Chapter 15
Phytomelioration in the Northern Aralkum

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15.1 Introduction

The open sandy and salty soils of the dry seafloor are sources of widespread salt and dust storms (see Chaps. 5–7). This endangers the agriculture in the surrounding regions (especially the districts of Kzyl-Orda in Kazakhstan and Karakalpakstan in Uzbekistan) and leads to salt desertification (Agakhanjanz and Breckle 1994). An effective procedure to decrease the spreading of salt and dust of the desiccated seafloor and open salinized fields is the cultivation of soils and permanent plantings (Breckle 2003; Breckle and Wucherer 2006, 2007; Dimeyeva et al. 2000; Dimeyeva 2001, 2007, Dimeyeva and Ogar 2006; Hüfler and Novitskiy 2001; Kaverin and Salimov 2000; Kaverin et al. 2005; Novitskiy 1997; Meesa and Singer 2006; Wucherer 2001; Wucherer and Breckle 2005; Wucherer et al. 2005). The goal of phytomelioration must be the preferential treatment of the natural development of a vegetation cover and the creation of a natural reproduction with seeds (see also Chaps. 16 and 17). The plantings should benefit not only the cover of vegetation, but also the land use for the people.

Phytomelioration on the desiccated seafloor of the Aral Sea has been an important task for academic scientists and forest managers since the sea began to retreat. The first recommendations were made in the 1980s (Kurochkina et al. 1983; Kurochkina and Makulbekova 1984; Makulbekova and Wucherer 1990). They had theoretical character.

The first planting experiments of the institutes of forest economy of Kokchetav and Tashkent in the 1990s considered that sand and sandy-loamy plains were suitable for phytomelioration. But saline coastal soils with a heavy texture need land-reclamation procedures.

The continuing shrinkage of the Aral Sea led to the desiccation of vast areas of the seabed with highly saline heavy sediments. New ecological conditions required new approaches for phytoreclamation of all types of soils, including solonchaks of heavy texture.

The Kazakh Institute of Forest Economy conducted experiments at the eastern coast (Kaskakulan area) in 1989–1992, and obtained many basic results concerning

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conditions for afforestation (Kaverin et al. 1994; Kaverin and Salimov 2000; see Sect. 15.2). Some experiments on phytomelioration were conducted through a UNESCO project (Dimeyeva et al. 2000; Geldyeva et al. 2001; Meirman et al. 2001a). Two experimental plots were established for identification of suitable plants for phytoreclamation of saline soils. Seeds of 17 perennial and annual halophytes were sown in autumn. Only four species of annual saltworts (*Climacoptera aralensis, Halogeton glomeratus, Atriplex pratovii, Suaeda acuminata)* germinated, survived and reached the generative stage in a plot of heavy soil texture with salt content in surface horizons up to 24.5% and 1.91–3.11% in underlying horizons. The perennial species did not survive. On a plot of light soil texture with salt content in surface horizons of 2.63% and 0.56–1.46% in underlying horizons, of six species (*Haloxylon aphyllum, Salsola nitraria, Salsolaaustralis, Petrosimonia brachiata, Climacoptera aralensis, Cimacoptera lanata*) five survived and fruited, but saxaul did not. The experiments again showed that sandy soils have more favourable conditions for implementation of phytomeliorative measures than clay soils; the aridity of the first vegetation period plays a major role in the establishment of seedlings; species from local flora are more useful for phytoreclamation than introduced species.

In the framework of two German BMBF projects, “Succession processes on the desiccated sea floor of the Aral Sea and perspectives of land-use” (1998–2001) and “Combating desertification and rehabilitation of salt deserts in the Aralkum” (2002–2005), different methodical planting approaches on the dry seafloor were tested systematically (Breckle 2003; Breckle and Wucherer 2006, 2007; Meirman et al. 2001b; Wucherer 2001; Wucherer and Breckle 2005; Yair 2001).

In the first project, minicachment methods were tested. Experimental sites were selected on the Bayan transect at the eastern coast (10 km to the southwest of the mouth of the Syr Darya). Saxaul and tamarisk saplings were planted in experimental plots. The method of planting into pits was successful for tamarisks. For saxaul, it was better to plant into deep furrows (see Sect. 15.5.1).

In the second project, large-area plantings were carried out at the eastern coast in the surroundings of the former island of Kushzhitmes. New adapted planting strategies were developed. They include changes of the spatial priorities and selection of additional species for plantings according to environmental conditions (see Sects. 15.3, 15.5, and 15.6). The development of shelterbelts for villages is particularly important (see Sect. 15.4). This work is a result of research cooperation between the University of Bielefeld (Germany), the Kazakh Institute of Forest Economy, the Institute of Botany in Almaty and the Kzyl-Orda Institute of Agroecology.

15.2 Experiments of the Institute of Forest Economy of Kokchetav on the Kaskakulan Transect

The Institute of Forest Economy of Kokchetav (Kazakhstan) joined the BMBF project (2002–2005), so as to continue the institute’s work at the eastern coast of the Aral Sea and to warrant information exchange concerning the plantings.

Fig. 15.1 Plantings at the eastern coast of the Aral Sea (Satellite picture – source NASA). *1* in the environment of the former island of Kushzhitmes, *2* in the environment of the former island of Kaskakulan

V.S. Kaverin (the representative researcher and manager of the Institute of Forestry) organized the plantings and observances in the area of the Kaskakulan transect at the eastern coast (Fig. 15.1, area 2) on the dry surface of the seafloor of the 1960s and 1970s and partly that of the 1980s. The local conditions for reforestation in the area of the former island of Kaskakulan at the eastern coast were inspected in the years 1987–1989 and plantings were conducted in 1989–1992. The experimental area comprises a transect of 51-km length, which passes from the former coastline to the west in the direction of the water table of the Aral Sea. Twenty-two plots following this transect with a surface area of 400 ha on salinized soils were established. The following species were tested: *Populus diversifolia, Nitraria schoberi, Haloxylon aphyllum, Tamarix ramosissima, Tamarix hispida, Calligonum caput-medusae, Calligonum rotula, Astragalus brachypus, Eremosparton aphyllum, Halimodendron halodendron, Eremosparton aphyllum, Krascheninnikovia ceratoides (=Ceratoides papposa), Alhagi pseudalhagi, Glycyrrhiza glabra, Haloxylon aphyllum* and *Halocnemum strobilaceum.*

The afforestations were performed with seedlings, saplings and rhizomes as well as seed sowings. The plantings took place in autumn and in spring. The seeds were sown in autumn and winter. The highest establishment rate and the best phytomeliorative properties were seen with *Haloxylon*. The other species either did not establish themselves or had a very low establishment and growth rate.

All plantings were carried out manually.

Four types of soil conditions (habitats) for afforestation were identified (during plantings):

1. Good conditions: Coastal plains with sandy and light loamy-sandy sediments; the salt content in the soil layer from 5 to 30 cm is 0.16–1.04%; Cl^- 0.04–0.33%, groundwater is at a depth of 1–2 m, highly saline with a salt content up to 45 g L^{-1}.
2. Satisfactory conditions: Coastal plains with sandy loam and loam sediments with blown sand cover; salt content in the soil layer from 5 to 30 cm is

0.67–1.62%, Cl^- 0.10–0.88%; groundwater is at a depth of 1.8–3.2 m, highly saline with a salt content up to 65 g L^{-1}.

3. Relatively satisfactory conditions: Coastal plains with loam, clay-loam and clay sediments; salt content in the soil layer from 5 to 30 cm is 1.62–3.96%; Cl^- 0.39–1.40%, groundwater is at a depth of 1.8–2.3 m, highly saline with a salt content of 50–65 g L^{-1}.
4. Moving barchans: Salt content is up to 0.9 g L^{-1}; Cl^- up to 0.32%.

15.2.1 Experimental Plots and Results of Plantings

15.2.1.1 Sandy Soils (Habitat 1: Plots 3, 12, 13, 14)

Experimental Plot 3

This experimental plot is 13.6 km west of the former coastline on the dried seafloor from the 1960s. The upper horizons are moderately saline; the middle horizons rather strongly saline (Table 15.1). The soil profile consists of sand from 0 to 40 cm, and from 40 to 50 cm silty loam starts with increasing portions of clay below. The maximum salinity is at 50–60 cm. The groundwater level is at 2.1 m. On the plot very few individuals of *Halocnemum strobilaceum* and some remnants of dry reed could be observed.

In April 1989 seedlings of *Haloxylon, Tamarix, Halocnemum* and *Populus* and saplings of *Calligonum* were planted. The plantings of *Haloxylon a*nd *Tamarix* had the following technical variants:

- Removal of salt crust and upper soil up to 5 cm
- Sand heaps around the stem base of seedlings and saplings
- Plantings in furrows

Table 15.1 Soil salinity (percentage of dry matter) on plots of the Kaskakulan transect (four habitats)

Plot (habitat)	Soil horizon (cm)	Total salinity (%)	Cl^- (%)	SO_4^{2-} (%)
1 (H2)	5–30	1.62	0.41	0.82
3 (H1)	5–30	0.87	0.19	0.49
5 (H3)	5–30	2.3	1.0	0.6
6 (H3)	5–30	1.58	0.39	0.59
7 (H4)	5–30	0.2	0.06	0.06
12 (H1)	5–30	1.04	0.33	0.73
13 (H1)	5–30	0.16	0.04	0.05
14 (H1)	5–30	0.77	0.08	0.47
15 (H2)	5–30	0.67	0.11	0.35
16 (H2)	5–30	0.7	0.1	0.4
17 (H3)	5–30	1.54	0.67	–
19 (H4)	5–30	<0.9	<0.32	–

After 3 years the rate of establishment of *Haloxylon* was 17.0–37.2% for autumn plantings and it was 22.5% higher for spring plantings, with variation from 10.5% to 66.2%. The average height after 12 years reached 2.65 m and the diameter was 3.0 m × 3.44 m. Removal of salt crust had increased the rate of establishment by about 9.1–12.8%, whereas sand accumulations around the seedlings had increased the rate by only 0.9–6.7%. The rate of establishment in furrow plantings was about 28.1%.

The seedings were also performed in three technical variants:

1. Seeding below a mechanical cover of reed mats
2. Seeding under a mechanical cover with plastic mats
3. Seeding of granulated seeds in furrows with one-sided or two-sided accumulation of soil along the furrows

The seedings with granulated seeds on a snow cover were more effective than seeding on a soil surface without snow cover.

The plantings on experimental plot 3 were very successful insofar that a high natural germination rate was observed in the following years. After 6 years the new plants reached a height of 50–150 cm. The density of plants was very high, up to 20–95 individuals per square metre, which caused new establishments to be restricted to open gaps. Vitality was moderate. Seeds were observed up to 70 m from fruiting mother plants.

Experimental Plot 12

This plot is 7.5 km west of plot 5. The soils are moderately to strongly saline (Table 15.1). On the substrate surface remnants of reed were present. The whole soil profile consists of sand, some enriched with some silt at 30–60 cm. The groundwater level was at 1.65-m depth.

In 1989 this plot was devoid of any vegetation, except for very few *Haloxylon aphyllum* and *Tamarix* individuals. Between 1990 and 1992, in autumn and spring seedlings of *Haloxylon aphyllum, Tamarix, Halocnemum strobilaceum a*nd *Ceratoides papposa* were directly planted in the unprepared soil.

After 3 years the rate of establishment of *Haloxylon* was 1.3–64.8% for spring plantings and 1.5–23.6% for autumn plantings, that of *Tamarix* was 0–16% for autumn and spring plantings and that of *Halocnemum strobilaceum* was 0–69% for spring plantings and 0–2% for autumn plantings. *Ceratoides papposa* died off.

Experimental Plot 13

This plot is 3 km west of plot 12. The soils are degraded coastal solonchaks (Table 15.1). The soil profile exhibits sand between 0- and 70-cm depth. Below that a light loam follows. The groundwater is at a depth of 1.6 m.

In 1989 this plot was devoid of any vegetation, except for very few *Haloxylon aphyllum, Nitraria schoberi* and *Tamarix* individuals. Between 1990 and 1992, in autumn and spring seedlings of *Haloxylon aphyllum and Tamarix* were directly planted in the unprepared soil.

After 3 years the rate of establishment of *Haloxylon* was 25.5–64.1% for spring plantings and 1.4–24.1% for autumn plantings, and that of *Tamarix* sp. was 12–38% for spring plantings and 9–36% for autumn plantings.

Experimental Plot 14

This plot is 3.5 km west of plot 13. The soils are moderately saline (Table 15.1). The soil profile is entirely composed of sand. The groundwater level was at 1.55 m.

In 1989 this plot was devoid of any vegetation, except for very few *Halocnemum strobilaceum* and *Tamarix* individuals. Between 1990 and 1993, in autumn and spring seedlings of *Haloxylon aphyllum, Tamarix, Halocnemum strobilaceum a*nd *Ceratoides papposa* were directly planted in the unprepared soil.

After 3 years the rate of establishment of *Haloxylon* was 12.0–40.0% for spring plantings and 0–15.0% for autumn plantings, and that of *Tamarix* sp. was 8–32% for spring plantings and 3–34% for autumn plantings. *Halocnemum strobilaceum* and *Ceratoides papposa* died off.

15.2.1.2 Loamy-Clayey Soils, with Sand Cover (Habitat 2: Plots 1, 15, 16)

Experimental Plot 1

This plot is 3.2 km west of the former coastline, on the desiccated seafloor from the 1960s and the beginning of the 1970s. The soils are rather strongly salinized (Table 15.1). The upper soil horizon down to 30 cm is sandy, below it is loamy. The groundwater level is at about 1.8 m. A vegetation cover is totally lacking, except for very sparse individuals of *Halocnemum strobilaceum* and a few dry *Atriplex pratovii*.

In April 1989 seedlings of *Haloxylon, Tamarix* and *Ceratoides papposa* and saplings of *Tamarix, Calligonum* and *Populus* were planted. *Haloxylon* was subsequently planted until 1992, in autumn and in spring. All saplings and seedlings died in the same year as they had been planted except for *Haloxylon* saplings from spring 1989. They died after the dry summer of 1990.

Seeds from *Haloxylon* were also sown in a mixture with salt-free sand (1:5, 1:10, 1:15, 1:20). The seedings from autumn 1989 resulted in an intensive germination; most seedlings died in the second year. Seedings in 1990 and 1991 resulted in no germination. Granulated seeds (granulation hydrogel and clay) were also sown in autumn 1989. Germination was successful, but again most seedlings died in 1990 and the few remnants died in 1991. As a conclusion, the conditions for *Haloxylon aphyllum* on this experimental plot are not suitable. However, in the subsequent

Fig. 15.2 *Halocnemum strobilaceum* plant community with *Kalidium capsicum* (natural development) (Photo: Wucherer, September 2010)

years this area exhibited some invasion by *Halocnemum strobilaceum*. Intensive germination of *Halocnemum* was observed in 1990 and 1991. Five years later, most of the area was covered by *Halocnemum* up to 70% (Fig. 15.2). The bushes reached about 30–50 cm; and even a few individuals of *Halostachys caspica* were observed. Later, this habitat was also colonized by *Kalidium caspicum*.

After 3 years the rate of establishment of *Haloxylon* was 0–12.5% for spring plantings and 0% for autumn plantings.

Experimental Plot 15

This plot is 3.5 km west of plot 14. The soils are moderately saline (Table 15.1). This plot is adjacent to mobile barchan dunes. The soil profile is sandy from 0 to 30 cm, below it is loam and deeper it has increased clay content. The groundwater level was at 1.85 m.

In 1989 this plot was devoid of any vegetation, except for very few remnants of dead *Atriplex pratovii*. Between 1990 and 1993, in autumn and spring seedlings of *Haloxylon aphyllum, Tamarix* and *Halocnemum strobilaceum* were directly planted in the unprepared soil.

After 3 years the rate of establishment of *Haloxylon* was 0–16.5% for spring plantings and 0–11.5% for autumn plantings, that of *Tamarix* was 0–27.3% for spring plantings and 0% for autumn plantings, and that of *Halocnemum strobilaceum* was 0–37.3% for spring plantings and 0% for autumn plantings.

Experimental Plot 16

This plot is 43 km west of the former coastline on the desiccated seafloor of the 1970s, and west of the former island of Kaskakulan. The soil profile is sandy from

0 to 30 cm, below it is clay, both rather saline (Table 15.1). The groundwater level was at 2.0 m.

In 1989 this plot was devoid of any vegetation, except for very few remnants of dead *Atriplex pratovii*. Between 1990 and 1992, seedlings of *Haloxylon aphyllum, Tamarix, Halocnemum strobilaceum a*nd *Ceratoides papposa* were planted. The rate of establishment of *Haloxylon* was up to 61%, with the rate for plantings in spring being more than double that for plantings in autumn. After 10 years the plants had reached a height of about 1.72 m and a diameter of 1.86 m × 2.70 m. Vitality was very good.

After 3 years the rate of establishment of *Haloxylon* was 1.3–64.8% for spring plantings and 1.0–23.6% for autumn plantings, that of *Tamarix* was 0–15.6% for spring plantings and 0–15.7% for autumn plantings, and that of *Halocnemum strobilaceum* was 0–69.3% for spring plantings and 1.8% for autumn plantings. *Ceratoides papposa* died off.

15.2.1.3 Loamy-Clayey Soils (Habitat 3: Plots 2, 5, 6, 17)

Experimental Plot 2

This experimental plot is 11.6 km west of the former coastline on a site which became dry in the late 1960s and early 1970s. The soil profile exhibits sand in the upper 10 cm and then down to 120 cm it is loamy with an increasing content of clay. The groundwater level is at 2.3 m. Vegetation on the plot was very sparse with a few individuals of *Halocnemum strobilaceum* and *Atriplex pratovii*.

Seedlings of *Haloxylon, Tamarix and Kraschenínnikovia (Ceratoides)* and saplings of *Tamarix, Calligonum,* and *Populus* were planted in April 1989. *Haloxylon* was subsequently planted until 1992, in autumn and in spring. All saplings and seedlings of *Tamarix* and *Haloxylon* died in the same year as they had been planted. The rate of establishment of *Haloxylon* was 0–38.8% for spring plantings and 0% for autumn plantings. For *Haloxylon* saplings planted in spring 1991 the establishment rate was 38.8% after 10 years and for those planted in 1992 the establishment rate was 12.5% after 10 years. Then the average height was 157 cm. In those plots there was regular seeding and germination during the last 5 years. Seedlings reached 10-cm growth height after the first year. The older saplings and young plants had a height of up to 1.1 m. Coverage reached 50–80%. Seeds from fruiting plants were detected at a distance of at least 10 m from mother plants. This successful establishment is correlated with very good weather conditions during the years 1991 and 1992 and the right time of the plantings. Other species died off.

The seedings had been done with some specific preparations of the substrate, especially a mechanical pressing of the surface. Then reed bundles were used at 3-m distance, and along those 20-cm-high plastic walls had been installed. On both sides of these protective plastic walls the seeds were sown in the following four technical variants:

1. Removal of salt crust and seedings with loosening of soil
2. Removal of salt crust and seedings with a salt-free sand mixture (1:5)
3. Seeding on salt crust with loosening of soil
4. Seeding on salt crust without other technical substrate preparations (control)

Almost all seeds germinated perfectly, but almost all seedlings (more than 99%) died the following summer. Only some single individuals could establish themselves, especially with the first two treatments. Those individuals were the germinal centre for a small but considerable stock and spreading community after 10 years.

Experimental Plot 5

This experimental plot is about 16.7 west of the former coastline. It is situated on the desiccated seafloor of the 1970s. The soils are strongly saline (Table 15.1). The upper horizon of soil substrate is composed of loam (0–10 cm), from 10 to 30 cm it is sand and below 30 cm it is mainly loam with increasing parts of clay. The groundwater level is at 1.8 m. Only very few individuals of *Haloxylon* with a height up to 1.5 m were present.

In April 1989 seedlings of *Populus* and *Elaeagnus* were planted. In autumn 1989 and the subsequent 2 years, *Haloxylon, Halocnemum* and *Tamarix* were planted directly on the unprepared surface. Additionally, *Haloxylon a*nd *Tamarix* were planted in the following variants:

- Removal of salt crust
- Sand heaps around the stem base of seedlings and saplings
- Plantings in furrows

Most of the seedlings died (less than 1% rate of establishment). Very few *Haloxylon* saplings stayed alive. But these few individuals became parallel to the slowly decreasing salinity in soil the main centres for a subsequent secondary colonization. In the furrow plantations the rate of establishment was comparatively good at 10–14%. After 8 years the plants reached a height of about 129–143 cm, with a diameter of 130 m × 167 cm. Between and in the furrows the secondary colonization was considerable. The young offspring were about 2–4 years old. On average there were three to four offspring per 10 m in the furrows. Between the furrows about five to ten individuals per square metre were counted. Plantings in furrows exhibited first a rather low rate of establishment, but later a considerable and successful secondary colonization could be observed.

After 3 years the rate of establishment of *Halocnemum strobilaceum* was 0–59.8% for spring plantings and 0–28.1% for autumn plantings. *Tamarix* died off.

Experimental Plot 6

This plot is between plots 3 and 5. The soils are moderately saline (Table 15.1). There is a sandy layer between 0 and 10 cm, below that down to 2 m there is loam and in lower parts there is increasing clay. The groundwater is at 1.9 m.

During the planting time in 1989, the soil surface was free of any vegetation; it was densely covered by shells. In the following 4 years, seedlings of *Haloxylon aphyllum* und *Halocnemum strobilaceum* were planted in autumn and in spring directly in the unprepared substrate in long rows of 100-m length. In each row the distance between seedlings was between 1 and 1.6 m. The rows were separated by 10, 20 and 30 m for *Haloxylon aphyllum*, and 5, 10, and 20 m for *Halocnemum strobilaceum*.

After 3 years the rate of establishment of *Haloxylon* was 3.0–42.0% for spring plantings and 8.0–21.4% for autumn plantings, and that of *Halocnemum strobilaceum* was 23.8–76.0% for spring plantings and 0–20.5% for autumn plantings. *Tamarix* had a very low establishment rate (2–4%).

Experimental Plot 17

This plot is 8.5 km west of plot 16, about 51 km west of the former coastline. The soil is a degraded loamy-clayey coastal solonchak (Table 15.1). The soil profile is sandy only from 0 to 10 cm, and below that it is loam with clay. The groundwater level was at 2.1 m.

In 1989 this plot was devoid of any vegetation, except for very few dead *Atriplex pratovii* remnants. Between 1990 and 1992, in autumn and spring seedlings of *Haloxylon aphyllum, Tamarix* and *Halocnemum strobilaceum* were directly planted in the unprepared soil.

After 3 years the rate of establishment of *Haloxylon* was 0–18.2% for spring plantings and 0–3.0% for autumn plantings, and that of *Halocnemum strobilaceum* was 0–45.6% for spring plantings and 0–26% for autumn plantings. *Tamarix* had a very low establishment rate (0–3%).

15.2.1.4 Discussion

The rate of establishment and the growth of *Haloxylon aphyllum* is very variable. On plots 3, 12, 14 and 16, with low salinities in the upper horizon, the establishment was successful (Fig. 15.3). On plot 5 establishment happened only with improved substrate conditions, e.g. in furrows. On plot 1, where the salinity was high, almost no success with saxaul was recorded. Instead, a community with *Halocnemum strobilaceum* started to develop.

Plantings in furrows is preferential for establishment. *Haloxylon aphyllum* exhibits a higher rate of establishment for spring plantings, especially on sandy and sandy-loamy substrates (Figs. 15.4 and 15.5).

Fig. 15.3 *Haloxylon aphyllum* plantings (12 years old) on the Kaskakulan transect (Photo: Wucherer, September 2003)

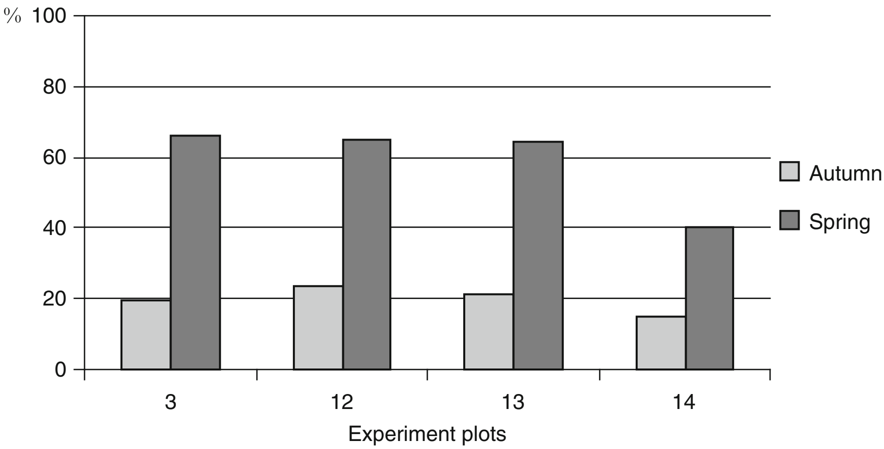

Fig. 15.4 Establishment rate of *Haloxylon aphyllum* on sand soils from autumn and spring plantings

Despite the rather good rate of establishment in spring plantations, the variability of *Haloxylon* is still very high even within plots:

- On sandy soils, 1.3–64.8%
- On sand-covered loamy-clayey soils, 0–68.4%
- On loamy-clayey soils, 0–40.6%

For *Halocnemum strobilaceum* this variability is very similar in and between plots and from year to year:

- On sandy soils, 0–69%
- On sand-covered loamy-clayey soils, 0–75.6%
- On loamy-clayey soils, 0–76.0%

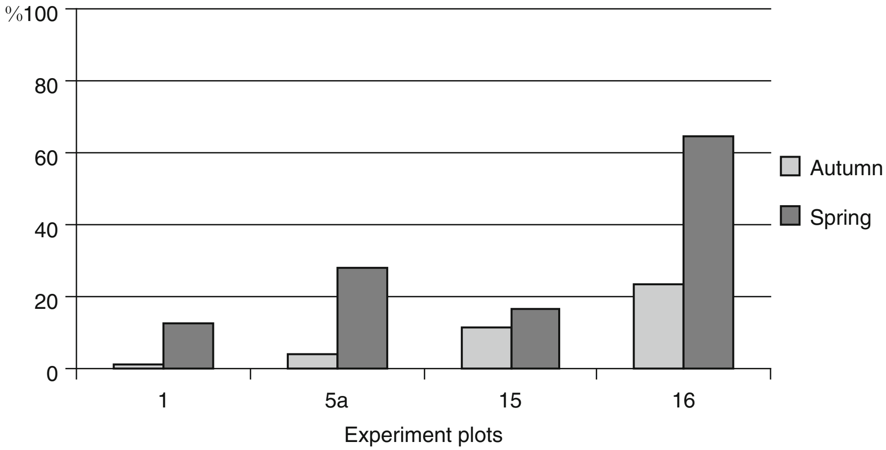

Fig. 15.5 Establishment rate of *Haloxylon aphyllum* on coastal solonchak with a layer of sand in the topsoil from autumn and spring plantings

This also indicates very high variability from year to year according to climatic conditions.

The removal of the salt crust and accumulation of sand around the seedlings exhibits only a marginal positive effect. Seedings with *Haloxylon* are, however, distinctly more successful in mixtures of seed and sand (1:5). Also, granulated seeds can be used. Seeding on a snow cover in spring is especially successful.

In general, the establishment was successful on sandy soils and partly on loamy coastal solonchaks with sand cover and a low salinity of the topsoil. Establishment on the loamy coastal solonchaks occurred only with improvement of the soil surface, such as in the furrows. Springtime is more effective for the accomplishment of the plantings: the establishment is clearly higher. Precipitation variability plays a key role in the establishment of species and in the sustainability of plantings, which is very difficult to achieve.

Haloxylon aphyllum is the most promising culture species for phytomelioration on the desiccated seafloor. Experiments have shown that the plantings were clearly more effective than sowing. In all cases, even only a few surviving individuals play a decisive role in the formation of a future vegetation cover within only a few years.

15.2.2 Growth Rates

The growth rates of *Haloxylon aphyllum*, *Halocnemum strobilaceum* and *Tamarix* on various stands were investigated during the planting experiments (Table 15.2). *Haloxylon aphyllum* bushes reached a maximum height of 2.56 m after 10 years on sandy sites, and a diameter of 2.20 m × 3.20 m. The vitality on loamy-clayey

Table 15.2 Growth rates of planted species

Planted species	Age (years)	Biometrical parameters (cm)		
		Height	Diameter of bushes	
			Along the rows	Perpendicular to the rows
Sandy soils				
Haloxylon aphyllum	3	94.7 ± 5.4	81.1 ± 5.2	79.4 ± 5.8
	5	129.8 ± 4.8	104.7 ± 6.4	115.2 ± 5.6
	6	142.6 ± 3.2	123.2 ± 5.6	151.5 ± 6.3
	7	195.9 ± 5.0	170.0 ± 10.1	205.8 ± 7.5
	8	239.4 ± 6.7	254.2 ± 10.9	287.5 ± 9.4
	10	255.8 ± 8.8	222.8 ± 7.5	322.6 ± 12.7
Halocnemum strobilaceum	5	33.4 ± 2.5	88.2 ± 3.6	91.5 ± 2.9
	6	34.9 ± 1.3	94.4 ± 2.6	98.5 ± 3.2
	7	41.1 ± 1.5	112.3 ± 5.6	119.8 ± 4.6
	8	47.6 ± 2.3	143.8 ± 3.9	151.8 ± 4.7
	10	46.0 ± 0.9	139.4 ± 3.4	157.3 ± 3.1
Tamarix sp.	5	48.8 ± 14.8	57.5 ± 10.3	52.5 ± 10.3
	6	74.5 ± 5.9	71.8 ± 4.5	76.4 ± 5.7
	7	122.5 ± 31.7	161.3 ± 43.7	151.3 ± 36.1
Loamy-clayey soils, with sand cover				
Haloxylon aphyllum	4	126.4 ± 6.9	103.6 ± 7.1	110.1 ± 6.4
	5	154.9 ± 1.4	129.1 ± 3.7	143.6 ± 4.8
	6	166.2 ± 5.2	160.8 ± 7.3	164.4 ± 7.7
	7	165.6 ± 8.4	154.9 ± 10.7	161.3 ± 11.2
Halocnemum strobilaceum	4	32.4 ± 2.9	99.7 ± 3.1	98.1 ± 3.1
	5	44.4 ± 1.6	111.0 ± 3.2	114.0 ± 2.8
	6	45.4 ± 1.9	105.5 ± 3.6	125.0 ± 3.6
	7	33.8 ± 3.1	88.8 ± 8.1	108.4 ± 6.9
Tamarix sp.	5	70.6 ± 4.3	78.8 ± 4.8	83.9 ± 4.9
	6	81.1 ± 4.9	101.3 ± 5.9	104.8 ± 4.7
	7	93.9 ± 8.1	98.9 ± 9.1	99.4 ± 8.8
Loamy-clayey soils				
Haloxylon aphyllum	4	96.9 ± 7.9	84.6 ± 6.8	85.0 ± 6.9
	5	103.3 ± 6.4	93.4 ± 7.8	95.6 ± 7.5
	6	157.4 ± 4.1	134.1 ± 3.9	127.0 ± 4.7
Halocnemum strobilaceum	4	23.3 ± 1.4	61.1 ± 4.7	68.2 ± 4.9
	5	27.4 ± 3.8	76.5 ± 2.2	77.9 ± 2.3
	6	31.0 ± 1.2	103.4 ± 3.0	95.9 ± 2.8
	7	41.3 ± 3.8	125.3 ± 4.1	119.3 ± 4.1
Tamarix sp.	6	72.2 ± 18.3	70.7 ± 9.6	62.9 ± 8.9
	8	100.9 ± 5.6	113.0 ± 7.8	117.8 ± 7.6

soils with blown sand cover was highest after 6 years on sand-covered coastal solonchaks with 1.66-m height and 1.60 m × 1.64 m diameter (Fig. 15.6, Table 15.2).

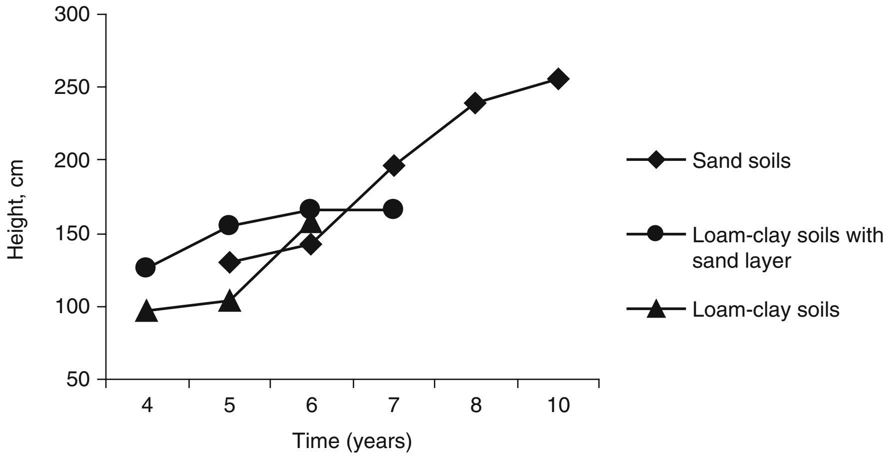

Fig. 15.6 Growing rate of *Haloxylon aphyllum* on different soil types

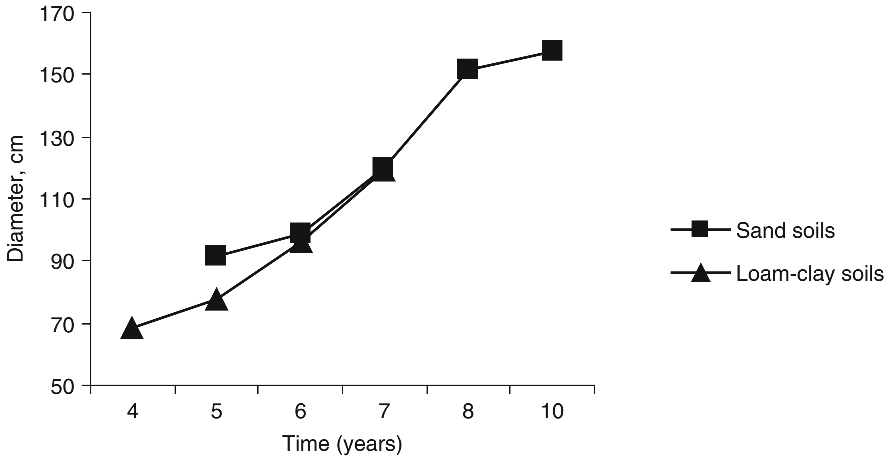

Fig. 15.7 Growing rate of *Halocnemum strobilaceum* on different soil types, indicated by the diameter of bushes

Halocnemum strobilaceum has a maximal vitality of 8–10 years old on sandy soils (height 48 cm, the diameter reached 1.44 m × 1.52 m). The vitality is the same on sandy and on loamy-clayey sites with blown sand cover in 6–7-year-old plants (Figs. 15.7, 15.26).

On heavy soils and with higher salinities, the vitality of *Haloxylon* is reduced. In *Halocnemum strobilaceum* the growth rate is comparable with the growth rates for the other two habitats.

15.2.3 Technology for the Stabilization of Barchans

Fixation and stabilization of barchan dunes was done with distinct methods of mechanical protection. The Forest Institute in Tashkent suggests using mechanical protection and then plantings of *Atriplex* and *Tamarix* with a distance of 4–5 m between the rows. Our investigations have shown that even only 3-m distance between rows is too much for a sufficient fixation of barchans. The optimal distance between rows was checked using reed bundles of 10–12-cm diameter and plastic covers with a width of 30–35 cm. In summer six experimental plots were chosen on six barchans.

15.2.3.1 Barchans (Habitat 4: Plots 7, 8–10, 19–21)

Experimental Plot 7

This plot is 5 km west of plot 5. The soil is covered with small barchan dunes. The soil profile exhibits sand from 0- to 70-cm depth and is slightly saline (Table 15.1). Below 70 cm there is loam and clay mixed until 2-m depth.

The plot area was free of vegetation in 1989. Within the following 3 years, seedlings of *Haloxylon aphyllum* and *Tamarix* species were planted in spring and autumn on one barchan surface, and seeds of *Haloxylon aphyllum* were sown. The length of the barchan was 42 m, the width was 20 m and the maximal height was 106 cm. The surfaces of barchan sands were covered by bundles of reeds in rows separated by 3 m.

Experimental Plots 8–10

These plots were similar to plot 7, bare of vegetation with isolated barchan dunes. The plantings were performed in the same manner as in plot 7. Fixation of the barchan surface, however, was different. In plot 8, reed bundles were placed not horizontally but vertically up to 30 cm; in plot 9 a plastic cover was used, fixed about 20 cm above the surface, in 15 rows. The same was done for plot 10, with 20 rows, each 35 m long, and with 3 m between rows.

Experimental Plots 19–21

All three plots are south of plot 5. The soil is covered by a rather dense pattern of barchans, with low to moderate salinity (Table 15.1).

In 1989 this plot was devoid of any vegetation. In 1991 one barchan in each plot was covered with reed bundles in rows separated by 1, 2 and 3 m. In 1992 *Haloxylon aphyllum a*nd *Tamarix ramosissima* were planted along these rows.

15.2.3.2 Discussion

The distances between rows were 1.0, 2.0 and 3.0 m. The average size of one barchan was about 0.12 ha, and the whole area fixed was 0.15 ha. This fixation experiment used 2,700 m of reed bundles and 2,700 m of plastic ribbons. Half of the barchans was covered in spring and the other half was covered in autumn for the relevant plantings. Along the protective rows on the barchans, seedlings of *Haloxylon, Tamarix, Eremosparton, Astragalus* and *Calligonum* were planted in spring and autumn. Additionally seedings with *Haloxylon, Calligonum* and *Nitraria* were done.

The seedings were not successful. The saplings of *Astragalus, Eremosparton* and *Calligonum* did not establish themselves. The rate of establishment of *Haloxylon* remained rather low (Table 15.3) at 2.5–7.6% for 3-year-old plants (height 0.55–0.87 m) and 1.2–7.5% for 7-year-old plants (height 1.87–2.12 m) of

Table 15.3 Growth rates of *Haloxylon* and *Tamarix* on barchans

Planted species	Age (years)	Biometrical parameter (cm)			
		Height (cm)	Diameter of plants		
			Along the rows	Perpendicular to the rows	Establishment rate (%)
Distance between reed bundles 1.0 m					
Haloxylon aphyllum	3	50.5 ± 2.9	–	–	2.5
	5	155.7 ± 7.1	164.3 ± 11.6	147.1 ± 8.6	1.2
	7	192.3 ± 7.2	222.0 ± 15.7	215.0 ± 12.4	1.2
Tamarix sp.	3	65.0 ± 8.8	–	–	1.5
	5	122.1 ± 14.1	122.2 ± 5.4	133.6 ± 6.3	1.2
	7	158.3 ± 10.7	196.7 ± 14.1	202.8 ± 16.4	1.2
Distance between reed bundles 2.0 m					
Haloxylon aphyllum	3	65.0 ± 8.8	–	–	7.0
	5	158.6 ± 19.1	179.3 ± 21.5	170.7 ± 17.2	2.0
	7	187.1 ± 10.1	232.1 ± 13.6	222.9 ± 13.8	2.0
Tamarix sp.	3	45.5 ± 9.5	–	–	1.5
	5	135.0 ± 21.0	147.5 ± 25.0	172.5 ± 23.0	1.0
	7	124.2 ± 11.7	128.3 ± 24.0	132.5 ± 22.6	0.5
Distance between reed bundles 3.0 m					
Haloxylon aphyllum	3	60.1 ± 9.1	–	–	–
	5	180.8 ± 4.4	144.3 ± 4.2	157.0 ± 3.7	7.6
	7	197.8 ± 4.3	184.4 ± 5.5	197.6 ± 5.4	4.7
Tamarix sp.	3	50.5 ± 8.4	–	–	7.5
	5	93.1 ± 5.9	100.9 ± 4.8	111.1 ± 6.1	3.2
	7	100.9 ± 5.6	92.8 ± 3.7	103.7 ± 6.2	3.2
Distance between plastic covers 3.0 m					
Haloxylon aphyllum	3	87.4 ± 6.6	–	–	5.6
	6	212.4 ± 8.3	178.9 ± 7.4	200.5 ± 8.8	2.7
Tamarix	3	42.3 ± 2.4	–	–	3.4
	6	122.5 ± 4.2	137.5 ± 14.4	132.5 ± 11.8	3.0

Haloxylon aphyllum. In *Tamarix* the height of 3-year-old plants was 0.42–0.65 m, and that of 7-year-old plants was 1.22–1.58 m.

The distance between rows did not have any influence on establishment or growth in *Haloxylon*. In *Tamarix* the vitality was lower in the rows separated by 3 m. Any mechanical fixation on barchan dunes creates more favourable conditions for the germination of diaspores from adjacent plants. Additionally, sedimentation of dust leads to better soil conditions after 7 years, which can be seen by the extraordinary germination rate of 28,000 seedlings per hectare, mainly along the protective rows. *Haloxylon* starts flowering at the age of 3–4 years; additionally, with immigrating therophytes the plant cover can then reach up to 50–60%. In general, on the barchan plots the primary establishment rate was relatively low (below 20%), but the secondary colonization was very effective.

15.3 Combating Desertification and Rehabilitation of the Salt Deserts on the Desiccated Seafloor

15.3.1 Reforestation Potential of Sandy and Salty Sites and Habitat Conditions

Phytoreclamation activity was conducted in the framework of the BMBF-GTZ/CCD project in 2002–2005. The Department of Ecology (University of Bielefeld in Germany) cooperated with the Institute of Botany and Phytointroduction (Almaty), the Institute of Agroecology (Kyzyl-Orda), the Institute of Forest Economy (Kokchetav), the forest firm Syr-Tabigaty (Kyzyl-Orda), and Barsa-Kelmes Nature Reserve (Aralsk). The following tasks were envisaged:

- To identify the habitat diversity in relation to reclamation
- To plant on large areas with different techniques
- To test the phytoreclamation properties of *Haloxylon aphyllum* in all its ecological amplitude from the sandy soils and barchans to the crusty-puffy coastal solonchaks
- To develop recommendations for phytoreclamation on large areas of the dry seafloor

The sandy areas of the desiccated seafloor define the older surfaces which became dry in the 1960s and 1970s, mainly between the deltas of the Syr Darya and the Amu Darya and around the former islands of Barsa-Kelmes and Vozrozhdeniya. Fine-grit sands with a grain size of 0.1–0.5 mm are characteristic of the whole coastal region. Medium-grained sands are only found in the estuary areas of the Syr Darya and the Amu Darya. The rock-forming material is mainly quartz. The amount of shell limestone in the sand ranges widely from 30% to 70%. The sand depositions at the eastern coast lie at 46–53 (rarely at 43) m asl, above sea level (asl), at the northern coast at 50–53 (rarely at 48) m asl and at the southeastern

Fig. 15.8 Salt desert on the dried-out lake bed of the Aral Sea around the former island of Barsa-Kelmes (Photo: Wucherer, June 2004)

coast at 36–53 m asl. The sandy depositions have been dry for 30–50 years. Plantings on sandy substrates are seen as a good prospect in the whole Central Asian region.

A much greater challenge is the salty substrates. The dry seafloor area of the 1980s, 1990s and even partly of the 1970s (about 70% of the surface area) is salt desert (Fig. 15.8). Here, the surface is covered with a salt crust. These salt surfaces are difficult to approach. The surface of the dry seafloor of the 1990s can exceptionally be approached smoothly in the area of the Bayan transect between the islands of Barsa-Kelmes and Kokaral. It is a mosaic of salt desert and sparse therophytic plant communities. These therophytic communities are dynamic, they are not stable and are no guarantee for surface protection. The salt deserts are very variable, and they represent a plurality of soil types: marsh solonchaks, sandy solonchaks, crusty-puffy coastal solonchaks, loamy coastal solonchaks with sand cover, takyr-like solonchaks, degraded solonchaks, etc. (Ishankulov and Wucherer 1984; Yair 2001). The soil type, horizonation and grain size of the lake deposits are crucial for salinity balance and the phytomeliorative properties of the soils. The conditions of reforestation are very hard and normally need improvement of soils. The following recommendations for phytoreclamation from Yair (2001) were accepted:

1. The sedimentary history of the Aral Sea area, characterized by frequent fluctuations of sea level, resulted in a complicated mosaic of environmental and edaphic conditions. This initial puzzle was affected later on by sand deposits in some parts of the desiccated sea bottom. This evolution, coupled with the high sensitivity of desert plants to slight spatial and temporal changes in salinity and water regime, determines the guidelines for a realistic phytoreclamation management policy (Yair 2001). The following principles are hereby indispensable:

    - Reclamation measures cannot be based on a single principle. They should be closely adapted to the local environmental conditions. In other terms, the recovery of the natural vegetation, and the prospects for reclamation, are not only a function of time since sea recession, but rather a function of the local sedimentary sequence.

- The prospects for reclamation are highly conditioned by particle size and thickness of the sedimentary units, which determine soil salinity and soil water regime.
- Sandy areas, characterized by a low salinity, good infiltration, good water preservation and low groundwater levels, represent the most favourable environment for the natural recovery of the vegetal cover as well as for phytoreclamation. At the other end of the spectrum we find the solonchak sites characterized by a very high salinity, limited infiltration and shallow saline groundwater. These areas are devoid of any vegetation and represent the main source of airborne dust and salt transported towards cultivated lands and villages. They represent the most problematic areas for reclamation, additionally being the main cause for the deterioration of adjoining arable lands.

2. The results of the experiments presented can serve as the basis for reclamation policy in the area. They lead to the conclusion that solonchak areas are very resilient to a change in their edaphic conditions. Planting without changing the environmental conditions is not an appropriate way to improve the situation. Reclamation of such areas must therefore be based on the alteration of their hydrological regime, if not all over the surface, at least locally.
3. Sand deposition on arable lands is very often regarded as a major cause of land degradation and desertification. This approach is not relevant in the case of sand deposition over silty-clayey, saline, compacted and hydrophobic areas, such as solonchaks, underlain by shallow saline groundwater. Sand deposition over such surfaces has only a beneficial effect. As stated earlier, a topsoil sandy layer has five beneficial effects: it improves infiltration depth, lowers the level of the saline groundwater, increases salt leaching, reduces capillary rise and increases water storage by the creation of a perched freshwater lens on top of an impervious saline substratum. Any reclamation policy should therefore attempt to artificially increase sand cover on top of saline solonchak surfaces.

According to the conditions of afforestation, we basically distinguish the following types of phytomelioration sites on the dry seafloor (Wucherer and Breckle 2005):

(A) Sand deserts

(A1) Sandy soils

(a) Sandy nonsaline soils, soil profile sandy of 2-m depth or more
(b) Sandy saline soils, soil profile sandy of 1–2-m depth

(A2) Barchan or dune fields

(a) A dune height of approximately 1 m
(b) A dune height of 1–3 m (rarely more)
(c) Sand dunes higher than 3 m (only the dunes along of the former coastline)

(B) Salt deserts

(B1) Coastal degraded solonchaks with a layer of sand in the topsoil and with a maximum of salinity in a certain soil depth (often from 20 to 100 cm)

(a) Loamy coastal degraded solonchaks with sand cover, soil profile mostly loamy-clayey, surface layer of sand
(b) Loamy coastal degraded solonchaks, soil profile with a sandy horizon down to 1 m

(B2) Crusty-puffy coastal solonchaks, soil profile loamy-clayey with or without sand cover of 1-m depth (with rather high salinity)

(a) Coastal solonchaks with maximal salinity on the soil surface
(b) Coastal solonchaks with maximal salinity at a certain soil depth (often 20–40 cm).

(B3) Marshy solonchaks

15.3.2 Methodical Approach

The planting plots were selected by Wucherer and Zhamantikov. The technology for the plantings was developed by Wucherer, Breckle and Kaverin.

The substrate surface was prepared and plantings were conducted in November 2002 and March 2004. Several plots (Fig. 15.9, Table 15.4,) were used for plantings south of the former island of Kushzhitmes (Fig. 15.1, area 1). It comprised an area of 248.1 ha of salt deserts with different salinity and texture on the dry seafloor.

The methods were:

1. Planting with use of a commercial tree planter, depth of tillage approximately 20–25 cm (238.6 ha);
2. Manual planting into previously prepared furrows for sand accumulation and into pits filled by sand (9.5 ha)

The plantings were arranged as follows:

- Double-row strips (with a separation of 5 m) from 200- to 1,000-m length with a distance of 30–35 m between the strips.
- One-row strips of 200 m length with a distance of 20 m between the strips.
- Plantings in pits filled with sand.
- Different locations on sandy and loamy soils with various salinities were chosen.

The evaluation of the plantings was done 1 and 2 years later (Fig. 15.10).

Seeds and saplings of local plants (*Haloxylon aphyllum, Tamarix laxa, Halocnemum strobilaceum*) were planted in November 2002 to March 2004. These species have different ecological adaptations to salinity (Chap. 12).

Haloxylon aphyllum (saxaul) is a stem-succulent, shrubby halophyte, which can grow up to 4–5 m, with a wide Irano-Turanian distribution. This species is

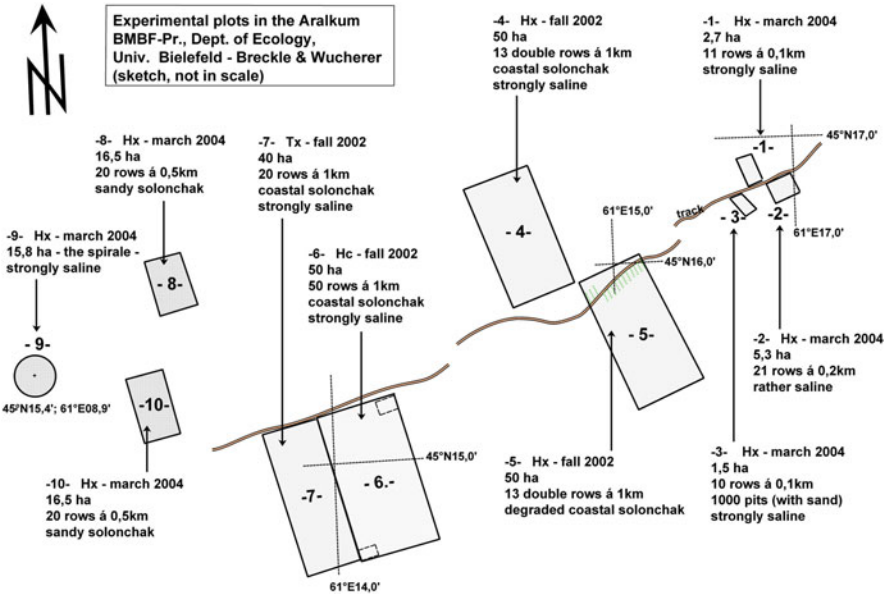

Fig. 15.9 Distribution of experimental plots in the surroundings of the former island of Kushzhitmes at the eastern coast of the Aral Sea

Table 15.4 Scheme of plantings on coastal solonchaks

Phytomeliorant species	Total planting area (ha)	Area of coastal solonchaks (ha)	Area of coastal solonchaks with sand layers (ha)
Haloxylon aphyllum	158.3	59.5	98.6
Halocnemum strobilaceum	50	50	–
Tamarix hispida	40	40	–
Total area	248.1	149.5	98.6

Fig. 15.10 German–Kazakh expedition in the surroundings of the former island of Kushzhitmes at the eastern coast of the Aral Sea (Photo: Wucherer, June 2004)

Table 15.5 Vitality parameters of *Haloxylon aphyllum* under different groundwater levels

Groundwater table (m)	2.5–5.0	5.0–7.0	>7	Very deep
Height (m)	4–7	2.5–4.0	1.5–2.5	1–1.5
Dry matter of wood (t ha^{-1})	30–50	10–25	5–10	<5

After Leontyev 1954

characterized by a broad ecological amplitude. It is normally found on moderate to slightly saline soils, and also on sand dunes and even on hamada rocky sites. Vitality strongly depends on groundwater availability; it produces a huge and deep root system (Table 15.5). Reproduction of saxaul is normally by seeds, but the cuttings from thin plants branches can regenerate vegetatively. The germination rate is very high and often up to 80–90%. The rate of establishment is much lower. Under natural conditions, only in very favourable years with enough soil humidity from winter rain and snow does a conspicuous rejuvenation take place, which is only every 3–5 years. The lifetime of saxaul is about 30–50 years but individuals of more than 50 years up to 100 years of age have been observed (Repetek desert research station in Turkmenistan).

Tamarix hispida is a recreting halophyte, a shrub with an Irano-Turanian distribution. Reproduction is by seeds as well as by suckers. Growth height under optimal conditions can reach 3 m, but normally it is 1–2 m. On saline sites *Tamarix hispida* needs a good groundwater level (1–2 m) for survival. The lifetime is only 10–15 years. On recent assimilating shoots of 30–40-cm length numerous scalelike leaves are formed; their length is 2–9 mm. These scaly leaves exhibit numerous salt glands (about 150–240 per square millimetre) on both surfaces. Recretion of salt is mainly by the salt glands as crystaline NaCl, but also by shedding leavy scales and branches. In July and August about 30–50% of the young branches can be lost depending on the drought situation.

Halocnemum strobilaceum is a stem-succulent euhalophyte, a dwarf shrub with a huge distribution from the Mediterranean to China. The size of the shrubs rarely exceeds 70 cm; the diameter can reach more than 2 m. Reproduction is by seeds and vegetative. The lifetime is about 10–12 years. Optimal development is observed with a groundwater depth of about 1–2 m. Vitality is less with a groundwater depth below 3 m, but vegetative sprouting is enhanced. This flat shrub often forms small mounds (chokolaks) by accumulation of dust and sand, forming a nepkha desert. Seed germination only occurs on wet solonchaks. *Halocnemum strobilaceum* is a halophyte which exhibits one of the highest salinity tolerances; accumulation in the small scaly succulent leaves can reach 50% of dry matter.

15.3.3 *Haloxylon aphyllum* Plantings on Different Sites

15.3.3.1 Plantings on Sandy Soils with Low Salinity (A1a Habitat)

The rate of infiltration of water in the sand is very high; capillary movement is very limited. This leads quickly to eluviation of the salts and destruction of the salt crust

(Yair 2001). The bigger the portion of sand cover in the soil profile, the faster leaching starts. These soils are almost unexceptionally spread over the dry surface of the 1960s. The plantings by the Institute of Forestry of Tashkent at the Aral Sea's southern coast on these surfaces, which were carried in the early 1990s, were successful. In the course of 13–15 years after the desiccation, the soil profile was desalinized up to 2-m depth. The causes were the sandy soils and the low saltwater concentration of the former lake water (10–15 g/l) at the beginning of the Aral Sea's desiccation.

The soil is low in humus (0.33% in the crust, 0.16% in lower horizons) and low in total nitrogen (0.011–0.024%). Carbonate is maximal in the lower horizons (4.9%; 1.52% on the surface). The pH is about 8.0–8.2. CEC is very low (3–6 meq/ 100 g) with prevailing calcium. The salinity in the soil profile varies from 0.36% to 0.58%. The salinity is due to sulphate and chloride.

The ecological conditions are very good for the natural germination and establishment of psammophytes (sand plants) (Wucherer and Breckle 2001, 2005; see Chap. 10). Within 10–20 years after desiccation, a persistent vegetation had developed on these sites. Blowing out of sand and salt dust from these substrates is very low.

15.3.3.2 Plantings on the Barchan and Dune Fields (A2a,b Habitat)

The lack of diaspores on the sandy sites of the desiccated seafloor of the 1970s and 1980s leads to a very slow primary succession (see Chap. 10). The huge open areas exhibit strong deflation and quick creation of dune fields. Along the eastern coast and the former islands of Uzun-Kair, Kyzylbai, Akpasty and Kosaral and in the Akpetki Archipelago the dune fields are widespread. The dune fields are oriented towards the south, southwest and southeast. The barchan fields between the former islands and the eastern coast are located on the lee side, and they became slowly and sparsely covered with vegetation (Fig. 15.11). The barchan fields on the western side of the islands are usually without vegetation, they spread to the west and cover

Fig. 15.11 Vegetation cover of the dune fields with *Haloxylon aphyllum* (Photo: Wucherer, September 2003)

Fig. 15.12 Plantings of *Haloxylon aphyllum* in the dune region on the dry seafloor of the 1970s (Photo: Wucherer, September 2004)

the primary loamy coastal solonchaks and thus diminish the salt-dust asset of the primary lake bottom.

Small-scale plantings in the dune region at the eastern coast (Fig. 15.1, area 1) were successful (Fig. 15.12). The establishment rate of *Haloxylon aphyllum* was above 80%.

At the former southern coast, extensive plantings on the dune fields were conducted successfully by the GTZ project (Hüfler and Novitskiy 2001).

15.3.3.3 Plantings on Poorly to Moderately Saline Sandy Soils (A1b Habitat)

These soils are sandy usually up to 1-m depth, in the upper soil desalinized and in the middle part of the soil profile poorly to moderately saline (Fig. 15.9, plot 10, 16.5 ha, 20 rows in 0.5 km). Such soil conditions are beneficial for the settlement and establishment of different plant species as well as for reforestations. Naturally, mixed plant communities are formed on these habitats with psammophytes, halophytes and tugai species. But vast dune fields and sand deserts are created because of limited seed input. At such a location, successful planting was carried out in March 2004. In June 2004 the establishment rate of *Haloxylon aphyllum* on average was over 90% (Figs. 15.13 and 15.14). By stabilization of the groundwater table there is a possibility to develop long-term plant communities.

15.3.3.4 Plantings on Coastal Solonchaks with a Sand Layer (B1a)

This habitat indicates a loamy-clayey soil profile, which has a sand layer on the soil surface. The sandy overlay can be of natural origin or secondarily formed by aeolian activities. Such a sandy layer eases the germination and establishment conditions for plants. This habitat is present at the spreading border of the sandy sedimentation deposits on the dry seafloor and at the edge of the newly forming dune fields and salt deserts. The soils offer good germination conditions for species

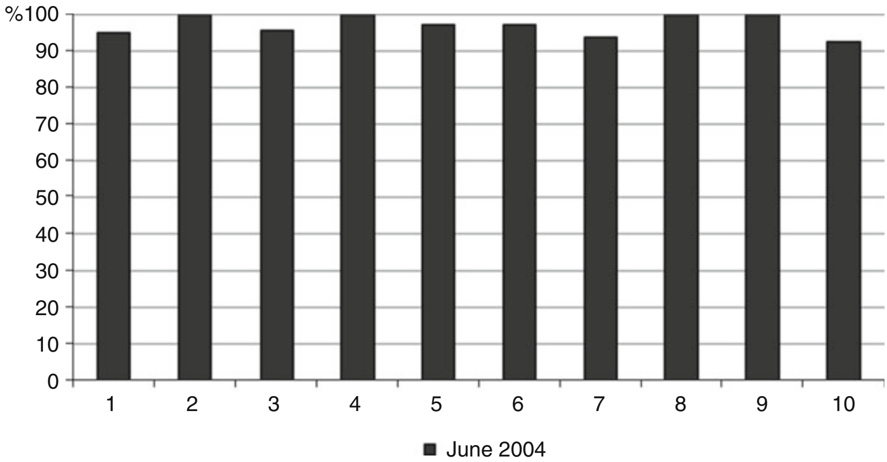

Fig. 15.13 Establishment rate of *Haloxylon aphyllum* on poorly to moderately salinized sand soils, ten strips, 100 m long (Plantings in March 2004 evaluation in June 2004)

Fig. 15.14 Plantings of *Haloxylon aphyllum* on poorly to moderately salinized sand soils (Plantings March 2004; record, June 2004) (Photo: Wucherer)

which tolerate moderate salinity, such as *Haloxylon aphyllum* and *Nitraria schoberi*. This location is not favourable for psammophytes (real sand plants such as *Calligonum*). The spontaneous vegetation is some annual saltworts and *Senecio noeanus, Strigosella circinnata, Atriplex pratovii* and *Salsola nitraria* with up to 15–20% coverage.

The soil is low in humus (0.62% in the crust, 0.25% in the lower horizons), and is low in total nitrogen (0.017–0.045%). Soil carbonate is up to 6%, 3% in the upper horizons. The pH is 8.0–8.2. CEC is rather high in clay horizons (26.5 meq/100 g), but is low in the sandy surface horizon (6.3 meq/100 g). Calcium prevails, but there is considerable magnesium in lower horizons, whereas the amount of sodium is rather low (2%, indicating no solonetzic structure). The soil profile is slightly saline down to 23 cm (0.18–0.93%). The lower horizon has a salt content of 2.13%. The salinity is due to chloride and sulphate.

The plantings on the coastal solonchaks with a thick sandy layer (50 cm, 20 rows, 0.5 km long) from March 2004 were successful (Fig. 15.9; plot 8, 16.5 ha). The establishment rate varied between 80 and 100% and did not change in autumn (Figs. 15.15 and 15.16).

Another habitat for the plantings of *Haloxylon* (plot 5, 50 ha, Fig. 15.9) is a loamy coastal solonchak with sandy cover of 30 cm on topsoil (autumn plantings). The 0–30-cm horizon is sandy and loamy sand. The topsoil to about 15-cm depth is dry, but from 15- to 30-cm depth is moist. In the horizons of 30–50 cm, thin layers

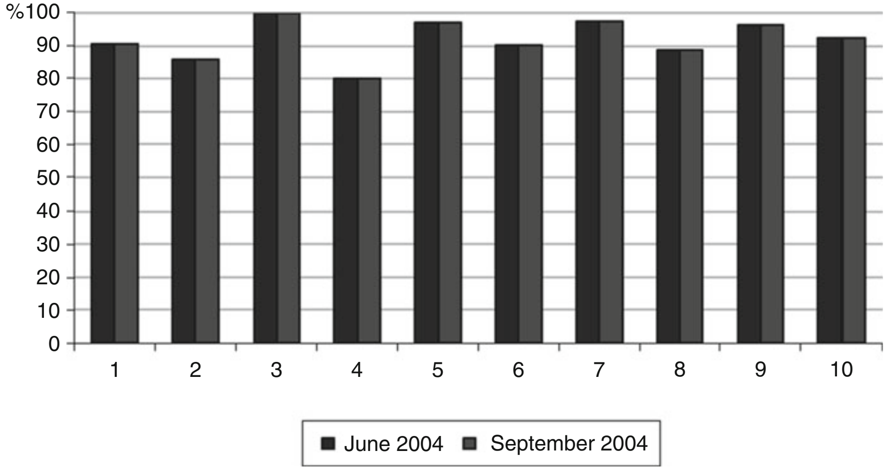

Fig. 15.15 Establishment rate of *Haloxylon aphyllum* on coastal solonchaks with thick sand layer, ten strips, 100 m long (Plantings in March 2004, record in June and September 2004)

Fig. 15.16 Plantings of *Haloxylon aphyllum* on coastal solonchaks with thick sand layer (Plantings – March 2004) (Photo: Wucherer, September 2004)

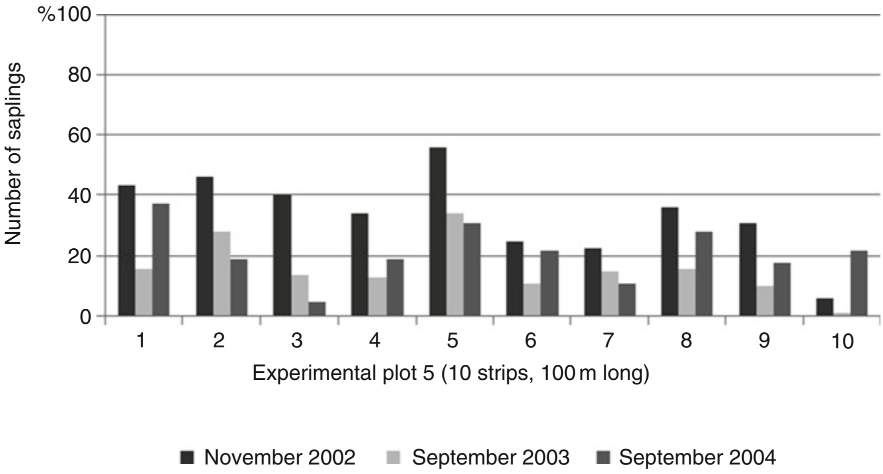

Fig. 15.17 Number of established saplings and seedlings of *Haloxylon aphyllum* on loamy coastal solonchaks with a sand layer, ten strips, 100 m long (Planting in November 2002, record in September 2004)

of sand and loam alternate. Beneath 50 cm, the soil is composed of loam and clay to a depth of 150 cm. The establishment rate of *Haloxylon aphyllum* in the first year (2003) was moderate and variable and ranged from 10 to 35 saplings on 100-m-long strips (Fig. 15.17). An increase in the number of saplings in 2004 was observed, most probably caused by further seeds from 2003 that did not show any morphological differences from the saplings in autumn 2004. The survival rate of saxaul saplings at the end of first year after planting was 37.4%. After 2 years, 26.2% of saplings had survived; about 300 seedlings per hectare were calculated in second year. Finally the planting on plot 5 was successful.

15.3.3.5 Plantings on Crusty-Puffy Coastal Solonchaks (B2b)

These soils are deeply salinized and are the main source of the salt-dust output from the Aral Sea floor. They are spread on the dry surface of the more recent seafloor desiccation, including the dry seafloor of the 1990s, of the 1980s and partly that of the 1970s. A coastal solonchak with a *Suaeda acuminata* plant community was chosen for the plantings (plot 6, with an area of 50 ha, Fig. 15.9) The annual halophytes appear either directly after the desiccation of the seafloor as water-level plant communities on the marshy solonchaks or on the coastal solonchaks in high-rainfall years. *Suaeda acuminata* is an indicator of a high salinity rate in the soil profile. Other annual saltworts (*Climacoptera aralensis* and *Salsola nitraria*) increase the coverage to 15–20%, rarely to 40–45%.

Exceptionally, here the topsoil (up to 4 cm) and the horizon of 105–130 cm are composed of loamy sand and coarse sand. Normally, the whole soil profile is composed of loam and clay. According to our classification, this site is a loamy coastal solonchak, the soil profile of which shows a sandy horizon within 1-m depth. But the thin sandy layer on the surface is insignificant for establishment.

The soil is low in humus (0.70% in the crust, 0.62% in the upper horizons, 0.21% in the lower horizons), an is low in total nitrogen (0.017–0.052%). Soil carbonate is up to 5.41%, and 3.38–2.87% in the upper horizons. The pH is 8.0–8.1. CEC is moderate (16.5 meq/100 g) in the surface horizon, but drops (7.2–14.0 meq/100 g) in the 1–35-cm horizon. Calcium prevails, but sodium is present at 9.8% (weakly solonetzic structure). The soil surface is saline (1.87%), an the profile is slightly saline down to 11 cm (0.33%). The lower horizons have a salt content of 0.99–1.59%, and are loamy clay. The salinity is due to sulphate and chloride.

The survival rate of saxaul saplings was 12–14%. Seedlings of saxaul produced roots at a moderate rate. A calculation in second year showed that saxaul saplings survived with a rate of less than 10%.

The afforestation conditions for plantings of *Haloxylon* are still unfavourable. The site conditions of this plot for *Haloxylon apyllum* are almost beyond the physiological amplitude.

15.3.3.6 Plantings on Crusty-Puffy Coastal Solonchaks in Furrows (Soil Site B2a,b)

These soils are saline and covered by a salt crust. The plot area was 8.0 ha (Fig. 15.9, plots 1 and 2; 2.7 and 5.3 ha). Plots 1 and 2 differ from each other. The plantings on plot 2 were performed in 11 rows, each 200 m long. The furrows were about 30 cm deep and about 60 cm wide. The soil profile is composed of clay and is strongly saline (B2a). The salinity is due to chloride and sulphate, the salt content is about 2.77% (salt crust 5.48%). The natural vegetation was a loose therophytic plant community with *Climacoptera aralensis,* a few *Atriplex pratovii* and some *Suaeda acuminata*.

In September 2004 the rate of establishment of *Haloxylon* was normally below 10% and the vitality of the saplings was rather bad (Figs. 15.18 and 15.19). This demonstrates, that these sites with loamy-clayey crusty-puffy coastal solonchaks are hardly suitable for the establishment of *Haloxylon aphyllum* even with improvement of the soil conditions, since all lower soil horizons are very clayey (75.6%).

Plantings on plot 1 were performed in 21 rows each 100 m long. The furrows had the same size as those for plot 2. The soil profile is mainly loamy and moderately saline (B2b). This coastal solonchak with a salinity maximum rather deep in the soil profile carried a natural vegetation of loose therophytic aggregations with *Climacoptera aralensis*, *Atriplex pratovii* and *Salsola nitraria*. The site conditions are more moderate, and the rate of establishment is thus higher, 20–80%, and there is a better vitality of the saplings (Figs. 15.20 and 15.21).

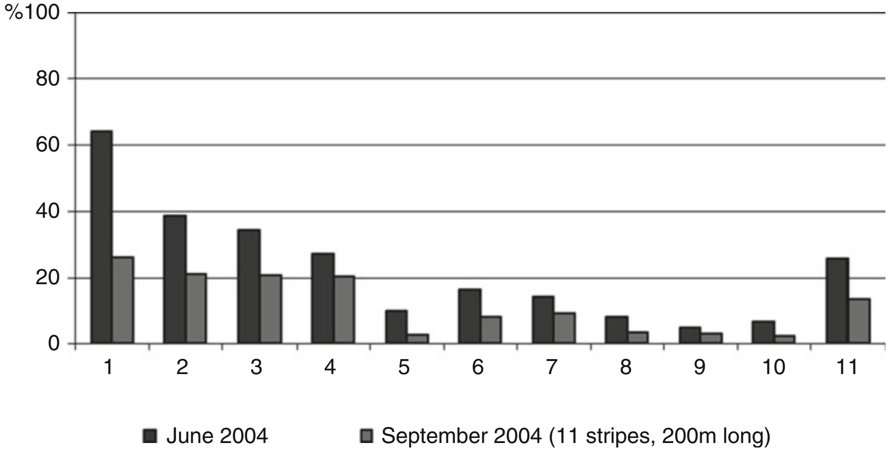

Fig. 15.18 Establishment rate of *Haloxylon aphyllum* on crusty-puffy coastal solonchaks with furrows, 11 strips, 200 m long (Plantings in March 2004, coverage in September 2004)

Fig. 15.19 Plantings of *Haloxylon aphyllum* on crusty-puffy coastal solonchaks (Plantings in furrows March 2004) (Photo: Wucherer, September 2004)

15.3.3.7 Plantings in Pits (Soil Site, Habitat B1b)

In autumn 2002, 1,000 pits were prepared (up to 100-cm depth and 60-cm diameter) on a coastal solonchak (the salinity maximum on the soil surface), and filled with sand. In March 2004, *Haloxylon aphyllum* was planted in the pits. In June 2004, the establishment rate was over 90% and in September it was still over 70% (Figs. 15.22 and 15.23). The improvement of the soil conditions had definitely increased the establishment rate.

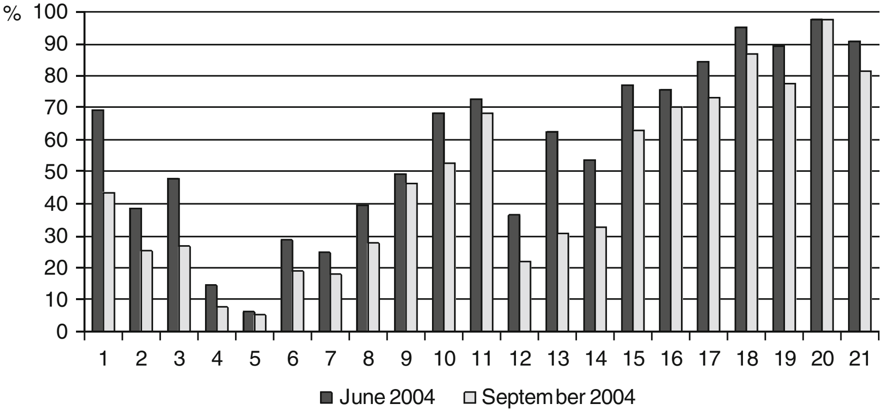

Fig. 15.20 Establishment rate of *Haloxylon aphyllum* on coastal solonchaks with an adjournment of the salinization maximum at a certain soil depth (Plantings in furrows in March 2004, record in June and September 2004)

Fig. 15.21 Plantings of *Haloxylon aphyllum* on coastal solonchaks with an adjournment of the salinization maximum at a certain soil depth (Plantings in 21 furrows in March 2004) (Photo: Wucherer, June 2004)

15.3.3.8 Efficiency of Plantings in Spring and in Autumn

In comparing two equal sites, it is obvious (Fig. 15.24) that the rate of establishment of *Haloxylon aphyllum* in spring plantings is about double that for autumn plantings.

15.3.3.9 Sowing and Germination of *Haloxylon aphyllum*

The seeds of *Haloxylon aphyllum* were sown on three planting plots with *Haloxylon* and *Halocnemum*. The seeds were collected 300 km from the Aral Sea's coast in the area of the village of Karmaktschi. The seeds were sown simultaneously with the

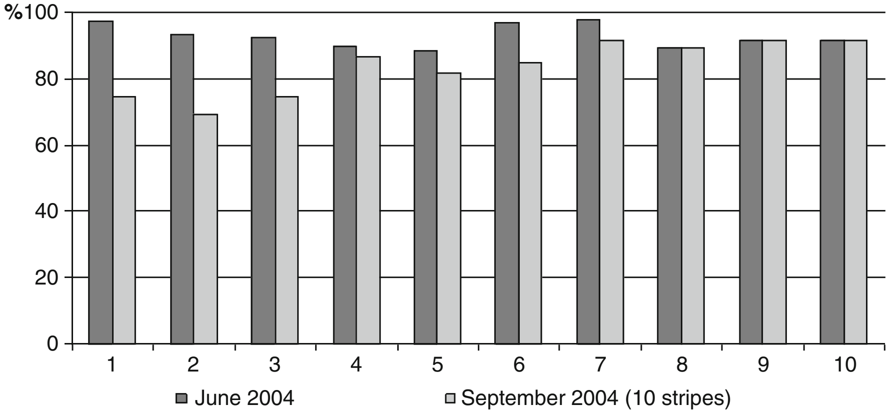

Fig. 15.22 Establishment rate of *Haloxylon aphyllum* on degraded coastal solonchaks (Plantings in pits in March 2004, ten strips, coverage in June and September 2004)

Fig. 15.23 Plantings of *Haloxylon aphyllum* on degraded coastal solonchaks (Plantings in pits, March 2004; coverage, June and September 2004) (Photo: Wucherer, June 2004)

plantings of the seedlings. In the *Haloxylon* plantings on the coastal solonchak only very few seeds germinated. This germination is statistically irrelevant. The germination and establishment of the first year on the loamy coastal solonchaks with sand cover were quite high. The extreme variability of the germination on the loamy coastal solonchak with sand cover is influenced by the prevailing ecological conditions in the topsoil.

15.3.4 *Halocnemum strobilaceum* Plantings

Halocnemum strobilaceum is a dwarf shrub, a euhalophyte withstanding very high salinities. Soils of natural sites with *Halocnemum* are often coastal solonchaks with

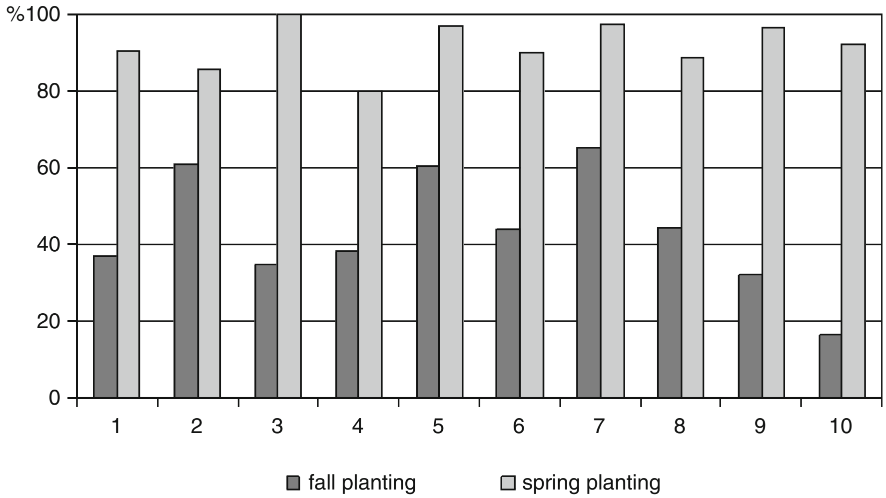

Fig. 15.24 Establishment rate of *Haloxylon aphyllum* on the coastal solonchaks with a sandy layer (autumn plantings in November 2002 and record in September 2003; spring plantings in March 2004 and record in September 2004)

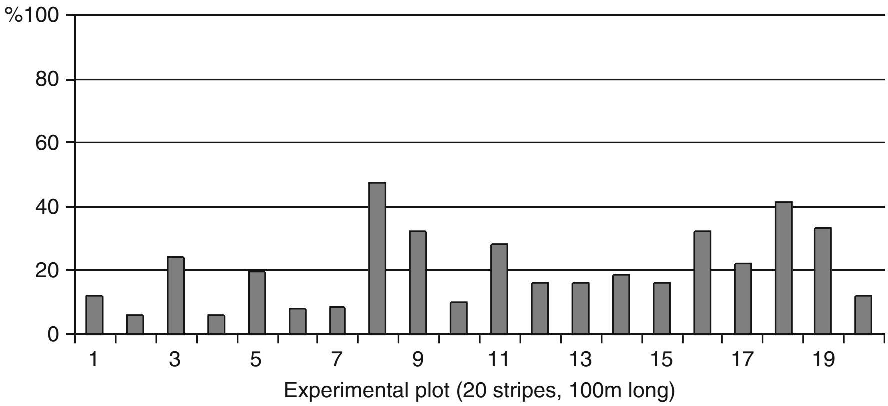

Fig. 15.25 Establishment rate of *Halocnemum strobilaceum,* ten strips (Plantings in November 2002, record in September 2003)

loamy and clayey horizons, often with sandy horizons in middle parts (1 m) of the soil profile (sites B1b). Those sites are obviously the ecological optimum (Fig. 15.26) for *Halocnemum*. Plantings were done on those sites without soil improvements (plot 6, 50 ha, Fig. 15.9). One year after the plantings, the rate of establishment was about 20–40% (Fig. 15.25). But the vitality of the saplings was rather bad, and dropped in the second year to less than 1%. This was mainly due to the dry summer, but was also due to technical difficulties in planting saplings of *Halocnemum*. Roots of *Halocnemum* do not have a strong taproot, and thus are

Fig. 15.26 *Halocnemum strobilaceum* plantings on the Kaskakulan transect (Plantings by V.S. Kaverin, 12 years old) (Photo: Wucherer, June 2003)

often stuck in the dry upper soil during the mechanical planting procedure. The planting success depends very much on the skill of the workers. Plantings by hand were successful (Fig. 15.26).

15.3.5 *Tamarix* Plantings

Plantings with *Tamarix* were done on plot 7 (Fig. 15.9, 40 ha in 20 rows of 1,000-m length) on strongly saline coastal solonchak. Plantings were done with cuttings, mainly *Tamarix hispida, Tamarix laxa* and *Tamarix elongata*, in autumn 2002. The first evaluation in spring 2003 indicated a severe loss of saplings. Almost none of the saplings were detected (50 seedlings and three saplings per hectare); the very few remnants exhibited severe signs of grazing by rodents, most probably hares. Another test planting with protection against grazing has not been done yet.

15.3.6 *Physicochemical Properties of Saline Soils on Planting Plots*

Not only grazing but also the specific physicochemical properties of the saline soils (Table 15.6) determine the survival rates of planted material. The evaluation of the physicochemical characteristics of soils was done for most of the experimental plots of the BMBF-GTZ/CCD project by L.A. Dimeyeva and V.N. Permitina. The results allow predictions to be made regarding the results and success of phytomelioration.

Soil samples for the study were collected from the rooted horizons. Chemical analyses of soil samples were done with the support of the Japan Research Association with Kazakhstan (PIE/JRAK).

Table 15.6 Physicochemical characteristics of saline soils in experimental plots

Plot no.	Depth (cm)	Toxic ions (mg eq/100 g soil)	Toxic salts (%)	Degree of salinity	Cl^-/SO_4^{2-} molar ratio	Soil texture
1	0–13	6.19	0.52	High	0.52	Sandy loam
	13–22	29.9	2.43	Very high	1.55	Clay
	22–90	35.5	2.56	Very high	3.18	Clay
1a	0–0.5	201.5	13.7	Very high	5.01	Clay
	0.5–25	57.1	3.9	Very high	2.83	Clay
1b	0–1	68.6	4.9	Very high	2.81	Loam
	1–25	8.63	0.83	Very high	0.84	Clay loam
2	0–0.5	13.2	1.12	Very high	0.76	Sandy loam
	0.5–11	2.01	0.25	Moderate	0.6	Sandy loam
	11–35	9.73	0.86	Very high	1.4	Loam
	35–65	19.5	1.16	Very high	2.71	Clay loam
3	0–0.5	5.36	0.51	High	0.54	Sandy loam
	0.5–8	1.05	0.08	Slight	0.77	Sand
	8–23	2.09	0.31	Moderate	0.23	Sandy loam
	23–80	3.87	1.59	Very high	0.76	Loam
4	0–0.5	3.59	0.29	Moderate	1.67	Sandy loam
	0.5–26	3.55	0.28	Moderate	1.94	Sand
	26–60	3.12	0.31	Moderate	1.5	Sand
	60–70	6.14	0.49	High	1.9	Sand

15.3.6.1 Total Effect of Toxic Ions

Soils of the Aral Sea coast have a significant salt content. Depending on qualitative and quantitative attributes of saline soils, they have different degrees of salinity and unequal toxicity of freely soluble salts. Only the toxic salts Na_2CO_3, $MgCO_3$, $NaHCO_3$, $Mg(HCO_3)_2$, Na_2SO_4, $MgSO_4$, NaCl, $MgCl_2$ and $CaCl_2$ have a hazardous influence on plants. Therefore it is more reasonable to examine the degree of salinity of soils by the presence of toxic ions and salts. Determination of the degree of salinity on the basis of the "total effect of toxic ions" (Vityzev 1973) by calculation defined the toxic ions in aquous extracts. That may not need differentiation of soils by salinity type. The concentration of ions in milliequivalents per 100 g of soil is used for calculation of toxic ions, and the percentage of toxic salts is used as an assessment of the degree of salinity. CO_3^{2-} ions form toxic salts (Na_2CO_3 and $MgCO_3$). HCO_3^- ions form toxic $NaHCO_3$ and $Mg(HCO_3)_2$ salts and nontoxic Ca $(HCO_3)_2$ salts. SO_4^{2-} ions can form toxic (Na_2SO_4, $MgSO_4$) and nontoxic ($CaSO_4$) salts. The same is true of Cl^- ions, the major salt formed being NaCl.

Coastal solonchak soils (plot 1) have considerable amounts of salts throughout the soil profile. Maximum of salts with prevalence of chlorides is found in lower horizons showing fewer desalinization processes. The total effect of toxic ions ranges from 6.19 meq/100 g of soil in the upper horizon to 35.5 meq/100 g of soil in the lower horizon (Table 15.6). The degree of salinity increases with depth. The content of toxic salts amounts to 2.5%. The degree of salinity is very high.

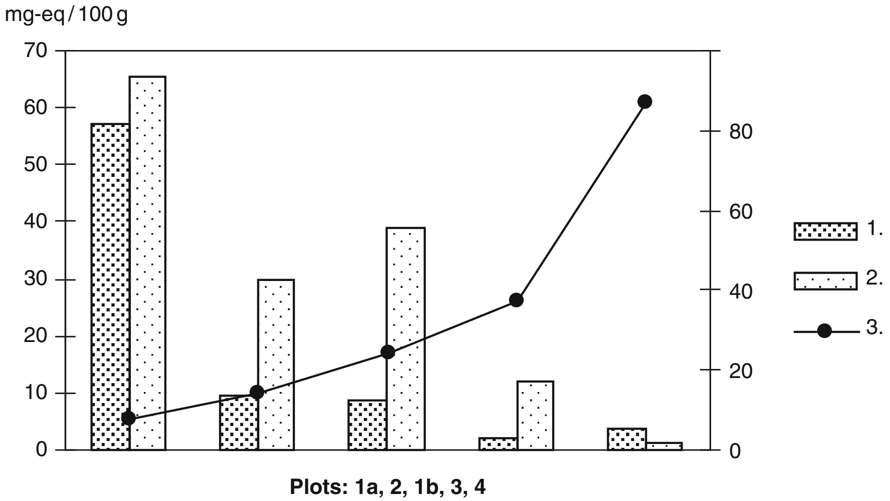

Fig. 15.27 Survival rates of saxaul saplings (*Haloxylon aphyllum*) on saline soils (in root-inhabited horizon) with differing physicochemical site characteristics: *1* total concentration of toxic ions (mg eq/100 g of soil); *2* content of silt and clay (%); *3* survival rate (%) in the first vegetation season

Replacement of saline soils by nonsaline substrates is the most promising method of land reclamation of coastal solonchaks and coastal soils of heavy texture. Addition of sand improves the physicochemical properties of saline soils and increases the survival rate of saxaul saplings up to 91.6%.

There is an important direct dependence of the survival rates of saplings and the total effect of toxic ions together with the texture of saline coastal soils (Fig. 15.27, see also Fig. 15.9, Table 15.6).

15.4 Shelterbelts for Villages

Experiments on rehabilitation of coastal ecosystems were continued by AEON Environmental Foundation/Japan, 2005–2006, and the Japan Fund for Global Environment, 2006–2008, in cooperation with L.A. Dimeyeva. Two tasks were included in the study:

1. Establishment of green shelterbelts around villages
2. Afforestation of the dry seafloor

Two villages were chosen for planting activity with participation of local people. Saplings of *Haloxylon aphyllum* were planted in a plot of 1 ha in a dry bed of Bozkol Bay (close to Kaukey village). The soil conditions are very harsh–highly saline clay. The method of pits with sand was used to increase the survival rate, which was 25% due to reclamation work. A green shelterbelt of 2.5 ha near

Karateren village was established in more favourable soil conditions (medium salt content, loam). The survival rate of saxaul saplings was 60% in the first year and 57% in the second year.

Thus, a modern approach in reclamation of salt deserts and combating desertification in the coastal areas is the creation of small plantations (oases, "green spots"). This will support the natural processes of propagation and creation of seed banks for acceleration of natural succession. On the other hand, green shelterbelts around villages will be created step by step (Dimeyeva 2008).

15.5 Perspectives and Necessity of Phytomelioration on the Desiccated Seafloor

15.5.1 Minicatchment Experimental Sets on the Bayan Transect at the Eastern Coast

These experiments were done within the Bayan transect close to the former eastern coast of the Aral Sea. Experimental plots were chosen on sites of the desiccated seafloor from the 1990s. On those sites only therophytic communities were present; there were no perennial species.

15.5.1.1 Plantings with Minimal and Maximal Technical Approach

In November 1998 on the experimental plots 1- or 2-year old saplings of *Tamarix laxa, Halostachys caspica, Halocnemum strobilaceum* and *Haloxylon aphyllum* were planted. Two variants were tested: planting on the smooth surface and planting in pits about 30 cm deep. About 600 plants were used. The rate of establishment was only about 2%.

The first half in 1999 was extremely dry and almost devoid of precipitation. In any case it is clear that the first year after phytomelioration plantings is very decisive for the success of the plantings. A minimal technical approach is not sufficient for success, especially in rather saline sites with puffy-crusty coastal solonchaks. It remains an open question if it is possible by better technological means to achieve better results even in very dry subsequent years.

In April 2000 again two plantings series were performed. One used furrows about 20 cm deep and 30 cm wide, filled with sand. The other used a modification of the minicatchment procedure by using rather deep pits of about 1-m and 50-cm diameter. One-third of the pit holes were filled by sand, and the upper parts were smoothed to create catchment areas with 10–15° runoff slopes. These slopes covered a length of 1.5–3 m, corresponding to an area of 2.25 m^2 and 9 m^2 for the bigger pits. In total, 64 small and 60 bigger pits were tested.

In the pits cuttings from *Haloxylon aphyllum, Tamarix hispida* and *Tamarix elongata* were planted. In the furrows *Haloxylon aphyllum* and *Halocnemum strobilaceum* were tested. The minicatchment test exhibited rates of establishment for *Haloxylon aphyllum* of 11.4% (planting on the smooth surface) and 22.2% (planting in pits about 30 cm deep), and for *Tamarix hispida* they were 71% (planting on the smooth surface) and 58% (planting in pits about 30 cm deep).

For plantings in furrows about 20 cm deep and 30 cm wide filled with sand the rate of establishment for *Haloxylon aphyllum* was 100% and for *Halocnemum strobilaceum* it was 42%. However, these tests revealed that only a rather laborious method is successful, which only can be used in small-scale plantings. Only the furrow technique is applicable on a larger scale.

15.5.2 Results of the Plantings in the Kushzhitmes Area

Satisfactory and good results were obtained for *Haloxylon*, worse results were obtained for *Halocnemum* and the worst results were obtained for *Tamarix*. The survival rate for *Haloxylon* in conditions of coastal solonchaks of heavy texture was 12–14% at the end of first vegetation period, was under 20% in coastal soils with thin blown sand cover and was up to 76–98% in coastal soils with thick blown sand cover between sand dunes. The establishment rate of *Haloxylon aphyllum* on the barchans was above 80%. The survival rate for *Halocnemum* in conditions of coastal soils with blown sand cover was 14% at the end of first vegetation period; only 1% of saplings survived 1 year later. Germination of *Haloxylon* seeds was higher in coastal soils with sand cover. Survival rates of *Haloxylon* saplings in furrow plots ranged from 10% to 90% on plot 1, which was caused by different soil conditions. Experiments with plantings into pits with sand exhibited a very high survival rate of saplings (above 90%).

The experimental studies resulted in a number of articles and recommendations (Breckle 2003; Breckle and Wucherer 2006, 2007; Dzhamantikov et al. 2003; Ogar et al. 2005a, b; Dimeyeva and Ogar, 2006; Dimeyeva and Permitina 2006; Kaverin et al. 2005; Wucherer 2001; Wucherer et al. 2005; Wucherer and Breckle 2005). Important information on methodology and site selection for phytoreclamation activity can be found in Dzhamantikov et al. (2003).

Green plantations are created by means of sowing seeds and manual or mechanized plantings. Seeding is possible only in years with favourable wet conditions, which cannot be predicted. There were good conditions twice during the 7-year experimental study. Therefore, seeding should constitute 10% of the total amount of forest melioration. Better results could be obtained by seeding in sand-accumulating furrows with sand cover not less than 15–20 cm. Planting should be conducted in early spring after the melting of snow cover or in first half of November.

Results on experimental phytoreclamation in different years and seasons have shown that the most promising time for planting is early spring. The most promising forest culture is *Haloxylon aphyllum*. The most suitable conditions for reforestation in the dry seabed are light textured soils (coastal sandy soils and coastal soils with sand cover). Soils of heavy texture need amelioration, e.g. by sand-accumulating furrows near to sand massifs and replacement of heavy ground by sand.

15.5.3 Phytomelioration Properties of *Haloxylon aphyllum*

The establishment and the growth of *Haloxylon* is dependent on the weather conditions, the hydrological conditions and the season of the plantings. Lake deposits or soils, of which the topsoil is lightly grained, are favourable for the plantings. The establishment was successful on the poorly to moderately saline sandy soils and the loamy coastal solonchaks with sand cover and a low salinity degree of the topsoil. On the crusty-puffy coastal solonchaks, however, the rate of establishment of *Haloxylon* is only up to 10% and the vitality of the young plants is very bad. The plantings on the coastal solonchaks with an improvement of the soil conditions (in furrows and in pits) increase the establishment rate of *Haloxylon*. The establishment rate for spring plantings is higher than that for autumn plantings.

Sowing of the *Haloxylon* seeds (fruits) on the loamy coastal solonchaks with sand cover produced very variable results, but was also effective. Sowing of granulated seeds on the snow cover in spring is more effective compared with sowing on the soil surface without snow. The mechanical treatment of the soil surface increases the establishment rate. Sowing on the crusty-puffy coastal solonchaks even with treatment of the soil surface or the improvement of the topsoil is almost hopeless, even though most sandy and sandy loam coastal soils do not have any morphological features of alkalinity.

However, the establishment of separate individuals on sites with extreme conditions is of crucial relevance for the success of the plantings and spreading of a spontaneous phytomelioration (Fig. 9.23, Chap. 9).

Established plants produce seeds after a few years, often 5–6 years. With an improvement of the site conditions or in wet years, the availability of seed material (from stock plants) can be sufficient to develop thick assets or patches of plant communities. This example shows that even the establishment emanating from very few individuals is an important part in the creation of the future vegetation cover and accordingly in the control of salt-dust blowouts.

On which sites should *Haloxylon* reforestation be organized? In the sand deserts adjacent to the Aralkum no big dune or barchan fields without vegetation are present; they are mostly covered with vegetation. The emergence of local barchan fields is a result of an anthropogenic influence by keeping the sand surface open by overgrazing and trampling adjacent to villages. Normally those sandy sites have a naturally sufficient self-growth potential in this region. If the impact by the people has stopped, a rather fast natural resettlement and spontaneous regeneration of the vegetation starts. This is also due to the sandy sites of the dry seafloor from the 1960s and early 1970s. They do not have to be planted, as they are usually already covered with vegetation.

The younger dune fields of the dry seafloor are usually devoid of vegetation. The salinity of the dune fields, which is rarely linked to the groundwater table, is rather low compared with the salinity of the coastal solonchaks. The salt-dust output of the dune fields is minimal. The creation of dunes favours the transfer and spreading of the sand in all directions (also in the direction of the actual coastline) and favours the covering of the crusty-puffy coastal solonchaks with sand. The leaching procedure is initiated and the salt-dust asset decreases as a consequence of an already thin cover of 3–5 cm sand on the soil surface. Hence, sand is an important natural phytomelioration factor on the dry seafloor of the Aral Sea. The dune fields do not have to be planted, but rather should have contrarily a free development to fulfil their natural phytomeliorative function. The barchan fields at the eastern coast of the Aral Sea on the western side of the former islands (Kaskakulan, Uzun-Kair, Kushzhitmes, Kozzhetpes) are also spreading also in the western direction (to the lake) and cover the primary loamy coastal solonchaks of the Aral Sea floor.

The loamy coastal solonchaks with a sand cover can and must be planted for two reasons:

1. There are often widespread crusty-puffy coastal solonchaks. These saline soils indicate good site conditions for germination on the dry seafloor of the 1970s and 1980s. Plantings can remarkably contribute to minimizing the salt-dust output. The technological effort is not excessively expensive.
2. There are often island-like sand accumulations on the dry seafloor (even on the dry seafloor of the 1990s), where the distribution pattern of the lake deposits is very variable (e.g. at the northern side of the former island of Barsa-Kelmes or the town of Muinak). The plantings on these sand islands can lead to the creation of vegetation islands in the salt desert and this can lead to a second spreading of vegetation.

On the crusty-puffy coastal solonchaks *Haloxylon* plantings can only be successfully performed with an improvement of the soil conditions (e.g. in the furrows or pits, filled with sand). Some seedlings can reach the generative phase, however, rather fast, but a second spreading does not occur, since the seeds of *Haloxylon* do not germinate on coastal solonchaks. Therefore, plantings on crusty-puffy coastal solonchaks are only worth performing at locations where natural desalinization of the topsoil is expected, and where sand islands are present.

15.5.4 Development of New Planting Strategies

15.5.4.1 Change of Areal Priorities

A vast area of the dry seafloor has developed between the eastern coast of the former Aral Sea and the former island of Vozrozhdeniya. A salt swamp and a huge salt desert have been created. The dry surface is about 60,000 km. It will not grow considerably in the coming years. The salt-dust output, however, will increase immensely. The experiments and the plantings of the institutes of forestry of Kokchetav and Tashkent as well as of the GTZ projects in Uzbekistan and of the Department of Ecology of the University of Bielefeld project in Kazakhstan are predominantly limited to the dry surface of the 1960s, 1970s and 1980s. These experiments have provided worthwhile information on the technology of plantings with *Haloxylon aphyllum* and a few other species on special soil types. However, for the plantings emphasis must be placed on the dry surfaces of the 1980s and 1990s as well as on the surface, which recently dried out. These expanded deflation surfaces are the source of the salt-dust output, the salinity of which is usually very high, and chemistry of which is rather variable. Plantings must accordingly be conducted on moderately to highly saline soils and solonchaks.

15.5.4.2 Selection of Reforestation Species

A forest will never be able to grow according to the climatic conditions of this continental desert with temperature extremes between −45°C and 45°C and an average yearly precipitation of about 100 mm. The phytomelioration in the region of the Aral Sea, this means plantings of species which are suitable for the conditions of the climate and the soil, have to take into account the relevant ecological situation. This is a significant limitation, which even under optimal conditions only allows a reconstruction of a low desert bush vegetation, which still features a possibly high cover degree to minimize the open soil surface. The most suitable species for many sites is the bush *Haloxylon aphyllum*; however, this species only thrives on soils of moderate salinity. *Haloxylon* can only be planted on coastal solonchaks with an improvement of soil conditions. Finally, the use of *Haloxylon* is limited for plantings on the dry seafloor of the 1980s and 1990s. The selection must hence be extended to more euhalophytic species, which can withstand more salinity in the soil, such as *Halocnemum strobilaceum.*

In the region there are many other perennial euhalophytes from the genera *Halostachys, Kalidium, Salsola,* and *Suaeda*. However, the technology for planting them is practically unknown and must be developed further.

15.5.4.3 Adjustment to the Planting Technologies and Location Mapping

Experimental studies on phytomelioration of saline soils of different texture have shown that the most important factors affecting the survival rate of saplings are the total effect of toxic ions determined by the degree of salinity and the total amount of toxic salts, and the soil texture of the rooted soil horizons.

The technologies tested (construction of furrows, mechanical enforcement of the topsoil, removing the salt crust, minicatchment procedure, etc.) should also be used for the plantings of euhalophytes, but only with consideration of the specific habitats and the biological properties of the reforestation species. Total soil and vegetation mapping of the dry seafloor has been conducted only roughly. This is an essential requirement for plantings. The planting experiments have shown that the sites within 50 ha were not uniform. Hence, the planting plots should be smaller. The basis for a second settlement wave should be formed by small centres of fruiting old plants. For the expansion to other saline sites on the dry seafloor without vegetation, remote sensing by satellites is essential.

15.5.4.4 Consideration of Other Planting Priorities

Loose sands and migrating dunes are dangerous for humans in the village areas as a consequence of the regional overgrazing and deforestation. Therefore, plantings of loose local sand dunes surrounding villages and residential areas must be encouraged. These wind-protection plantings should also involve bigger tree species, as long as watering is possible, and in pits. According to the previous experiences, those plantings around villages must be performed, secured, treated and protected from fire and grazing in cooperation with the rural population.

15.6 Discussion and Final Conclusions

Experimental studies on phytomelioration of saline soils of different texture have shown that the most important factors affecting the survival rate of saplings are the total effect of toxic ions determined by the degree of salinity and the total amount of toxic salts, and the soil texture of the root-inhabited horizons.

The assortment of plant species for phytomelioration of the dry seafloor with a good prospects is very small. Saxaul (*Haloxylon aphyllum)* is noticeably distinguished among them. It has a wide ecological amplitude and can grow in diverse sites of salinity and soil texture environments. However, the disturbed root system of saplings is affected by salinity and drought stress. Methods of melioration can help to overcome toxic stress. Soils of heavy texture need reclamation, e.g. by establishment of sand-accumulating furrows near sand massifs taking into account the main direction of the prevailing wind and replacement of heavy ground by sand.

Plantings of sarsazan (*Halocnemum strobilaceum*) saplings should be realized in plots with a groundwater table not lower than 1.5 m. Such conditions have usually developed after 10–12 years of the continental regime. This is not always under the influence of the continued desiccation process.

Planting *Tamarix* saplings in the dry seabed of the 1970s is problematic because of this biotope is inhabited by hares, which greatly or totally destroy the plantations.

The improvement of the environmental situation and the living conditions of the people and the struggle against poverty in the region at the Aral Sea is one of the biggest challenges for the struggle against desertification according to the United Nations Conventions to Combat Desertification. It can only be managed by numerous measures by countries concerned with the help of the global community. Here it is indispensable to have constant scientific guidance and to build up and to constitute appropriate monitoring. Planting on saline soils is an effective measure for decreasing the salt-dust output from the dry seafloor and for soil stabilization. The two most important goals of the phytomelioration are attainable. Firstly, there is the protection of the population from sandstorms, which is a local problem. For this, local wind-protection plantings must be established in and around the villages and residential areas with their degraded environment. Secondly, the protection of the population from salt-dust storms, which is the bigger and especially not a local but a regional problem. In addition to this, large-scale plantings must be done directly at the sources of the salt-dust output. The solution of the environment problems is vitally important for the population in the region around the former Aral Sea.

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