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Succession Processes and Vegetation on the Desiccated Sea Floor of the former Aral Sea

Siegmar-W. Breckle, Bielefeld

Abstract. The Aral Sea, east of the Caspian Sea, was once (until 1960) the 4th largest lake on the globe. It has almost disappeared. The water body decreased to only 12 %, the remnant water surface area to about 22 %. Huge irrigation programs during Sovjet times have changed the whole water balance of this huge tectonic basin under an arid continental climate regime. The desiccated sea floor with about 55.000 km^2 is a huge area and an excellent example to study succession processes. This desiccated sea floor area is called the new desert Aralkum. The Aralkum nowadays, exhibits mainly a mosaic of salt deserts. These salt deserts are the source for salt dust storms. The temporal and spatial dynamics during the last 50 years has been tremendous. Many halophytic vegetation types have been distinguished, their composition is very variable. Succession studies can serve as a basis for phytoreclamation as well as for nature conservation in this "catastrophic" environment.

1 Introduction

The Aralkum, the new desert on the desiccated sea floor of the Aral Sea, developed since 1960, when the coastline started to retreat. This was caused by the strongly increasing water use for irrigation, water which was diverted from the main tributaries Amudarya and Syrdaya (ALADIN & POTTS 1992, AGACHANJANZ & BRECKLE 1993, BABAEV & MURADOV 1999, BRECKLE & AGACHANJANZ 1994, BRECKLE et al. 1998, 2001b,c). The Aral Sea basin is located in the Central Asian desert belt with high continentality and aridity and a strong evaporative demand. The general climatic conditions can be depicted from Fig. 1, the ecological climatic diagram of Aralsk.

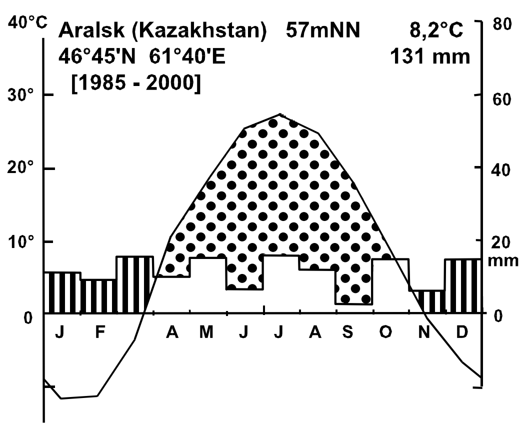

Fig. 1: Ecological climatic diagram of the meteorological station Aralsk, indicating very high continentality, strong winter and severe summer heat and drought (after BRECKLE et al. 2008).

The older sea floor mainly consists of sandy substrates, these parts of the Aralkum are nowadays sandy deserts subject to strong eolian processes and formation of sand dune systems. The younger desiccated sea floor is mainly characterized by silt, loam and clay substrates. During desiccation the salinity of the sea water increased steadily, these deserts are salt deserts. They cover now about 70 % of the Aralkum, 20 % are sand deserts and the remnant 10 % are swampy areas (salt swamps etc.). The former Aral Sea is now divided in some smaller remnant water bodies, mainly three basins, the northern "Small Aral Sea" (totally on Kazakhstan territory), and the southern "Big Aral Sea" with its Western deep basin and an Eastern shallow basin (on Uzbekistan and Kazakhstan territory) (Fig. 2).

The Eastern coast is almost totally flat; this has caused here the largest retreat of more than 100 km. Altogether, now 55.000 km^2 are desiccated sea floor, an area, which distinctly is larger than the whole Netherlands (41.530 km^2). The desiccation has caused a steady retreat. Close to the actual coast the primary succession started. This primary vegetation moved more or less synchronously with the retreating coastline forming an ever-increasing gradient behind. The invasion of species from the adjacent desert areas (Kyzylkum and Karakum) is obvious. It needs long distance transport of diaspores.

2 Desiccation history

The hydrological water balance of the Aral Sea basin before 1960 was rather in balance as it was for some centuries. The Aral Sea basin in the preceding millenia, however, was subject to several severe regression and transgression periods according to the fluctuating climatic conditions in the mountains of Central and Middle Asia and to varying overflows of the Amudarya via the Sarykamish depression and Uzboi wadi to the Caspian Sea (LETOLLE & MAINGUET 1996). It has a very dynamic history (ALADIN 1998).

The recent regression is very fast and has led to a very low water level almost not known from history. The discharge of the Amudarya fell within the last 50 years from about 49 km^3 H_2O annually and 14 km^3 H_2O from the Syrdarya (about 40 km^3 underground discharge) to less than 10 km^3 (Amudarya) and 5 km^3 (Syrdarya) (GIESE et al. 1998). Thus, within less than 50 years the water level fell from 53 m asl to about 26 m asl (Big Aral Sea). Compared to the situation of 1960, the water volume fell to about 12 % , the water area to about 22 % and the salinity rose from 0.9 % to about 7-9 % (Big Aral Sea). By construction of a dam at the Berg Bay, the Small Aral Sea is now a separate water body, only fed by the Syrdarya. It has now reached again an artificially constant level of 43 m asl (BRECKLE & WUCHERER 2006, 2007). The eastern basin of the Big Aral Sea which is very flat and shallow will change its shape within the very next few years drastically to a huge salt swamp, whereas the western deep basin will keep its shape rather constant. The "ideal" situation under the given catastrophic circumstances in hydrological sense would be to develop an overflow of the western basin in the north to the eastern basin by diverting all the remnant Amudarya drainage water to the western basin. This would lead to a decrease in salinity in the western basin. The eastern basin then would function as a big evaporation pan.

Fig. 2: Coastlines of the Aral Sea from 1960, 1990 and 2007, exhibiting the tremendous desiccation and the formation of the Aralkum (adapted from LETOLLE&MAINGUET 1996, BRECKLE & WUCHERER 2006, 2007, BRECKLE et al. 2008)

3 Primary and secondary succession, spatial and temporal dynamics of vegetation

Along the steeper west and north coasts, the desiccated sea floor gradients are rather short with narrow belts up to 5 or 10 km width. Along the east and south east coast, however, the desiccated sea floor is partly more than 100 km wide. This is altogether a huge area, where primary succession took and takes place during the ongoing desiccation process.

The shorter gradients on the desiccated sea floor at the north coast are characterized by typical belts, here often with stripes of *Tamarix*, which are easily visible from the higher chinks, the cliffs from late tertiary and early quaternary.

The primary succession starts with a broad *Salicornia* belt, which can develop for 2 or 3 years but which is very variable in density (Fig. 3), productivity and vitality from year to year. In some years it is even lacking. Very few other annuals can be seen, too, in this belt (e.g. *Suaeda acuminata, Climacoptera aralensis, Petrosimonia triandra, Bassia hyssopifolia).* In reality, it is to say, that the very first stages of succession on the moist surface, are here represented also by a cover of Cyanobacteriae (Fig. 5, 6), as it is all over the globe on many other primary succession surfaces (BRECKLE 2002C, WUCHERER & BRECKLE 2001). After drying of the soil, often only few annuals remain, and it develops a typically bare succession desert with salt crusts. This can be many km wide on the eastern Aralkum; it is the source of severe and harmful salt dust storms (e.g. NASA: http://rapidfire.sci.gsfc.nasa.gov/gallery/?2006164-0613/AralSea.A2006164.0925.1km.jpg). Sooner or later, after some years, depending on the favourable moisture conditions and on the salinity processes in soil, as well as on the long distance transport of diaspores, other annuals and the first perennials germinate. The replacement of annuals by perennials is rather low (Fig. 4).

The oldest sites are now often covered by a rather dense scrub with *Haloxylon aphyllum* (Black Saxaul), which almost could be regarded as somehow being the zonal semidesert vegetation, if the particle size of substrate is clay, silt or fine sand. Middle and coarse sand areas which fell dry also some decades ago often are covered by a loose and rather species rich vegetation of psammophytic *Calligonum* shrubs (there are now 32 species of *Calligonum* known from Aralkum).

The whole flora of the Aralkum comprises now 344 species of vascular plants (WUCHERER et al. 2001, DIMEYEVA & ALIMBETOVA 2006, BRECKLE et al. 2008). The Aralkum flora is a typical immigration flora derived mainly from Karakum and Kyzylkum, with a low content of original features, typical for North Turan and South Turan desert provinces (LITWINOV 1905, KUZNETSOV 1995, DIMEYEVA & KUZNETSOV 1999, DIMEYEVA & ALIMBETOVA 2006). It consists of many interesting species, the Chenopodiaceae being the most numerous plant family with 84 species.

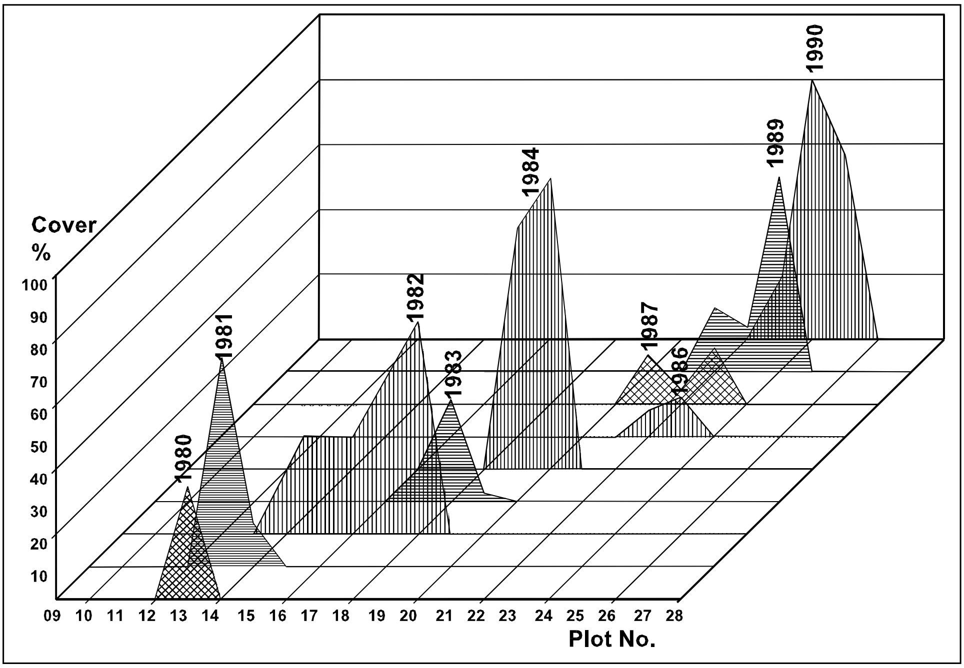

Fig. 3: The spatial and temporal gradient of the *Salicornia* belt on the desiccated sea floor of the Aral Sea during the steady retreat of the coast line at the shallow east coast (modified from WUCHERER & BRECKLE 2001, 2005)

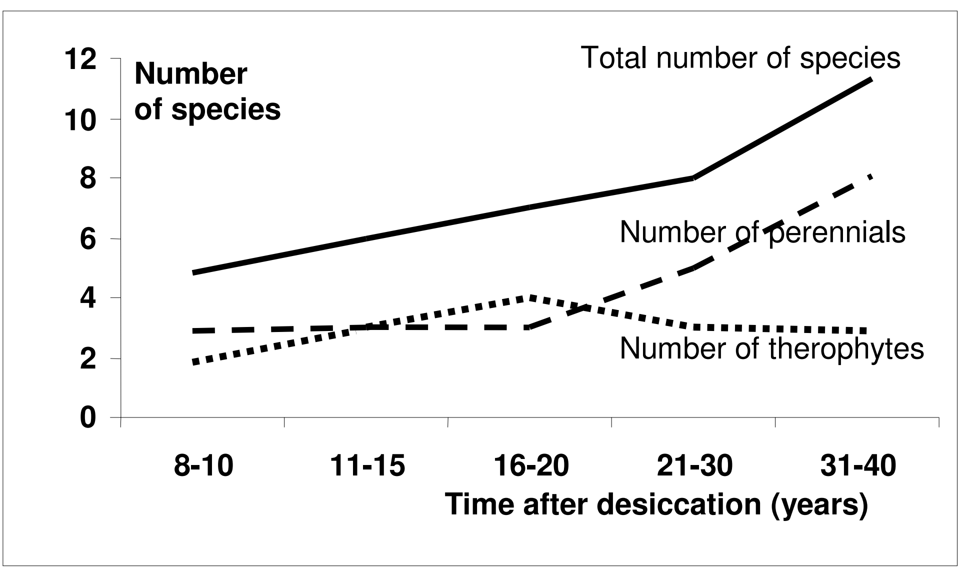

Fig. 4: The spatial and temporal gradient of annuals and perennials on the desiccated sea floor of the Aral Sea during the steady retreat of the coast line at the shallow east coast (modified from WUCHERER & BRECKLE 2001, 2005)

On the older parts of the desiccated sea floor, sandy substrates prevail. On those areas a rich psammophytic vegetation starts to develop (Fig. 5), depending on the eolian processes of sand movement and dune formation with deflation and accumulation of sand as well as on the water storage capacities of the sandy substrate.

On those areas where fine grained soils prevail, with silt and clay, salinity is much higher. These are the areas of the desiccated sea floor of the last decades when the sea water of the Aral Sea was already much more saline. Those substrates are less favorable for colonization with plants. Depending on the availability of a thinner or thicker sand sheet (from sand dust storms), on the chemistry of the salt crust (which is often a mixture of NaCl, but also sulphates, carbonates etc.) and on the slow ongoing desalinization process various halophytes start to conquer that areas (Fig. 6).

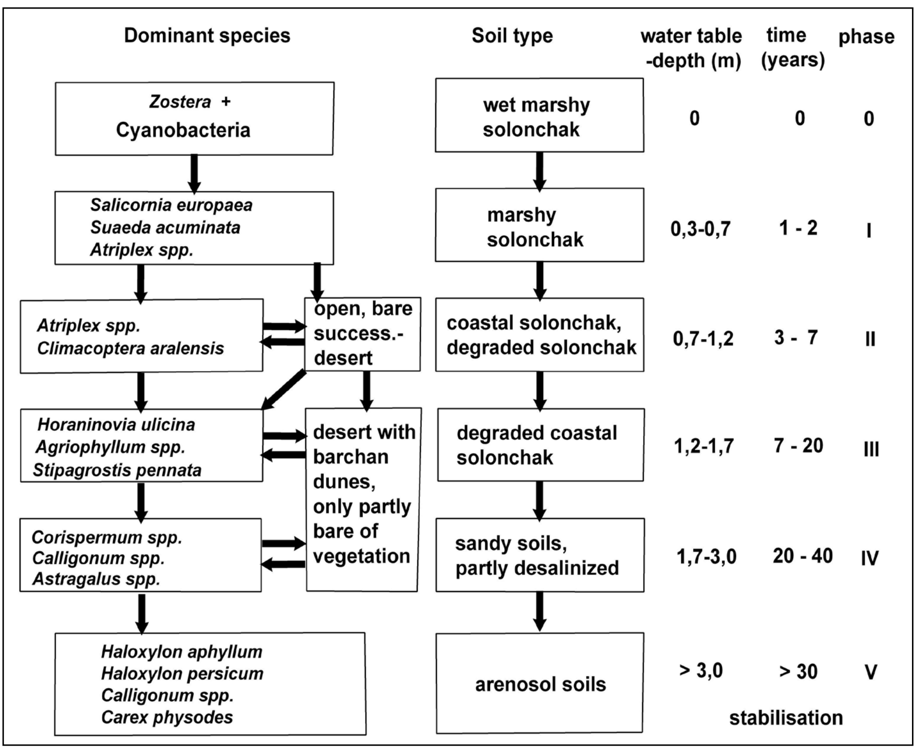

Fig. 5: The main direction of primary succession after the desiccation of the Aral Sea floor on sandy (older) substrates (modified from WUCHERER & BRECKLE 2001, 2003, 2005, BRECKLE et al. 2008)

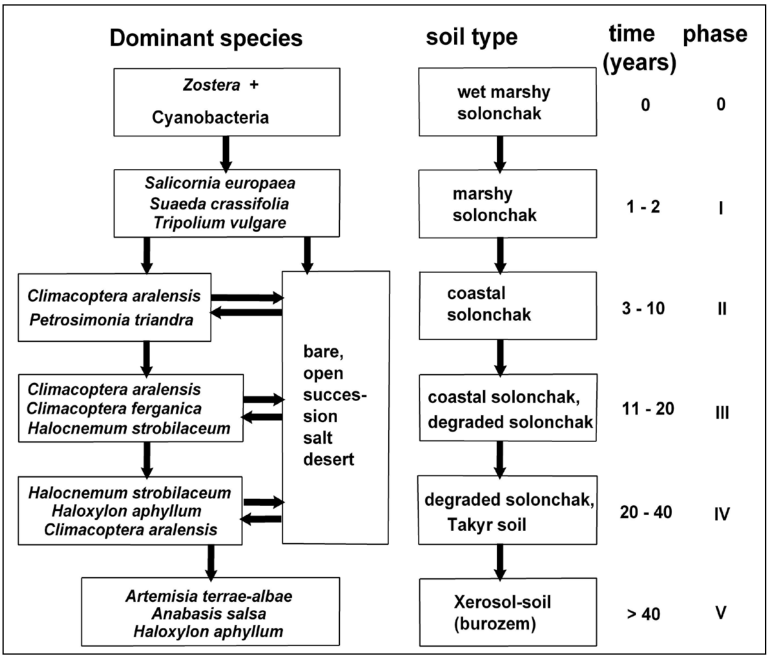

Fig. 6: The main direction of primary succession after the desiccation of the Aral Sea floor on loamy, clayey (younger) substrates (modified from WUCHERER & BRECKLE 2001, 2003, 2005, BRECKLE et al. 2008)

On both substrates during the primary succession process a rather regular sequence can be observed, but after the first reproductive cycles (when secondary succession starts to prevail) a totally unpredictable mosaic of vegetation with a mixture of species is found. The composition of species varies from year to year, certainly because the climatic conditions also vary tremendously from year to year, as it is seen from the length or lack of snow cover, the intensity and length of the normally rather long winter frost period, the occurrence and intensity of rains in spring and from the starting date of the heat and drought period in late spring or beginning of summer. Thus, the given succession sequences in Fig. 5 and 6 are only a rough and a generalized draft for the majority of investigated gradients, indicating the most dominant plant species. But the vegetation cover is often characterized by great patchiness and complexity.

Solonchaks are vegetated by communities of *Halocnemum strobilaceum, Kalidium caspicum, Nitraria schoberi, Tamarix laxa, Suaeda physophora*. Communities of *Anabasis aphylla, A. salsa, Artemisia terrae-albae* are distributed in undulating plains with more or less sand. Sagebrush communities with ephemerals and perennial saltwort (*Artemisia terrae-albae, Salsola orientalis, Eremopyrum orientale, Poa bulbosa*) usually occur in a complex with annual saltworts (*Salsola nitraria, Climacoptera brachiata*) depending on local salinity conditions and on less saline hummocks, as well as on moisture conditions in spring. Halophytic herbs as e.g. *Limonium suffruticosum, L.gmelinii, Aeluropus littoralis, Atriplex pungens, A.pedunculata, A.littoralis*, and some others are intermixed.

Psammophytic shrubs (*Calligonum aphyllum, Eremosparton aphyllum, Salsola arbuscula*) can occur in combination with *Halocnemum strobilaceum* and tamarisk communities (*Tamarix hispida, T. laxa*). Mobile sand dunes often are partly fixed by *Stipagrostis pennata* and scattered *Eremosparton aphyllum* or *Salsola arbuscula,* sometimes mixed with *Astragalus brachypus, Ammodendron bifolium, Atraphaxis spinosa* and other shrubs. Indicator species of disturbance (*Anabasis aphylla, Peganum harmala, Salsola nitraria*) occupy overgrazed areas normally not far from the former coastline.

The final stages of succession give a good hint on the zonal vegetation of these desert areas. They are similar to those of the adjacent Kyzylkum and Karakum deserts. Especially saxaul (*Haloxylon aphyllum*) is present in most vegetation types (Fig. 5, 6). This is a good indication also for the strong necessity and usefulness of saxaul for bioreclamation of the open bare desert areas in the Aralkum. Only few species are suitable for phytomelioration under these severe climatic and edaphic conditions. There is still a strong need to check the various *Tamarix*-species, *Halostachys belangeriana*, *Nitraria schoberi*, shrubby *Salsola*-species and especially the most salt-tolerant Chenopodiaceae, *Halocnemum strobilaceum,* for their capacity of phytomelioration (KAVERIN 1998, BRECKLE et al. 2001a,b, 2008). Also the halophytic behaviour needs additional experiments (BRECKLE 1995, 2000, 2002a) in order to understand the natural conditions governing halophytes in salt deserts (BRECKLE 2002B, BRECKLE et al. 2001a). Efforts of planting saplings and various seeding experiments have shown that a rather considerable acceleration of covering the ground can be achieved in order to minimize salt dust storms (KAVERIN 1998, WUCHERER & BRECKLE 2005, WUCHERER et al. 2005, BRECKLE & WUCHERER 2006, 2007). It is hoped that islands of plantings within few years may form reproductive centers for colonization of the adjacent wide-stretching bare grounds.

4 Conclusions

The formation of the Aralkum since 1960 is the biggest succession experiment mankind is performing unintentionally. But it is also called one of the biggest ecological catastrophes. Under the severe climatic (continentality, frost, heat, drought, sand storms) and edaphic conditions (salinity, alkalinity) the primary succession starts with very salt resistant annuals (*Salicornia, Petrosimonia, Suaeda*). Halophytic perennials need a rather long time to conquer the area. However, they are those plant life forms which lately can minimize the severe salt dust storms which have their source in the open, salt desert with its puffy and crusty solonchaks. Thus, phytomelioration projects, which have started in the area (in Kazakhstan and Uzbekistan), using mainly only the widespread occurring saxaul (*Haloxylon aphyllum*), can be improved by studying thoroughly the natural primary and secondary succession processes and the governing ecological conditions.

Since some parts are very rich in various halophytes, the former nature reserve Barsa Kelmes recently has been enlarged considerably in order to preserve some of the old saxaul "forests" and parts of the new Aralkum flora with a very interesting fauna. Basically, succession studies can thus serve also for new nature conservation projects in a "catastrophic" environment.

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Address of the author:

Prof. a.D. Dr. Siegmar-W. Breckle
Bielefeld University, Department of Ecology
Wasserfuhr 24-26
33619 Bielefeld, Germany
e-mail: sbreckle@gmx.de