BRECKLE, S.-W. 2003: Rehabilitation of the Aral Sea Environment, Kazakhstan. Proceedings of the International workshop (Aleppo, May 2002): "Combating desertification – rehabilitation of degraded drylands and biosphere reserves". UNESCO-MAB dryland series No.2 : p. 47-57

Rehabilitation of the Aral Sea Environment, Kazakhstan

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Abstract

The Aral Sea environmental crisis not only affects the dry sea floor adjacent to the Aral Sea (the new Aralkum desert covering forty-two thousand square kilometres), but also vast stretches of the sea's two main tributaries, the Amudarya and Syrdarya rivers.

The dry sea floor amplifies the environmental disaster, as from fifteen to fifty million tonnes of salt (mainly NaCl but also alkaline salts, herbicide residues and other pollutants) is swept by sandstorms across villages and irrigated lands every year. The resulting degradation and desertification processes threaten the entire population of the area and endangers their livelihoods. Current knowledge and information on the status of land degradation and activities in the Aral Sea region affected by the crisis has improved but is still incomplete. Regular monitoring of the status of the various ecosystems and land-use practices is necessary and important because of its dynamic yet unstable ecological balance. Rehabilitation of the main parts of the degraded region requires: (1) restoration of lost ecosystems (2) phytomelioration of open salt flats and sand dunes (3) establishment of a network of regional protected areas (4) establishment of a sustainable land-use system for grazing and, where possible, small local irrigated agricultural systems incorporating trees and garden crops. The projects should take into account the harsh ecological and climatic conditions of the area: namely high salinity levels, drought and high temperatures during the summer months, and severe winter frosts.

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Introduction

The Aral Sea crisis is unique in that there are no analogous features in terms of size or intensity found anywhere else in the world (Agachanjanz 1988, Walter & Breckle 1994, Letolle & Mainguet 1996, Giese 1997, Klötzli 1997, Breckle *et al*. 1998). The last millennia has witnessed several regression and transgression periods in the Aral Sea relating to changes in regional and global climatic systems. However, the rapid regression observed since the 1960s (see Table 1) has been caused by the major irrigation projects undertaken during the Soviet era in the catchment areas of the Amudarya and Syrdarya rivers flowing through Uzbekistan, Turkmenistan, Kirghizia and Kazakhstan. The waterflow from the rivers to the Aral Sea fell from an annual average of about sixty or seventy cubic kilometres before 1960 to a low of about four to ten cubic kilometers. But since 1990, the average water input into the Aral Sea has increased again to almost fourteen cubic kilometres annually. This very positive development signifies a deceleration of further drying out of the Aral Sea.

Table 1: Dynamics of the water surface of the Aral Sea and the dry sea floor (Breckle et al. *2001). Data from the Small and Great Aral Seas*

Year	Water Level (m NN) (km^2)	Water Surface floor (km^2)	Area of Dry Sea (% NaCl)	Salinity
1960	53.4	68 000	0	0.9
1970	51.5	61 000	7 000	1.2
1980	46.0	52 000	16 000	1.7
1990	38.5	38 800	29 200	3.4
1999	32/36 *	27 700	40 300	4.2/ 3.2 *
2001	31/37 *	23 000	45 000	5.2/ 2.5 *

* approximate data

In 1960, the Aral Sea was the world's fourth-largest lake. The area of the dry sea floor is now greater than the Netherlands, and the area of the remaining Aral Sea is less than one-third its original size. The dry sea floor on the east coast flats stretches over approximately one hundred kilometres (Figure 1).

The volume of water has decreased even more dramatically. From the original water body, only 15–18 percent remains. The northern part is now hydrologically independent and has become the Small Aral Sea, while the larger southern part (the Great Aral Sea) is separated into a shallow basin to the east and a deeper basin to the west (Figure 1). These basins are partitioned by the Vozroshdenie Peninsula, on which remnants of Soviet biological and chemical weapons pose a further threat to the wider environment. The Small Aral Sea was separated by an artificial dam, but this was ruptured by a violent storm in April 1999 . The Syr Darja is now discharging its surplus water into the Great Aral Sea and is thus about 70km longer than before until a new dam will be constructed. In addition, water loss by evaporation and the drop in water input from the two feeder rivers has led to a dramatic increase in the salt concentration of the seawater, from being slightly brackish before 1960 to hyper-saline (in the Great Aral Sea) today. This has caused the loss of the halieutic fauna and the resultant demise of the once prosperous fishing industry.

At present, the wider Aral Sea basin hosts a very complicated system of canals, reservoirs, irrigated and abandoned fields and hydro-technical constructions. It includes 7.9 million hectares of irrigated lands, mostly abandoned and therefore salinized, a 323,200-kilometre irrigation network and 161,800 kilometres of drains and collector basins (Orlovsky *et al*. 2001). Despite such wide-scale water construction, the irrigation techniques commonly used are the same or worse than during the Middle Ages—mainly border, basin and furrow irrigation. Under such a land-use system, a large quantity of water is non-exploitable or lost, while further quantities are drained into large depressions or transported to other dispersed areas. Improper irrigation leads to secondary salinization, waterlogging and desertification. The diversion of drainage water to the rivers results in the deterioration of water quality while its diversion to marginal desert areas results in the waterlogging of pastures and the environmental degradation of the total area.

The sequence of natural primary succession (Breckle 2002*b*) on the dry sea floor varies depending on the substrate. Vast stretches are made up of sandy soils, which have mainly developed during the first phase of the desiccation process (1960–1980) when salinity rates were still relatively low and sand dune systems were developed by aeolic activity. Over the last two decades salinity has increased to seawater concentration and the desiccated surfaces now exhibit strongly saline solonchak soils that are high in clay content.

Primary succession on sandy soils (Figure 2) is characterized by rather high biodiversity. Over a period of several years, succession leads to typical psammophytic tufts of vegetation, which are only sufficiently dense locally while vast areas are open mobile sands. Primary succession on saline clay soils (Figure 3) is characterized by a relatively slow advancement of plants. The desert under succession is typically bare of plants, making up the majority of the area. However, the plants are dynamically represented as these open areas contain halophy tic vegetation during the first years of the succession process consisting of the annual *Salicornia europaea* (wet soils) and *Atriplex fominii*, *Suaeda* and other annual halophytes during successive years, depending on weather and water conditions (moist or dry soils). Invasion of the lower shrub, *Halocnemum strobilaceum*, the most salt resistant plant species in the area, and found in other salt-deserts of Central-Asia (Breckle 2002a, 2002c) takes place in some areas, while elsewhere remains an open and bare salt desert. Vital remnants of the Tugai forest can be found along rivers and water channels of the delta areas.

The ecological characteristics observed during the succession process have been studied by Wucherer & Breckle (2001). The studies reveal how one of the final stages in the succession sequences could become dominated by *Haloxylon aphyllum* (the Saxaul), which can grow to a height of 6 metres. Such vegetation cover could effectively halt the action of the wind on the bare surfaces. It should be noted that destruction of the vegetation was first begun in the nineteenth century. Woodlands made up of *Haloxylon aphyllum* and *Tamarix* species were cut down to provide the Aral steamship flotilla with firewood (Dimeyeva 2001). Clearing became more intense after the construction of the railway at the beginning of the Twentieth century and as a result, the *Haloxylon* woodlands on the islands and the coast of the former Aral Sea were almost totally cleared. This was one of the main threats to biodiversity in the region during many decades. Other human activities impacting and contributing to the desertification process in the area include overgrazing and techno-genic factors such as the chemical and aeronautical industry.

1. Rehabilitating the Environment.

Many disputes still continue as to future directions in the planning and development of the area. Restoration of the Aral Sea to its 1960 dimensions would necessitate the cessation of most agricultural activities along the main two rivers. However, due to the dramatic population increase and the growing need for food production through intensified agriculture, this seems highly unrealistic. Yet more should be done to increase water efficiency and drainage to prevent further salinization.

Another possible solution discussed involves deviating water from the large Siberian rivers (the Sibaral Project). This would be a major project involving considerable ecological risk for the northern Siberian forest, the mire, and the tundra areas as well as being excessively costly. The deviation of water from the Indus to the southeast is even more fanciful. Thus, plans to improve the water table in the region should take into account the *lower* level of water in the Great Aral Sea as well as the level of controlled water from the dam in the Small Aral Sea. Essentially, it is important to note that in the future the water level of the Great Aral Sea may vary from decade to decade.

Recommended objectives for the near future:

(1) Minimize salt and sandstorm effects.

(2) Conserve the high biodiversity of the specific vegetation on the dry sea floor and along the old Aral Sea coast.

(3) Improve the present situation of the desiccated sea floor.

An integral part of the programme is to improve living conditions in the villages and towns adjacent to the Aral Sea. Projects to improve the socio-economic situation should include improving health systems, guaranteeing access to clean water and energy, and maintaining the food supply and infrastructure.

Recommended actions to achieve these aims:

(a) Establish extensive planting systems of seedlings on the sandy surfaces and on the *solonchak* (Russian for “salt marsh”) by applying new techniques for snow and water run-off collection. Apply scientific knowledge to succession processes and sequences.

(b) Establish biological research stations and research projects to observe and monitor desertification processes in the major landscape units.

(c) Build capacity through working with local people, sharing responsibility for projects, providing ecological training and education, and increasing public awareness of the problems of desertification.

(d) Work together with Uzbek and Kazak projects (with governments, district officials etc.) in areas of rehabilitation and conservation, and collaborate more effectively with development and international aid agencies.

(e) Establish a nature reserve system, in relation to landscape planning and subsequent evaluation by satellite imagery.

(f) Protect the remaining small spots of Tugai forests and promote their dispersal.

(g) Promoting the National Park as potential sites for ecotourism (hot springs, cultural monuments, safari trips etc.).

(h) Establishing a management system for sustainable grazing in limited areas.

(i) Establishing a management system for hunting in limited areas as a means of wildlife protection.

(k) Establishing small development centres for irrigated lands along water channels surrounded by trees and garden plants, creating intensive agricultural oasis systems, surrounded by forest shelter belts.

(l) Rehabilitating salinized agricultural land along the Syrdarya and Amudarya rivers by concentrating on small units and intensified agriculture using modern technology.

(m) Minimizing effects from the old chemical and biological weapons experimental area in Vozroshdenie.

The above-mentioned efforts are a number of the small or larger projects that can only be accomplished through cooperation with local authorities. In any case, few alternatives remain since an improvement of the present disastrous situation must be attained.

Due to the multiplicity of potential actions, it is not possible to discuss all the mentioned necessary future efforts and projects in detail. However, relating to our research results and future research activities, some remarks and data on phytomelioration will be given.

2. Phytomelioration

The desiccated Aral Sea area is an inhospitable substrate for the colonization of plants, and without an additional water supply, establishing a dense vegetation cover is next to impossible. Thus, only small local centres of irrigated land can be planned and used for intensive agriculture in the development of small new oasis systems. Annual precipitation amounts to approximately 100mm, and consists mainly as snow during long cold winter periods. Annual temperatures are typically strong continental, exhibiting very hot spells in summer, up to 45°C, and very severe frosts during the winter, falling to below –35°C (absolute minimum –45°C in Aralsk, Figure 4). This suggests that only a small number of plant species are suitable for phytomelioration projects. Dimeyeva (2001) suggested two methods for biodiversity conservation: (1) the restoration of lost ecosystems (2) the establishment of a network of regionally protected areas.

Phytomelioration and afforestation have been carried out periodically along the Aral Sea coast. Restoration of natural ecosystems could be acquired by artificial phytocenoses. The natural vegetation units remaining along parts of the sea coast can serve as a model for the creation of man-made ecosystems, as well as an important source of diaspores. Reintroduction in suitable habitats of the disappearing wild vegetation could accelerate the natural succession process and help create a seed bank furthering the natural dissemination of the vegetation. One four-hectare plot and a number of one-hundred-square-metre test plots were established southwest of Aralsk to revive *Haloxylon* and *Tamarix* communities (Dimeyeva 2001). Saplings of *Haloxylon aphyllum, Tamarix laxa* and *T. hispida* were planted and seeds of *Haloxylon aphyllum, Ceratoides latens, Salsola orientalis* and some annuals were sown in the test areas. Early results of the growth and establishment of the species are very promising, clearly demonstrating that such artificial plantings are necessary and prove to be successful. It should be noted that the heterogeneity of the soil found in the test areas reveal uneven growth responses and that another important factor remains the variability of the winter and spring rains. It has been shown that good results of sapling plantings and seeding projects require at least one wet winter season. This was also demonstrated by Meirman *et al.* (2001) with experiments on solonchak soils. Most replanting projects were carried out in sandy areas.

For several years the "afforestation of the desert" a project located on the Uzbek southwestern Aral Sea floor, has been taking place and as recently as last year, became a development project financed by Germany. With the help of heavy machinery, a vast area covering thousands of hectares of sandy substrate was planted with *Haloxylon aphyllum*, and a tree nursery was created. Results so far are very promising as salinity is low and in the sandy soils rainwater is perfectly protected against evaporation and can be almost totally utilized by the plants. Over time, an equilibrium between plant density and height will be established depending on the amount of water used through transpiration and evaporation (negligible for sand). However, natural sand dune systems in the area demonstrate how open vegetation cover, in equilibrium with the autochthonous water supply, is sufficiently dense to minimize sand storms, sand movement and thus dune development. Eventually, old *Haloxylon* stems could be sustainably used for firewood or other purposes.

The vast saline areas desiccated after 1980 pose many problems for afforestation. Problems arise due to the high salinity of the solonchak soil as well as the very high percentage of clay contained in the soil, which alters the physical and chemical structure of the soil preventing the penetration of roots and thus the establishment of most plants. Again, it is necessary to look towards natural succession as a model, taking into consideration the geo-morphological features of the area, in order to evaluate the best environmental conditions for plant colonization on such harsh substrates. Field experiments carried out on a crust solonchak (0–2 cm crust: 24.5 percent salt per dry matter, 10.4 Cl; 5.15 percent SO_4^{2}; 7.85 percent $Na^+ + K^+$) situated to the southwest of the former Kaskakulan island (Meirman *et al*. 2001) demonstrated that seeding experiments can be successful, despite the low germination percentages (Table 2) and slow growth observed throughout the dry year. The experiment also revealed the suitability of the annual *Chenopodiaceae*, however perennials were shown to require special treatment.

Table 2: Phytomelioration was performed on crusty clay soils (solonchak) near Kaskakulan, eighteen kilometres west of the former coastline. It was impossible to evaluate the germination percentage, but the number of plant individuals was taken into account. Seeding was carried out in Nov. 1997. Ch = *Chenopodiaceae*

Plant/ date:		Number of plants on recorded areas 22.04.98	01.06.98	23.08.98	Plant height (cm) 01.06.98	23.08.98
Suaeda acuminata	(Ch)	77	62	51	1.0	5.0
Halogeton glomeratus	(Ch)	27	27	27	4.0	9.0
Climacoptera aralensis	(Ch)	35	32	11	1.0	2.0
Atriplex fominii	(Ch)	43	30	10	1.0	8.0
Atriplex tatarica	(Ch)	125	89	0	1.2	-
Petrosimonia bracchiata	(Ch)	39	37	0	1.5	-
Salsola nitraria	(Ch)	23	23	0	0.5	-
Climacoptera lanata	(Ch)	17	16	0	1.3	-
Kalidium caspicum	(Ch)	14	6	0	1.0	-

For the year 1997, no germination was observed among the following species: *Limonium gmelinii, Karelinia caspica, Pseudosophora alopecuroides, Halostachys caspica* (Ch), *Haloxylon aphyllum* (Ch), *Suaeda microphylla* (Ch), Salsola *australis* (Ch) and *Halocnemum strobilaceum* (Ch)

The experiments reveal that the harsh environmental conditions enable only a few species to grow and establish (23.5 percent). During another seeding experiment (Table 3) carried out by Meirman (2001), it was observed that some perennial species had successfully germinated, particularly *Haloxylon aphyllum*.

Table 3: The table below demonstrates phytomelioration by seeding experiments on solonchak soil near Kaskakulan, twelve kilometres west of the former coastline. It was impossible to evaluate the germination percentage, but the number of plant individuals was taken into account. Seeding was undertaken in November 1997. Ch = Chenopodiaceae

		Number of plants on recorded areas			Plant height (cm)	
Plant/	date:	22.04.98	01.06.98	23.08.98	01.06.98	23.08.98
Climacoptera aralensis	(Ch)	65	64	41	4.7	8.3
Haloxylon aphyllum	(Ch)	21	20	17	5.4	7.0
Climacoptera lanata	(Ch)	16	16	11	3.3	6.7
Salsola nitraria	(Ch)	24	23	8	1.5	4.5
Petrosimonia bracchiata	(Ch)	17	16	3	2.2	3.3
Salsola autralis	(Ch)	20	13	1	4.4	6.5
Suaeda micropyhlla	(Ch)	17	17	0	0.2	-
Kalidium caspicum	(Ch)	9	4	0	1.0	-

No germination was observed with *Halocnemum strobilaceum* (Ch)

One very important phenomenon was observed. It was found that many seedlings germinated and grew during the spring months due to surface desalinization following snow melt. The seedlings began to die off in June because of surface salinization, due to the high rate of evaporation of the fine particle soil, and by the unearthing of roots by strong winds. In the second field experiment, ecological conditions were more favorable. The slight sand cover on the solonchak surface allowed for germination as well as 67 percent development of seedlings at the vegetative stage. Most plants were healthy and the annuals produced seeds.

We can draw the following conclusions:

(1) Even small proportions of sand or a shallow sand cover on the solonchak soil provides improved conditions for the implementation of phytomelioration measures.

(2) The aridity of the first vegetation period plays a major role in the establishment and thus survival rate of seedlings and saplings.

(3) Local flora species are more effective for phyto-reclamation. Species derived from spontaneous natural succession sequences are best suited.

(4) The development of soils and formation processes on the dry Aral Sea floor are still continuing; a final balance between herbaceous cover and shrubs has not yet been reached (no climax situation observed).

(5) Soil formation is dynamic and depends on local annual climatic conditions and long-term vegetation cover.

(6) Vegetation changes are rapid and quite unpredictable. The creation of a viable seed bank would enable the vegetation to better adapt to the varying weather conditions.

Experiments in the future will be performed on a larger scale by applying special techniques for promoting rainwater run-off and the accumulation of winter snow. Large-scale soil improvement is not achievable, whereas the starting conditions for seedlings and saplings have to be improved by technical means. Planting saplings in hollows, in order to accelerate the colonization of bare soils, will complement seeding. Increasing vegetation cover will minimize sand and salt dust storms. Irrigated soils that are currently redundant because of strong salinization require leaching for its reclamation. Vast quantities of water would be necessary (Rau 2001). This can be only achieved with reasonable economy on good soils on selected parts close to villages and towns, and by its conversion to intensive garden land.

3. Conservation

Two hundred and sixty six vascular plant species have so far been recorded from the Aralkum (Wucherer *et al*. 2001), of which 28.2 percent are *Chenopodiaceae*. This unique flora and the various combinations of new vegetation types are in addition to the high biodiversity, which should be protected. The Barsakelmes State Reserve, an island founded in 1939 as a nature reserve, represents the model for the vegetation and the main ecosystem types in the Aral Sea region, land that has remained largely unchanged. Following the fall in sea level over many years, the island resembles the former islands of Kaskakulan, Uzynkair and Akbasty and today it is reduced to a flat hill. It would be very important to expand the protected areas to include territories of the exposed sea floor. Setting up a network of regionally protected areas at the local authority level will conserve the biological diversity found in the natural environment. This has to be implemented by the attribution of a larger area as a National Park. The interesting fauna (*Gazella subgutturosa, Equus hemionus, Saiga tatarica* etc.), which is partly recovering, would also be under protection. This National Park should also include an example of the Tugai forests found within the delta of the big rivers (Ogar 2001). Due to the more constant water levels, this would be better achieved within the smaller Syrdarya delta. In addition, a water conservation zone along the whole Amudarya channel downstream to the Tyuamuyn dam is required in order to restore and protect the riverbank by developing riparian forests. The gallery forest belt stretching along the river should be one and a half to two kilometres wide (Novikova 2001, Treshkin 2001). Land ploughing, cattle grazing, deforestation, fire wood collection, construction work and the discharge of wastewater into the river should be prohibited within this belt. In order to preserve the genetic and species diversity of the well-watered Tugai ecosystem, it is necessary to establish the Nurumtubek and Nazarchan Tugais, and also the new mouth of the Raushan Canal and the Kokdarya floodplains as nature reserves.

Conclusion

The Aral Sea crisis is extremely complex. Only joint efforts at various levels can improve the environmental situation and thus the socio-economic conditions of the inhabitants living in proximity to the crisis region. International developmental aid should not only be directed to specific economic projects, but should also be directed towards sustainable landscape planning, conservation and capacity building. It should enable people to become empowered while seeking by themselves new possibilities for the modernization of agriculture and other management systems combined with water saving techniques and better energy supply, perhaps for the development of handicrafts, or future ecotourism etc. Other actions to improve the environmental situation in Kazakhstan are given in non-exhaustive lists with concrete measures by Karibaeva (2001) and Baitulin (2001). All these actions take into account participatory involvement of communities and local populations for the conservation and rational utilization of natural resources.

Since water needs and consumption will increase in the future, water and energy saving techniques have to be applied as early as possible. The only solution for all the Central Asian states, not only for the Aralkum area, is to improve water efficiency and use, by applying recycling techniques for used water to prevent severe water shortages and to use renewabele energy -sources. The most urgent task is to halt secondary salinization caused by salt dust storms from the dry sea floor, but also from the devastated old irrigation fields now totally salinized. Rehabilitation of these areas is vital. Research can substantially contribute to help solve these ecological questions and problems.

Acknowledgements

I greatly appreciate the support of the German Federal Ministry for Education and Research (BMBF) in funding this research, along with the invaluable assistance and cooperation provided by the Botanical Department of the Academy of Science in Almaty; the Agroecological Institute in Kzylorda; the Kazakh National Environmental Centre; the Institute of Ecology and Sustainable Development, Almaty; the United Nations Convention to Combat Desertification

UNCCD-Focal Point for Kazakhstan, Almaty; the Environmental Research Centre in Leipzig; and many colleagues, friends and students. The technical help of students and Miss Anja Scheffer is also gratefully acknowledged.

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