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Natural and Anthropogenic Dynamics of Vegetation in the Aral Sea Coast

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Abstract: Natural dynamics (primary successions) is studied in the dry seabed of the Aral Sea. Long-term studies of vegetation have identified three types of primary successions: psammosere, halosere and potamosere (sere of shrubby riparian vegetation). They differ by soil texture and salinity, patterns of temporal dynamics, and stages, selected on a basis of ecological-physiognomic features of dominant plants. Late seral stages were identified for succession types: psammophytic shrub (*Calligonum* spp, *Astragalus brachypus*, etc.) for psammosere; haloxerophytic and xerophytic dwarf semishrubs (*Anabasis salsa, Artemisia pauciflora, A. terrae-albae*) for halosere. There is a change of a dominant plant and succession dynamics in late seral stages in potamosere (*Tamarix* spp. → *Calligonum* spp, *Haloxylon aphyllum*, *Artemisia terrae-albae*). Anthropogenic dynamics of vegetation (secondary successions) depends on factors of disturbance. There is a set of anthropogenic factors causing degradation of vegetation cover: (1) agricultural: overgrazing, haymaking, plowing, clearing trees and shrubs; (2) linear structures (paved and dirt roads); (3) water management: construction and operation of hydraulic structures, fluctuation in river runoff and the sea level, disturbance in the natural flooding regime; (4) fires; (5) recreations. The leading factors in the region are connected with water management and irrigation. To identify the dynamics of plant communities and potential degradation trends, there are series of shifts (successional series): hydro-, xero-, halo-, psammo- seres characterizing moisture content and edaphic environments. Changes in the hydrologic regime of the Syrdarya river, building of the hydraulic structures lead to reduction of hydromorphic vegetation and a change it into halophytic desert. The construction of the Kokaral dam and restoration of the Small Aral Sea has led to the rehabilitation of wetlands and plant diversity. Hydrogenous succession facilitated a gradual recovery of populations of rare species listed in the Red Data Book of Kazakhstan, IUCN, Europe (*Scirpus kasachstanicus, Nymphoides peltatum, Salvinia natans, Typha minima*).

Keywords: Aral Sea, Primary, Secondary Successions

1. Introduction

Vegetation dynamics is the gradual directional irreversible changes caused by both internal and external factors [1; 2]. V. Sukachev [3; 4] distinguished the following types of successions in natural vegetation dynamics: syngenetic, endoecogenic, exogenic.

Autogenic successions caused by internal factors, allogeneic ones are related to external causes. Division successions on the primary and secondary was first introduced by F. Clements [5]. Primary succession is the establishment of plants on land that has not been previously vegetated. Secondary succession is the invasion of a habitat by plants on land that was previously vegetated, but destroyed by natural or human disturbances [6]. Primary and secondary successions refer to autogenic [2; 7]. They are controlled by four basic models [8; 9]: facilitation, tolerance, inhibition, and neutrality.

Anthropogenic successions are a special case of allogeneic (exogenic). After termination of the external factor allogenic succession is replaced by autogenic restoring. Classification of anthropogenic successions is based on the agents that cause them: technogenic, fire, irrigation, recreation, etc.

The desiccation of the Aral Sea has started in the early 60s of the last century. Primary succession covers a territory of 60,000 square kilometers. About 70% of the desiccated area are represented by salt desert. Long-term study has demonstrated that the primary succession rate is rather slow, especially within the dry seafloor of 2000s. Vegetation change sequence, trend of plant colonization and probable final stages depend on the sea sediments (substratum). The dry seabed (Aralkum) is a natural laboratory for studying the process of climate aridization, desertification, formation of primary plant communities and ecosystems. The remoteness from populated areas, inaccessibility to transport, and unsuitability for grazing to a minimum reduced anthropogenic impact. Therefore, the primary succession of the Aral coast can be seen as a classic example of autogenic ecological succession of the coastal plains in the time of marine regressions started from pioneer plants of the initial stage to the late seral plant communities.

The flora of the Aral Sea coast (in the limits of Kazakhstan) comprises 414 vascular plant species of 192 genera and 43 families. There are 24 (5.8%) endemics of Kazakhstan in the species list [10]. The dry seabed has been colonized by 344 species (83%) [11], among them are 19 endemics. The flora of the wetlands of the Syrdarya river delta front and the surrounding area consists of 112 vascular plant species of 82 genera and 35 families [12]. Four plant species are listed in Red Data Book of Kazakhstan [13]: *Nymphoides peltatum* (S.G.Gmel) O. Kuntze, *Atriplex pratovii* Suchor., *Scirpus kasachstanicus* Dobroch., *Tulipa borszczowii* Regel. In the flora of the wetlands are found European threatened species [14]: *Salvinia natans* (L.) All., *Typha minima* Funck.

2. Study Area & Methods

Study on natural dynamics was carried out in the dry seabed and the ancient marine terraces of the Aral Sea. Anthropogenic dynamics was studied in the Syrdarya river delta.

Traditional methods of field geobotany [15; 16] were used for identifying patterns of natural and anthropogenic vegetation dynamics, including: landscape and environmental profiling; geobotanical description of main plant communities. Collection of herbarium specimens was conducted simultaneously with the study of vegetation cover in all habitats. The Vegetation Description Form was used to record vegetative and environmental characteristics of the 100 (200 sq. m) sample plots. The form included the following information: GPS coordinates, elevation, topography, soil type, percent cover, species list, degree and type of disturbance, etc.

The study of plant successions is based on direct and indirect methods [17]. To study anthropogenic vegetation dynamics method of anthropo-dynamic series (transects) [18] was used. The spatial position of plant communities and their successional status is determined by a distance from the source of disturbance and the impact intensity [19]. The assessment of the degree of anthropogenic transformation is determined according to the criteria of vegetation disturbance: species composition, dominant of plant community, projective coverage, abundance, productivity, vitality, habitus, status of litter, presence of indicators of transformation, coverage of biological crust [20-23]. To identify the degree of disturbance is necessary to know the characteristics of undisturbed plant communities. Condition of a soil cover is also taking into account.

3. Results & Discussions

First investigations on the formation of vegetation cover in the dry seabed of the Aral Sea in Kazakhstan were started in the late 1970s the last century, when the sea level desiccation has become a disaster [24; 25]. In that time were already identified the main types of vegetation (Halophyta, Psammophyta, Potamophyta) and schemes of anticipated changes depending on different factors [26]. The initial stages of primary succession (syngenesis, *sensu* Sukachev[27]) have been described in detail by Kurochkina and Wucherer [28; 29]. Physiological aspects of primary successions were investigated by Pankratova [30; 31]; the dynamics of aboveground productivity of plant communities along spatial and temporal gradient – by Dimeyeva [32]. Psammophytic succession of the south-eastern coast of the Aral Sea was described in detail by Wucherer and Breckle [33]. Causes influencing primary successions such as time, exogenic factors, and plant sources were revealed [34].

Three types of primary successions: psammosere, halosere and potamosere (sere of shrubby riparian vegetation) have identified and described in 2007 [35; 36]. They differ by soil texture and salinity, patterns of temporal dynamics, indices of plant diversity and stages, selected on a basis of ecological-physiognomic features of dominant plants. Assessment of distribution and structure of vegetation in the Aral Sea ancient marine terraces helped to identify the late seral and sub-climax stages [37]. The age of the ancient marine terraces is over 3000 years [38].

The sandy belt encircles the whole Aral Seashore. At first stages of the sea regression, plant colonization all over the coastline was by psammosere.

Currently on coastal sands have been formed psammophyitic shrub vegetation (*Calligonum* spp, *Astragalus brachypus, Eremosparton aphyllum, Atraphaxis spinosa*), often with the participation of desert tree *Haloxylon aphyllum*.

Five stages of succession have been found for the psammosere:

(1) Stage of annual halomesophytes and halomesoxerophytes (*Salicornia europaea, Suaeda crassifolia, S. acuminata*) on marshy solonchak soils;
(2) Stage of annual halomesoxerophytes (*Atriplex pratovii*) on coastal solonchaks and coastal solonchakous soils with blown sand cover;
(3) Stage of psammoxerophylous grass *(Stipagrostis pennata*) on slightly saline hummocky sands;
(4) Stage of psammomesoxerophilic shrubs (*Calligonum* spp., *Eremosparton aphyllum, Astragalus brachypus*, with *Haloxylon aphyllum*) on non-saline hummocky sands;

(5) Stage of sub-climax xerophytic dwarf semishrub (sagebrush, wormwood), and haloxylon (*Artemisia terrae-albae, A. arenaria, Haloxylon aphyllum*) on plain and undulating sands, and late seral mixed psammophytic shrub (*Calligonum* spp., *Astragalus brachypus, Salsola arbuscula*) communities on hummocky sands.

Psammophytic succession is subject to the facilitation model. Within 2-3 years salt-marsh grounds keep moisture to support the growth of succulent halophytes. Gradually, the groundwater level decreases, surface horizon of sandy soil loses moisture after that wind started to change ideally smooth.

relief to undulated. Such conditions become favorable for the *Atriplex pratovii* colonization. Sustainable desalinization takes place after 10 years of continental development [39]. By this time, communities of *Stipagrostis pennata* and *Eremosparton aphyllum* are formed. The Soil becomes more stable, litter is accumulated, in plant communities appear psammophytes of continental sands (*Chondrilla brevirostris, Linaria dolichoceras, Astragalus lehmannianus, Artemisia arenaria*). Gradually exogenous factors lose their importance, thus endogenic processes start playing a leading role.

The severe salinity and heavy texture of soils are the main features of vegetation development in halosere. This is the most widely spread succession type. The halophytic succession passes several stages from annual hyperhalophytic saltwort communities to the haloxerophytic and xerophytic dwarf semishrub communities.

Five stages of the halosere have been identified:

(1) Stage of annual halomesophytes and haloxeromesophytes (*Salicornia europaea, Suaeda acuminata, S. crassifolia*) on marshy solonchaks;
(2) Stage of annual haloxeromesophytes and halomesoxerophytes on coastal solonchaks;
(3) Stage of halomesoxerophilic shrubs (*Halostachys belangeriana*) on coastal solonchaks and coastal solonchakous soils;
(4) Stage of halomesoxerophilic dwarf semishrubs (*Halocnemum strobilaceum*) on coastal solonchaks and coastal solonchakous soils;
(5) Stage of haloxerophilic and xerophilic dwarf semishrubs: (a) anabasis (*Anabasis salsa*), black sagebrush (*Artemisia pauciflora*) on desert solonetz; (b) kochia (*Kochia prostrata*), sagebrush (*Artemisia terrae-albae, A. scopiformis*), suaeda (*Suaeda physophora*) on brown desert solonetzic soils.

Halosere represents a succession, the development of which is a model of tolerance in conditions of changes in groundwater level, salinity of soil horizons and redistribution of salts in the soil profile. The environment determines the selection of salt-tolerant species.

Potamosere is typical for the formation of the tugaic (floodplain) shrub vegetation. In the dry seabed of the Aral Sea communities of *Tamarix* genera (*T. laxa, T. elongata, T. hispida, T. ramosissima*) belong to this type. Tamarisk thickets in river valleys pertain to desertified tugai [40].

Tamarisk community development takes place mostly in the surf belt, when the sea stays for a long time at the same elevation mark. As the sea desiccates, there can be formed several belts parallel to the coast line. In the composition of plant communities are observed meadow-riparian species (*Aeluropus littoralis, Calamagrostis dubia, Alhagi pseudalhagi Karelinia caspia, Argusia sibirica,* etc.), psammophytes (*Salsola paulsenii, Coryspermum aralo-caspicum, Stipagrostis pennata*), halophytes (*Limonium otolepis, Salsola nitraria*) and ephemerals (*Hyoscyamus pusillus, Senecio noeanus, Strigosella circinata)*. Vegetation development follows the facilitation model, when the predominating species create proper conditions for smaller plants normally associated with the dominant species.

The formation of plant communities related to tugaic vegetation in the dry sea floor is largely depends on ecological conditions and biological features of the dominant species. The root system of tamarisk is closely associated with groundwater table. Tamarisk can grow when the ground water level is 1.5-5 m.

Roots can go down to 7-8 m deep caused by groundwater decrease. In the transition to automorphic ground conditions, riparian shrubs lose the dominate role and are replaced by desert species: haloxylon, sagebrush, wormwood [41]. In the area of ancient marine terraces, tamarisk becomes ecological relict. By reducing groundwater level tamarisk community is changed by late seral desert species.

For the potamosere, three stages have been detected:

(1) Stage of dense shoots of tamarisk (*Tamarix* spp.) on marshy solonchaks in the surf belt;
(2) Stage of formation of tamarisk communities; stabilization of species composition and ecological conditions (during the life time of the dominant);
(3) Stage of change in vegetation type - tugaic shrub by desert psammophytic shrub (*Calligonum* spp., *Astragalus brachypus, Ammodendron bifolium*), haloxylon (*Haloxylon aphyllum, H. persicum*), and sagebrush, wormwood (*Artemisia terrae-albae, A. arenaria*).

Anthropogenic dynamics of vegetation (secondary successions) depends on factors of disturbance. There are several anthropogenic factors causing destabilization of vegetation cover and the environment in the coastal area and the Syrdarya river delta.

Agricultural factors: livestock breeding (well-worn paths, overgrazing in watering places); plant breeding (haymaking, plowing, discharge drainage water to the river); clearing trees and shrubs. Grazing is a major factor impacting negatively on floodplain vegetation. Due to overgrazing the diversity of grass species reduces; the process of fodder plants (*Phragmites australis, Calamagrostis epigeios, Alhagi pseudalhagi*) disappearance provides vacant niches for occupation of toxic and unpalatable species (*Xanthium strumarium, Peganum harmala, Sphaerophysa salsula,* etc). Desert rangelands, in general, are characterized by a medium degree of disturbance with a strong degree in a distance of 5 km around wells and villages. Some areas of shifting sand are strongly desertified, it is connected mainly with overgrazing, wind erosion and shrub- and woodlands clearing. Vegetation of sandy dunes with psammophytic shrubs, tamarisk and haloxylon communities are moderately disturbed by grazing. Communities of annual and perennial saltworts in salty areas are weakly changed due to their poor properties as forage. Each rangeland type has its own series of degradation depending on initial species composition and soil. However, strong degree of desertification causes convergence of different vegetation types to formation weed aggregations with dominance *Ceratocarpus arenarius, Heliotropium argusioides, Euphorbia seguierana, Peganum harmala, Cousinia affinis, Iris tenuifolia, Salsola nitraria* in the sandy deserts and *Ceratocarpus urticulosus, Anabasis aphylla, Climacoptera brachiata* – in the clay deserts.

Reeds in the area are traditionally mowed for hay. Denudation of the coastal zone may disrupt the natural functioning of ecosystems, reduce their role as natural filters and shelter for waterfowl.

Fires can occur under the influence of both natural and anthropogenic factors. Reed stand is frequently subjected to intentional burning by humans with expectation of young shoots emergence in replace of burned out old grass. The fires involve floodplain forest and shrubs as well. The functioning of ecosystems becomes disturbed. Reed communities recover quickly, though the restoration of tugaic woodlands takes a long time. Mature tugaic trees cannot recover: they are replaced by shrubs.

Recreation is connected with the spontaneous development of tourism on the coastal area of the Small Aral Sea and campings of fishermen on the river banks. Irregular activity leads to accumulation of garbage and the total destruction of vegetation on the coastal strip. Mesophytic grass and forb meadows (*Calamagrostis epigeios, Glycyrrhiza glabra, Lythrum salicaria, Althaea officinalis*) are trampled down, damaged woodlands, mainly young shoots of *Salix songarica, S. wilhelmsiana, Elaeagnus oxycarpa*.

Linear structures (paved and dirt roads), especially new dirt roads, laid out along the shoreline of the Small Aral Sea and the Syrdarya river, causing disturbance of the vegetation or completely destroy it in the area of 10-20 m away the rut of roads.

The leading anthropogenic factors in the region are connected with water management and irrigation. To identify the dynamics of plant communities and potential degradation trends, there are series of shifts (successional series of plant communities): hydro-, xero-, halo-, psammo-seres characterizing moisture content and edaphic environments [42]. Alteration in hydrologic regime to less watering leads to reduction of hydromorphic vegetation and a change it into halophytic desert; ecological ranges become shortened with less floristic and phytocoenotic diversity. Successions of vegetation have mixed natural-anthropogenic origin: climax stage is not reached [43]. Change the ecological situation due to human impact in the Syrdarya river valley and the delta has began in 40th of the XX century. By the 1960s the rate of water flow use in the river basin approached to the unit. Series of dams in upper and middle stream completely stopped spring-summer floods in 1971, decreased run-off volume, increased mineralization. Anthropogenic factors are leading exogenous factors which control vegetation dynamics in the Syrdarya river valley and delta. Natural plant communities have practically disappeared, especially in irrigation regions. Natural vegetation cover disturbed in all elements of landscape structure. Earlier described plant communities have preserved as separate fragments differing by more simple spatial structure and incomplete floristic composition.

Disturbance of agricultural technologies and crop rotation led to secondary salinization of soils, 60% of irrigated lands affected by high salinity in 2000 [44]. Due to deterioration of the ecological conditions part of agricultural fields have abandoned. Only halophytes (*Halocnemum strobilaceum, Halostachys belangeriana, Suaeda microphylla*, etc.) can grow in fallow lands.

The Hydrological regime of delta lakes has an influence on wetlands [45]. Decreasing of water level changes hydrophyte vegetation (*Typha angustifolia, Scirpus lacustris, Phragmites australis*) into halophytic meadows (*Aeluropus littoralis, Juncus gerardii, Crypsis schoenoides*) and shrublands (*Tamarix hispida, T. laxa, Lycium ruthenicum*). New wetlands have formed along irrigation canals. Plant communities are distributed by short ecological ranges according to changes of soil moisture and degree of salinity: *Typha angustifolia, T. laxmannii, Scirpus littoralis* → *Calamagrostis epigeios, C. pseudophragmites* → *Karelinia caspia, Suaeda acuminata, S. microphylla, Saussurea amara*, etc.

Tugai forest in a middle stream of the river valley has decreased by 70-75% [21]. Natural communities of turanga (*Populus pruinosa, P. diversifolia)* has preserved by several fragments, shrublands (*Salix songarica, S. wilhelmsiana*) – in the lower flow. River-channel straightening is one of limiting factors for distribution of the floodplain forest.

In 2005 the Aral Sea was divided into the Small and Large Aral due to completion of the Kokaral Dam. After construction of the dam the Small Aral Sea level raised by 12 m. Mineralization of the sea water decreased from 23 to 5.2 (7.5) g/l. Restoration of the Small Aral Sea has led to the rehabilitation of wetlands and biodiversity [46; 47; 48]. Hydrogenous succession facilitated to a gradual recovery of populations of rare species listed in Red Data Book of Kazakhstan, IUCN, Europe (*Scirpus kasachstanicus, Nymphoides peltatum, Salvinia natans, Typha minima*).

The newly developing vegetation in the Syrdarya delta front is subject to various degrees of disturbance. The conditions of the aquatic vegetation, including beds of *Nymphoides peltatum*, *Potamogeton perfoliatus*, *P. crispus, P. pectinatum, Myriophyllum spicatum*, and submerged thickets of *Zostera noltii* correspond to their natural state.

The grassy marshes of reeds, *Typha angustifolia*, *Scirpus littoralis, S. lacustris*, *Bolboschoenus planiculmis, B. maritimus* covering the area between the ducts of the Syrdarya mouth, are not disturbed due to inaccessibility. The emerging communities of mixed grass meadows with seedlings of willow on the flats are not transformed. Young floodplain forests are impaired weakly and moderately. Middle-aged willow (*Salix songarica, S. wilhelmsiana)* forest reveals a severe level of disruption due to grazing and recreation. The cattle are grazed in the coastal thickets of reeds and cattail and the grass is mowed for hay.

Heavily disturbed soil and vegetation cover is observed near the dam. The soils of these areas are completely destroyed mechanically till the parent rock. In such areas the original soil is replaced by backfilling and pavement. The vegetation is represented by sparse aggregations of annual saltworts interspersed with single bushes of tamarisk. Plant communities grown in adjacent to the road areas and downstream of the dam are heavily disturbed.

4. Conclusions

The study of natural and anthropogenic vegetation dynamics is an important task for environmentally unstable the Aral region. Assessment of the modern state of vegetation cover helps us to identify the processes of desertification and determine the main goals to reduce the negative consequences of the ecological crisis. Principles of management of natural and anthropogenic vegetation dynamics are based on a determination of successional status of plant communities. The study of primary successions, the sequence of stages is a scientific basis for the phytomelioration. Acceleration of primary plant succession is achieved by introduction of late succession species of competitive (C) strategy (*Haloxylon aphyllum*) at the initial stages [49]. A study of secondary successions allows us to identify the opportunities for natural revegetation after termination of human impact, or to choose the methods and species-phytomelorants to speed up the recovery of degraded pastures or create green shelter belts around settlements [50].

Assessment of restoration potential of hydromorphic ecosystems after construction of the Kokaral Dam showed that over a period of 6-8 years, wetlands were rehabilitated [47; 48]. The wetlands maintain high biodiversity of ecosystem components; therefore in 2012 they were included in the Ramsar List of globally important wetlands. National Important Plant Area site “The Syrdarya River Delta” was described in the river delta front and the deltaic lake Raimkol [51].

However, anthropogenic factors have a significant impact on vegetation and biota, therefore, the conservation of the most valuable sites and giving them the status of nature reserves will preserve them for future generations. In the Aral Sea region already exists “Barsa-Kelmes” Nature reserve, where ecosystems of northern deserts are protected, including the desiccated floor of the Aral Sea [52]. Taking into account the significance for biodiversity conservation it is proposed to establish the nature protected territory “Cluster area of the Syrdarya delta front” within the area of the “Barsa-Kelmes State Nature Reserve” [47]. In the buffer zone adjacent to a protected natural area is important arrange monitoring over the rate of anthropogenic load and implement ecologically-friendly nature management.

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