (*Haloxylon aphyllum, Salsola richteri, Tamarix hispida, Peganum harmala, Alhagi pseudalhagi, Phragmites australis*), Phragmites australis community with *Tamarix hispida* (*Phragmites australis, Atriplex fominii, Tamarix hispida*), as well as *Typha angustifolia,* sparse marginal growth of *Karelinia caspia*. There are also plantations of *Haloxylon aphyllum, Salsola richteri* и *Calligonum aralense*.

According to the data of Kamalov et al. (2001) [17] and Shomurodov & Adilov (2019) [29], annual hyperhalophytes dominate on the initial stage of succession, and then perennials, subshrubs and shrubs replacing them. But the results of our study showed that representatives of different life forms can appear on the initial stages of the primary succession, depending on the landform, lithology and salinity of substrate. The shrub *Tamarix hispida* and perennial *Phragmites australis* are pioneer species on the bared sand hills of the northern part of the Muynak Peninsula; *Eremosparton aphyllum* is a pioneer on the aeolian sands; annual halophytes *Bassia hyssopifolia, Climacoptera aralensis* and *Atriplex fominii* appears on solonchacks on the initial stages of the primary succession.

A map of the vegetation of the western part of dried bottom of the Aral Sea with 27 plant communities belonging to 4 types of vegetation has been created on the basis of the research results.

4.3. Experiment on the fixation of shifting sands of dried bottom of the Aral Sea

It is not easy to create soil protecting cenoses on the dried bed of the Aral Sea because of constantly blowing north-eastern winds which impede the growing of plants through their sowing. In such areas the optimal method of soil is the planting of seedlings [30, 31]

On the experimental site, the seedlings were planted on sand dunes in rows perpendicular to the direction of winds. Tall plants were planted in the first rows, than subshrubs. The seedlings of *Krascheninnikovia eversmanniana* and *Artemisia ferganensis* were planted in depressions between dunes. After three months, the plants showed the following survival rate: *Salsola richterii* – 43.6%, *Calligonum caput-medusae* – 47.3%, *Nitraria schoberii* – 21.1%, *Krascheninnikovia eversmanniana* – 46.7%, and *Artemisia ferganensis* – 26.4%. The plants were developing normally and reached 35 cm in height (*Salsola richterii)*. The process of deflation and accumulation of 10-15 cm thick sandy layer was recorded in the experimental site fenced by 1.5 m high shield made of *Phragmites australis*. The process of deflation continued in summer-autumn.

The plants responded differently to the blowing of the sands. Young individuals of *Nitraria schoberii* and *Artemisia ferganensis* were little resistant to this process. In November all individuals *Nitraria schoberii* dried, and the survival rate of *Artemisia ferganensis* and *Krascheninnikovia eversmanniana* constituted 17.5% and 20.6%, respectively. Among the studied species, the most resistant species to deflation were *Calligonum caput-medusae* and *Salsola richterii,* whose acclimation rate was noted in the range 34.6-40.7%.

At the end of the first year of vegetation, the height of the above-ground part in separate *Salsola*

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richterii individuals reached 60-100 cm and formed 18-59 sprouts of the second order, which were 3-64 cm long.

At the end of the first year of vegetation the height of the above-ground part in separate individuals of *Salsola richterii* reaches 60-100 cm and forms 18-59 shoots of the second order reaching 3-64 cm. However, the length of the main shoot is below 30 cm. It is noteworthy that during the first year of vegetation individuals planted at the foot of a dune grow much better against the individuals planted at the top of the dune. In subsequent years no significant differences are noted in the growth and development. Fructification is recorded in well developed individuals at the end of the first year.

However, the survival rate of these young plants is low, ca. 20%. In the first year, the height of the newly grown plants was 15-20 cm, but at the end of the following year of vegetation it was 30-40 cm, and 3-4 shoots of the second order of vegetation were formed, which reached 4-18 cm in length. It is noteworthy that from the second year the death of the young plants was not recorded. The first year of the vegetation, the main sprout of *Calligonum caput-medusae* grows relatively slowly and by the end of vegetation the height ofthe above-ground is below 20-35 cm. the shoots of the first order grow orthotropously. The shoots of the second order are few (only 2-3). They in turn branch to the forth order reaching the length of 3-6 cm. In early April of the second year the buds start growing. By the end of the vegetation there are up to 14 shoots of the second order on one plant. The length of the shoot of the second order formed on the basal part of the main sprout is relatively shorter in comparison with subsequent shoots. The number of shoots of further orders is higher in shoots formed in the mid-part of the main sprout in comparison with the bottom and top parts of the plants. At the end of the second year of vegetation, the above-ground of кандыма reaches 40-60 cm, while at the end of the fourth year, 130 cm.

No vegetating *Artemisia ferganensis* planted on the top of a dune were recorded due to the deflation of sands. The root remaining open could not sustain frosts; therefore, the plants died. However, individuals planted in depressions between dunes survived without any losses. No dry individuals were recorded despite being buried under sands. All the individuals of *Artemisia ferganensis* planted in sands between the dunes pass the generative stage at the height of 50-80 cm. Under conditions of adyr hills in the Ferghana Valley, the vegetative shoots of *Artemisia ferganensis* can be both short and long, whereas no long vegetative shoots were recorded under conditions of the exposed bed of the Aral Sea. During the generative period the plants have shoots of two types:

During the generative period, the plants have shoots of two types, generative and short vegetative (brachyblasts). On most individuals, the leaves of the spring generation are preserved to the end of vegetation. In the third year, as many as 309 shoots of the second order, which were 7-42 cm in length, were formed in one plant.

A similar survivability under conditions of wind blowing and accumulation of sands was recorded in *Krascheninnikovia eversmanniana.* A year later after the plantation, all individuals planted from the windward side of the dune dried, whereas no dry plants were recorded in the site between the dunes. Under conditions of the exposed bed of the Aral Sea the height of the plants was below 30 cm at the end of the first year. They did not enter the generative period. In the second year of vegetation in October, the length of the shoots reached 43 cm, while the length of the shoots of the second order (up to nine) reached 5-17 cm. All the plants were fruit-bearing.

In the foothills, some individuals begin to flower in the first year of vegetation in culture, while in natural conditions the fruit-bearing is recorded in 5-10 year of vegetation. It is differentiated three types of shoots in generative period of ontogeny: short vegetative, growing vegetative and non-specialized generative shoots which were observed in our experiments, too. Generative shoots are those of the first and subsequent orders [32].

5. Conclusion

Ecotopic selection is the main mechanism of the primary succession of vegetation on the dried bottom of the Aral Sea. The landform, lithology, depth and salinity of groundwater, and the rate of regression of the coastal line are very important factors in this process.

Despite the opinion published in literatute that annual saltworts are pioneers on the dried bottom of the Aral Sea, the results of our study showed that the vegetation on the initial stages of the primary succession can be very different, depending on the above-mentioned factors. For example, *Tamarix hispida* and *Phragmites australis* appears on the bared sand hills of first stage of syngenesis, and *Eremosparton aphyllum* is a pioneer on the aeolian sand dunes.

The map of vegetation of the the western part of dried bottom of the Aral Sea with 27 plant communities belonging to 4 types of vegetation shows the considerable heterogeneity of phytocenoses. Despite the high phytocenotic diversity, the flora is poor, which can be explained by extreme conditions. The checklist of vascular plants includes only 62 species. The vegetation map compiled as a result of our study and the data of landscape profiles should be used as the basis for future monitoring of ecosystem dynamics. Also, the obtained information will help for identification of areas requiring protection and for planning of phyto-reclamation, including sand fixing on the southern part of the dried bottom of the Aral Sea. Based on field experiments, we revealed the most promising species for stabilization of quick sands on the exposed Aral Sea bed. These are *Salsola richterii, Calligonum caput-medusae, Krascheninnikovia eversmanniana,* and *Artemisia ferganensis,* all which re notable for their high rates of survivability, growth and development. *Krascheninnikovia eversmanniana* and *Artemisia ferganensis* were found not to be resistant to deflation process, but sustain sand burying in depressions between dunes, which is manifested in the absence of dry individuals and passing to the generative phase of development since the second year of vegetation.

A high tolerance to sand deflation was revealed in *Salsola richterii* and *Calligonum caput-medusae*. Their survival rate on sandy dunes constitutes 17.1-40.7%. A survival rate, formation of big biomass of plants reaching 300 cm in the fourth year of life and breeding through self-seeding (*Salsola richterii*) suggests that this is a promising species for the fixation of drifting dunes on the exposed bed of the Aral Sea.

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