Chapter 12
Halophytes and Salt Desertification in the Aralkum Area

S-W. Breckle and W. Wucherer

12.1 Introduction

The area of saline soils on the desiccated seafloor of the Aral Sea comprises about 42,000 km^2 (which is about three quarters of the dry seafloor, Chap. 2, Fig. 2.7). Within the agricultural areas with irrigated lands, a major proportion is secondarily saline; this amounts to about 22,000 km^2. In total, this means that the salt desert areas in Middle Asia have increased by more than 60,000 km^2 within the last 50 years. Salt desertification is spreading within the whole area, not only in the Aralkum. But it is a very old problem of mankind (Jacobsen and Adams 1958). All arid countries face the salinity problem (Waisel 1972, 2001; Hammer 1986; Oldeman 1994; Breckle 1982, 1989, 2002a, b; Wichelns 1999), e.g. in Australia (Dregne 1986), California (Sheridan 1981; Law and Hornsby 1982; Rhoades 1990), India (Singh 2009), China (Yang et al. 2005) and Iran (Shiati 1991). However, the Aral Sea basin is one of the most striking examples of salt desertification (Geldyeva et al. 1998; Novikova et al. 1998). The forecast that the eastern basin of the Aral Sea will have disappeared by 2010 (Breckle and Agachanjanz 1994; Agachanjanz and Breckle 1994) and huge solonchak areas will spread out was totally right, as can be seen now. A huge salt swamp has been observed already in 2009 (chap. 2).

The coast of the Aral Sea and the dry seafloor of the former Aral Sea are an excellent model where the processes of salt desertification can be seen (Glazovskii and Orlovskii 1996; Breckle and Wucherer 2007). In general, soil salinity assessments are essential for mapping land degradation in drylands as well as for agricultural surveys, and remote sensing is a helpful tool (Metternicht and Zinck 2008).

The strategies of plants for regulating salt content and for coping with salt stress are a precondition for survival, whether they are halophytes or nonhalophytes. The adaptation of plants to NaCl has to cope with the general osmotic effects of the ions, but also with the specific ionic effects of Na^+ and Cl^- on the metabolic processes (Fig. 12.1). Halophytes have evolved during long-term evolution by selection of

S.-W. Breckle et al. (eds.), *Aralkum - a Man-Made Desert: The Desiccated Floor of the Aral Sea (Central Asia)*, Ecological Studies 218,
DOI 10.1007/978-3-642-21117-1_12,

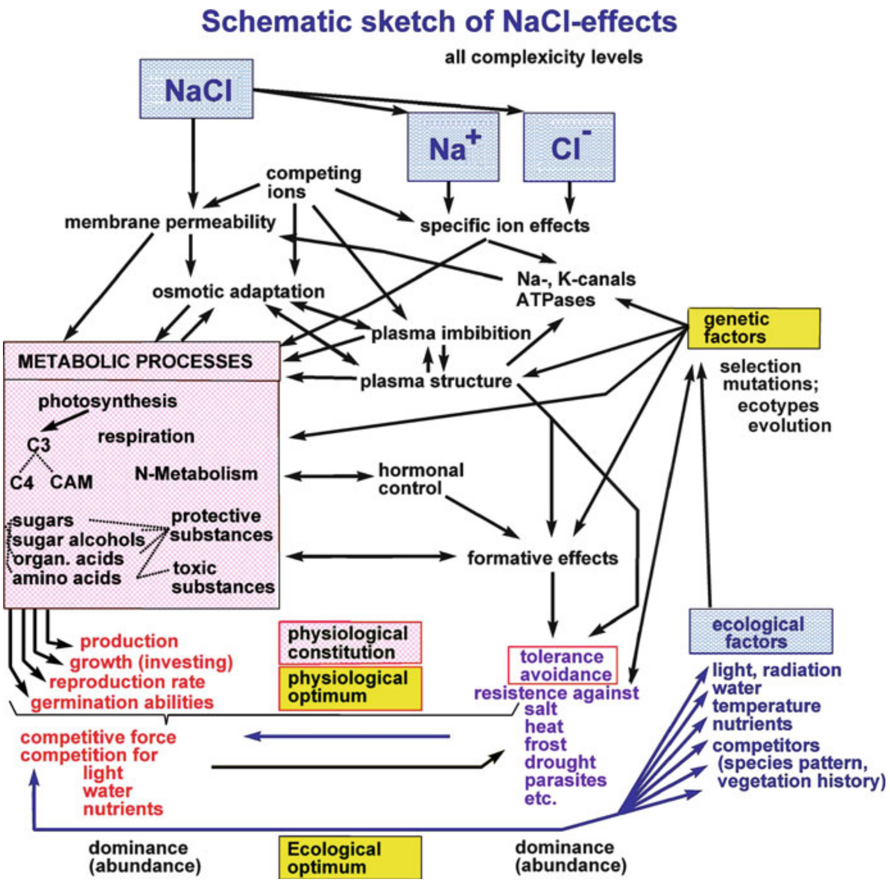

Fig. 12.1 The interrelations of NaCl effects on various complexity levels in plants (modified from Breckle 2005)

tolerant ecotypes in several plant taxa. In Central Asia, there is a biodiversity centre of halophytes (Wucherer et al. 2001). In arid sites with a continental climate, various types of salinity are known (chloride, sulphate, carbonate, magnesium and boron), more variable than along ocean coasts, depending on soil properties, climatic conditions and ecosystem processes. The presence of excessive ions in such ecosystems dominates over many other environmental factors. Only the supply of water is the other decisive factor in ecosystem development.

The invasion of the desiccated seafloor by halophytic species occurs under climatic conditions (chap. 4) which are rather variable from year to year (Breckle et al. 2001). The halophytic species, nevertheless, are on the other hand indicators of the degree of salinity at their site, and thus can be used to monitor salinity. A novel list of indicator values for salinity is presented (see below, Table 12.9). This can be used also for the necessary means of phytomelioration (Chaps. 15–17).

12.1.1 Halophyte Groups

Middle Asia and Central Asia are the evolutionary centres of many genera and species of the Chenopodiaceae. The Chenopodiaceae are characterized by their ability to accumulate inorganic ions, mainly sodium (Na^+). Only a few other angiosperm families are similarly able to withstand high soil salinities, e.g. Zygophyllaceae, Frankeniaceae, Tamaricaceae, Plumbaginaceae and a few grasses. However, there are many more genera in various angiosperm families which have evolved some degree of salt tolerance. In drylands, salinity has been such an important ecological factor that mechanisms of salt tolerance have evolved several times.

Plants have developed various mechanisms to cope with salinity. Table 12.1 gives an overview of some of the strategies which can be found in halophytes and which are sometimes even combined. Often morphological structures are typical for distinct adaptation strategies. Especially halosucculence of stems or leaves, or both, is very common in halophytes strongly adapted to salinity. Thus, succulent halophytes are either leafless and stem-succulent or have fleshy and succulent leaves. In both cases this kind of succulence has two components: the basic one is a genetically controlled succulence, whereas the second is a modifying variable

Table 12.1 Control mechanisms of halophytes to strive on saline sites (Breckle 1990, 2002a) and the main morphological strategy type

	Halophyte type
Avoidance	
Growth only during favourable seasons (time niche)	NoH, Ps, Su
Growth only on favourable sites (site niche)	Ps, NoH
Limitation of root growth and absorption activity to distinct soil horizons (site niche)	Ps, NoH
Evasion and adaptation processes	
Selectivity against Na^+ and Cl^-	NoH, Ps
Leaching of salt from shoots	NoH, Ps
Diversion of salt out of assimilating tissues	Ps
Compartmentation of salt within plant, within tissues, within cells	All plants
Accumulation of salt in xylem parenchyma in roots and shoots	All halophytes
Synthesis of organic solutes	All plants, Su
Retranslocation of salt to roots and recretion by roots	Halophytes
Disposal of older plant parts (“salt-filled organs”)	Ps, all halophytes
Recretion by gland-like structures on shoots	
By salt glands	EX
By salt bladders	NX
Tolerance	
Increasing salt tolerance of tissues, cells, organelles	LSu, SSu, NX, EX, Ps
Increase in halosucculence	
increasing leaf-succulence	LSu, (Ps)
increasing stem succulence, reduction of leaves	SSu

EX exocrinohalophytes, *LSu* leaf-succulent euhalophytes, *NoH* nonhalophytes, *NX* endocrinohalophytes, *Ps* pseudohalophytes, *SSu* stem-succulent euhalophytes, *Su* xerosucculents and can be induced by salts to a considerable degree. These types of halosucculence have to be distinguished from xerosucculence.

There are leaf-succulent euhalophytes which are annuals, e.g. some *Suaeda* species, *Halopeplis*, *Halimocnemis*, *Gamanthus*, *Girgensohnia*, etc. Other leaf succulents are herbal perennials (e.g. *Plantago*, *Aster*, *Suaeda*), and others are shrubs (e.g., some members of the genera *Salsola*, *Suaeda*, *Nitraria* and *Kochia).* In some others, the succulence of the fruit or parts of the fruit became very pronounced (*Gamanthus).* Regarding the adaptations of the photosynthetic pathway which have evolved, it is obvious that succulence has altered the anatomical structure dramatically, as can be seen in the various types that are exhibited by *Salsola* and *Suaeda* (Shomer-Ilan et al. 1981).

The stem-succulent euhalophyte lack leaves or have only minor scalelike leaves. The young stems are succulent, the older ones in perennial species can become rather woody. *Salicornia* and some species of *Anabasis*, for example, are annual stem-succulent species. Perennial stem-succulent halophytes are also found in *Anabasis*, *Kalidium*, *Aellenia*, *Ofaiston*, *Halostachys*, *Haloxylon*, etc. and also in the woody subshrub *Halocnemum strobilaceum* (Fig. 12.2), which is one of the most salt-tolerant species.

In contrast to halosucculents, most xerosucculents in general are very sensitive to salinity.

Many halophytes exhibit a rather rapid turnover of their leaves. The rosette leaves in *Limonium vulgare* are replaced during the vegetation period two or three times, and the leaves of *Aster tripolium* rather soon become yellow and new leaves replace them. This replacement is a mechanism of removal of large quantities of

Fig. 12.2 *Halocnemum strobilaceum*, young shoots (photo: Breckle, May 2004)

salt. Old leaves with high salt content are steadily replaced by younger leaves in many *Juncus* species. This is certainly one adaptation mechanism that enables the plant to get rid of excessive salts by shedding plant organs. A less specific adaptation is the rapid production of new leaves and dropping old leaves rich in salt. This can be observed in many pseudohalophytes. But the loss of leaves affects the supply of assimilates or hormones to the growing organs and thereby affects growth (Munns 1993; Munns et al. 1995).

But even more important in some halophytes is the existence of specific cell structures which can recrete (recretion in the sense of Frey-Wissling 1935, meaning elimination of substances not metabolically changed) inorganic ions, especially Na^+. This is done by salt glands, which have evolved several times in the angiosperms, and by bladder hairs. Salt glands eliminate salt to the outside (e.g., *Tamarix*, *Frankenia* – see Fig. 12.3 – *Glaux* and *Limonium* as well as some grasses); Bladder hairs accumulate salts in their huge vacuole (*Atriplex*, see Fig. 12.4; to a

Fig. 12.3 *Frankenia hirsuta*, in flower with many dry recreted salt crystals (photo: Breckle, May 2004)

Fig. 12.4 *Atriplex pratovii*. (**a**) Intact bladders from the lower side of leaves. (**b**) Crushed bladders from the upper side of leaves after wilting, forming a layer of salt crystals. North Aral Sea (photo: Breckle, **a** – May 2003; **b** – May 2004)

less extent *Halimione*, *Salsola*, *Chenopodium*) (Black 1954; Berger-Landefeldt 1959; Schirmer and Breckle 1982; Breckle 1992). In both cases the salts are physiologically isolated from active tissues. Here also the turnover of salt is rather rapid by recreting salt with salt glands in the exocrinohalophytes or into big bladders in the endocrinohalophytes.

Nonhalophytes exhibit almost none of these morphological adaptations. The dominant processes in the various morphological halophyte types are indicated in Table 12.1.

In general, it should be kept in mind that salt tolerance of a plant is not defined by the act of individual genes, by the individual regulation of each of them or by one specific metabolic process. Salt tolerance is a whole plant response (Hedenström and Breckle 1974; Breckle 1990, 1995; Munns 1993; Naik and Widholm 1993; Flowers and Yeo 1995; Ramani and Apte 1997), where many processes, such as efficient potassium pumping and accumulation, synthesis and transport of compatible solutes, plant signalling systems involved in tissue and in developmental regulation (Winicov and Bastola 1997), etc. are only some of many other important adaptations which are equilibrated in a harmonic way to fulfil those adaptive processes mentioned in Table 12.1.

It has to be stressed that salt tolerance has at least two quite differing aspects. One is the upper limit of salt that can be tolerated by an individual plant, which is necessary for survival. The other is the existence of a plant species that exerts successful reproduction, which is necessary for ecological success.

Salt tolerance of plants varies very much. It varies during different growth or development phases (Tobe et al. 2004, 2005), with ionic constitution of the soil solution (e.g. the presence of Ca and K as antagonists of Na), with microclimatic conditions (e.g. relative humidity), with life form and halophyte strategic type, with the plant organ affected by salinity and with the genetic variability of each species forming ecotypic varieties. Also, the effects of salinity on different growth stages and growth processes of plants have to be taken into account (Ungar 1996). Germination and seedling growth is normally more sensitive than growth of established adult plants.

For halophytes osmotic adaptation is accomplished not only by synthesis of organic compounds but also by absorbing inorganic ions, accumulated in the vacuole, counterbalanced by compatible solutes in the cytoplasm. As a rule, the osmotic potential of leaf cell sap normally differs by 0.5–1 MPa from that of the soil solution, enabling uptake of water.

12.1.2 Ion Pattern of Halophytes

For a long time, halophytes had been classified into chloride halophytes, sulphate halophytes and alkali halophytes, according to the main ions in cell sap or ash (Walter 1968). The alkali halophytes are those where a high proportion of organic acids (e.g., oxalate in *Halogeton* with up to 30% dry matter) are accumulated. It has long been known that halophytes are able to take up nutrients from the soil despite an excessive content of Na^+ and Cl^-. Most halophytes discriminate between Na^+ and K^+ and only few species are really sodiophilic (Moore et al. 1972). To demonstrate the characteristics in K^+/Na^+ discrimination, it is necessary to have the relevant soil samples from the rhizosphere of the respective plants. Then the accumulation factor for sodium in comparison with potassium can be calculated. It is easily seen that most species under a wide range of given cation ratios in the soil favour potassium uptake. The widespread Chenopodiaceae *Salicornia europaea* and *Suaeda maritima* can be termed sodiophilic, and so can *Climacoptera aralensis* and *Suaeda acuminata* (Tables 12.2, 12.3 and 12.4), whereas *Petrosimonia triandra* exhibits a rather balanced Na^+/K^+ ratio. In contrast, the grasses *Puccinellia distans* and *Stipagrostis pennata* and *Eremosparton aphyllum* very selectively accumulate potassium by a factor of 10–100 according to the soil Na^+/K^+ ratio; even in saline soils their Na^+/K^+ ratio is between 0.10 and 0.40 (Table 12.4). Slightly more sodium is accumulated in some Brassicaceae, e.g. in *Malcolmia africana*. All other Chenopodiaceae are more or less halophytic and exhibit rather high Na^+/K^+ ratios (Table 12.4), which is not really very different from the results from hot-water extracts and from acidic extracts (Tables 12.3 and 12.4). However, in the pseudohalophytes or nonhalophytes, the amount of nonvacuolar alkali ions (which are extracted additionally with the acidic extract) is considerably higher (Table 12.4). This is due to the calcium content, where by an acidic extraction up to 60 times higher amounts are analysed.

It is obvious that leaf succulents and stem succulents, such as species from the genera *Suaeda*, *Salicornia* and *Halocnemum*, accumulate considerably more Na^+ and Cl^- (3,000–5,000 mmol/kg) in comparison with other species. The ionic contents (Na^+ and Cl^-) of *Climacoptera* species and of *Ofaiston monandrum* are lower (2,000–3,500 mmol/kg) in comparison with those of species from *Salicornia* and *Suaeda*. Even lower are the values from *Petrosimonia triandra*. On the other

Table 12.2 Ion pattern of some common halophytic species of the Aralkum, analysed from hot-water extracts (*upper figure*) and from acidic extracts (*lower figure in italics*). Comparison of samples from Bayan (*Ba*) and from Karabulak (*Ka*); *n* number of samples, ion content (mmol kg^{-1} dry matter and standard deviation)

Species	*n*	Locality	Cl^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+/K^+
Climacoptera aralensis	3	Ba	2,913 ± 684	4,143 ± 512	420 ± 86	2.74 ± 0.30	98 ± 38	9.9
			–	4,940 ± 480	454 ± 78	228 ± 123	259 ± 10	10.9
	5	Ka	2,700 ± 489	2,882 ± 1,126	674 ± 182	4.03 ± 1.44	168 ± 26	4.3
			–	3,850 ± 1,452	793 ± 219	246 ± 106	287 ± 36	4.9
Petrosimonia triandra	3	Ba	600 ± 109	1,016 ± 289	570 ± 54	13,0 ± 8,3	306 ± 77	1.8
			–	1,525 ± 212	685 ± 68	404 ± 54	466 ± 45	2.2
	1	Ka	603	627	521	25	233	1.2
			–	668	603	329	383	1.1
Suaeda acuminata	1	Ba	4,731	4,722	416	88	150	11.3
			–	6,500	446	232	410	14.6
	9	Ka	4,370 ± 850	4,107 ± 598	729 ± 102	6.05 ± 2.8	246 ± 66	5.6
			–	4,741 ± 1,054	842 ± 112	264 ± 47	444 ± 73	5.6

Table 12.3 Ion pattern of some common halophytic species of the Aralkum, analysed from hot-water extracts. From Bayan (*Ba*) and from Karabulak (*Ka*). *n* number of samples, ion content (mmol kg^{-1} and standard deviation). For each species the halophyte type is indicated (second column; for an explanation of the abbreviations, see Table 12.1

Species	Halophyte type	*n*	Locality	Cl^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+/K^+
Climacoptera aralensis	LSu	8	3x Ba, 5x Ka	2,780 ± 531	3,356 ± 1,107	573 ± 199	3.55 ± 1.29	142 ± 46	5.9
Petrosimonia triandra	LSu	4	3x Ba, 1x Ka	600 ± 109	1,016 ± 289	570 ± 54	13.0 ± 8.3	306 ± 77	1.8
Suaeda acuminata	LSu	10	1x Ba, 9x Ka	4,406 ± 810	4,196 ± 597	697 ± 138	5.66 ± 2.9	236 ± 70	6.0
Suaeda crassifolia	LSu	2	2x Ka	4,485 ± 579	3,465 ± 298	427 ± 0.7	20.3 ± 6.3	545 ± 105	8.1
Ofaiston monandrum	SSu	2	2x Ka	2,196 ± 837	2,183 ± 1,289	423 ± 142	120 ± 149	532 ± 59	5.2
Salicornia europaea	Ssu	2	2x Ba	4,291 ± 157	3,857 ± 335	428 ± 132	5.4 ± 1.8	168 ± 23	9.0
Halocnemum strobilaceum	Ssu	1	1x Ba	3,042	3,748	506	2.02	133	7.4
Halostachys caspica	Ssu	1	1x Ba	1,095	2,088	509	2.61	60.0	4.1
Euclidium syriacum	Ps	1	1x Ka	314	127	497	142	95	0.26
Malcolmia africana	Ps	1	1x Ka	451	648	998	328	148	0.65
Eremosparton aphyllum	NoH	1	1x Ba	155	32.7	324	52.9	78.5	0.10
Stipagrostis pennata	NoH	1	1x Ba	78.0	44.7	327	141	43.4	0.32

Table 12.4 Ion pattern of some common halophytic species of the Aralkum, analysed from acidic extracts. From Bayan (*Ba*) and from Karabulak (*Ka*). *n* number of samples, ion content (mmol kg^{-1} and standard deviation), in *parentheses* factor for increased content related to hot-water extracts, see Table 12.3

Species	*n*	Locality	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+/K^+
Climacoptera aralensis	8	3x Ba	4,259 ± 1,261	666 ± 245	239 ± 104	277 ± 31	6.4
		5x Ka	(1.27)	(1.16)	(67.3)	(1.95)	
Petrosimonia triandra	4	3x Ba	1,233 ± 533	664 ± 68	385 ± 58	445 ± 56	1.9
		1x Ka	(1.21)	(1.16)	(29.6)	(1.45)	
Suaeda acuminata	10	1x Ba	5,017 ± 922	803 ± 164	261 ± 46	441 ± 70	6.3
		9x Ka	(1.20)	(1.15)	(46.1)	(1.87)	
Suaeda crassifolia	2	2x Ka	4,263 ± 4.2	504 ± 9.9	321 ± 35	707 ± 138	8.5
			(1.23)	(1.18)	(15.8)	(1.30)	
Ofaiston monandrum	2	2x Ka	2,905 ± 1,673	460 ± 120	366 ± 190	659 ± 36	6.3
			(1.33)	(1.09)	(3.05)	(1.24)	
Salicornia europaea	2	2x Ba	5,310 ± 306	472 ± 86	370 ± 94	565 ± 116	11.3
			(1.38)	(1.10)	(68.5)	(3.36)	
Halocnemum strobilaceum	1	1x Ba	5,850	579	64	151	10.1
			(1.56)	(1.14)	(31.9)	(1.14)	
Halostachys caspica	1	1x Ba	2,870	579	81	149	5.0
			(1.37)	(1.14)	(31.0)	(2.48)	
Euclidium syriacum	1	1x Ka	130	557	333	140	0.23
			(1.02)	(1.12)	(2.35)	(1.47)	
Malcolmia africana	1	1x Ka	714	1,130	572	184	0.63
			(1.10)	(1.13)	(1.74)	(1.24)	
Eremosparton aphyllum	1	1x Ba	18	436	258	139	0.041
			(0.55)	(1.35)	(4.9)	(1.77)	
Stipagrostis pennata	1	1x Ba	28	401	212	53	0.070
			(0.63)	(1.23)	(1.50)	(1.22)	

hand, the Na^+ and Cl^- accumulation of pseudohalophytes such as *Euclidium syriacum* and *Stripagrostis pennata* is very low.

The respective data on soil from the sites studied are given in Table 9.1 along the Karabulak gradient transect. All sites are rather alkaline. Salinity is also very variable between sites and between distribution along horizons. This depends on season, as salinity changes with evaporative demands in summer along the very long capillaries in loam and clay to the upper horizons and this may form a salt crust. However, lower horizons also often have a rather high salinity level, whereas middle horizons may store less saline water from winter snow or rains. This is shown by two examples of soil profiles (Fig. 12.5). In both soil profiles it is obvious that the sulphate salinity is as high as or even higher than the chloride salinity, but differs in the horizons.

It should be briefly mentioned that the various members of the Chenopodiaceae on the Aralkum cannot be put into one group of physiotypes (Reimann and Breckle 1993). Under natural conditions the sodium levels vary very much, as do the levels of other ions. There are many articles on the chemistry of halophytes and their internal ion composition (Albert 1982), as well as on the normally taxon-specific

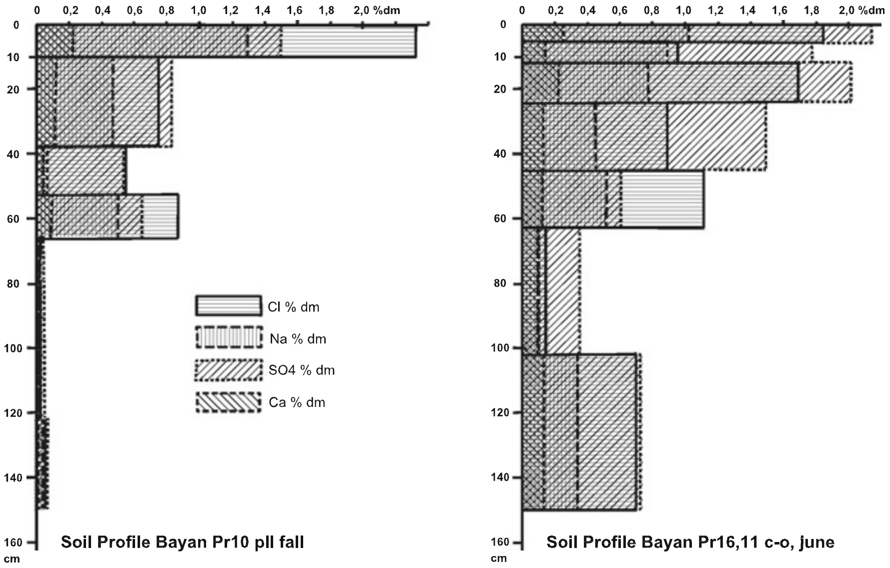

Fig. 12.5 Ion content in soil horizons of the Aralkum. *Left*: Soil profile Bayan Pr10 with main salt accumulation, mainly chloride in topsoil. *Right*: Soil profile Bayan Pr16 with salt, mainly sulphate accumulation in topsoil and in lower horizons

Fig. 12.6 *Suaeda acuminata*. Remnants from previous year, new seedlings and saplings. North Aral Sea (photo: Breckle, May 2003)

accumulation of compatible solutes (Popp 1985). The main characteristics of the physiotypes, e.g. Brassicaceae and Poaceae, are represented in the same ion pattern, as Albert (1982, 2005) extensively described.

It is always an open question to what extent the edaphic conditions influence the ionic pattern and content in plants (Mirazai and Breckle 1978). The Pontic–Irano–Turanian *Suaeda acuminata* (Fig. 12.6) is very common in Central Asia (Wucherer 1986). This species exhibits a wide ecological amplitude and thus can be found on very contrasting saline stands. Within the Karabulak transect on the northern coast of the Aral Sea, at seven localities *Suaeda acuminata* is present (Table 9.1).

It is obvious that the sodium and chloride contents of the aboveground plant organs of *Suaeda acuminata* on degraded coastal solonchaks and puffy coastal solonchaks are significantly lower. These soils contain significantly less salt in the topsoil. On these stands the sodium content is higher than the chloride content in comparison with the marshy solonchaks and crusty coastal solonchaks (Table 12.5). This example of *Suaeda* demonstrates that the ion content in halophytes growing on real solonchaks with high salinity is not distinctly influenced by the edaphic conditions.

Balnokin et al. (1991) studied the sodium, chloride and proline contents in *Salicornia europaea*, *Climacoptera aralensis* und *Petrosimonia triandra* along the Bayan transect on the eastern coast of the Aral Sea (Table 12.6). The content of proline as one of the typical compatible solutes apparently exhibits no clear correlation to the storage of salt in the plant tissues.

Table 12.5 Main ions in the stems and leaves of *Suaeda acuminata* (mol kg^{-1} dry matter) from the Karabulak transect and soil characteristics (10–20 cm) of the site. *EC* electric conductivity of soil extracts (mS cm), *DSF* dry sea floor (from the 1970s, 1980s or 1990s)

	DSF	Soil pH	Soil EC	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-
Degraded coastal solonchak	1970s	8.0	2.9	3.8	0.75	0.20	0.0048	3.5
Degraded coastal solonchak	1970s	8.1	1.1	5.0	0.59	0.18	0.0041	4.9
Coastal solonchak	1980s	8.5	12.8	3.5	0.76	0.19	0.0047	2.7
Crusty coastal solonchak	1980s	8.3	19.4	4.5	0.68	0.21	0.0035	5.1
Puffy coastal solonchak	1990s	–	–	4.5	0.60	0.20	0.0039	5.1
Coastal solonchak[a]	1990s	8.2	7.4	3.8	0.82	0.31	0.0118	3.9
				4.7	0.86	0.25	0.0046	5.0
Marshy solonchak[a]	1990s	8.4	1.3	3.4	0.84	0.33	0.0103	4.7
				3.6	0.66	0.36	0.0079	4.5

[a] Samples taken twice (4 and 12 May 1998)

Table 12.6 Ion content and proline content (mmol kg^{-1} fresh weight) in green tissues of halophytic plants from the Aralkum

Salicornia europaea			*Climacoptera aralensis*			*Petrosimonia triandra*		
Na^+	Cl^-	Proline	Na^+	Cl^-	Proline	Na^+	Cl^-	Proline
286	109	0.85	168	202	0.43	162	64	0.70
451	140	0.63	434	117	0.29	181	91	0.78
516	165	0.46	511	139	0.35	251	102	0.81
532	202	0.40	608	182	0.44	252	71	0.89
639	179	1.00	620	175	0.26	256	73	1.15
665	189	0.51	683	132	0.32	258	80	0.91
729	220	0.47	768	172	0.41	275	83	1.11
843	254	0.28	830	167	0.30	281	73	1.11
867	276	0.62	1,021	160	0.30	297	71	0.88
1,116	296	0.64	1,153	228	0.39	394	104	0.96

After Balnokin et al. (1991)

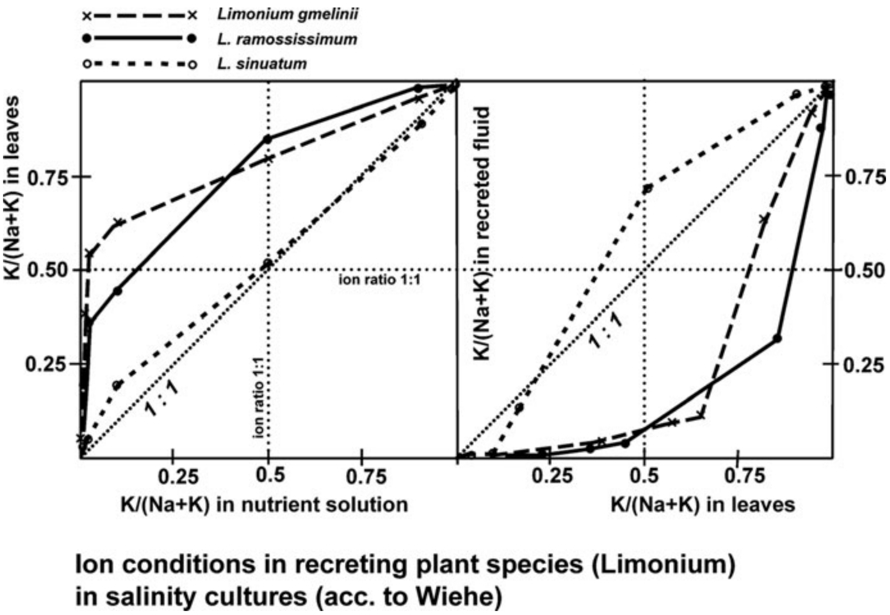

Fig. 12.7 Ion conditions in three *Limonium* species in salinity cultures (Wiehe and Breckle 1989) with various nutrient solutions differing in Na^+/K^+ ratio

The selectivity against ions differs in the various species according to their natural occurrence. The halophytes *Limonium gmelinii* and *Limonium ramosissimum* are very potassiophilic, as can be seen by the strong change in ion pattern (Fig. 12.7, left side) between nutrient solution and leaf cell sap. Again, there is a major change in ion composition between leaf cell sap and the recreted fluid. The ion pattern changes in such a way that the cytoplasm of the leaf cells is kept relatively low in sodium, whereas the gland fluid is rich in sodium (Fig. 12.7, right side). Such behaviour is not recognizable in *Limonium sinuatum*, a plant which inhabits slightly saline stands. In that species selectivity in both cases of transport is low (Fig. 12.7). It was also shown that the activity of the salt glands of the halophilic *Limonium* species (Wiehe and Breckle 1989) and *Aeluropus* has a threshold value and these start to recrete NaCl only after a distinct salinity level in the leaf is reached (Pollak and Waisel 1979).

There are many indications that also in the stem- and leaf-succulent halophytes, in the recretohalophytes and pseudohalophytes from the dry Aral Sea floor, different mechanisms and strategies for the adjustment and regulation of the salt concentration in the plant tissues are operating (Breckle 1995) and thus a differing salt tolerance in the various species leads to a specific pattern of species and halophyte types along salt gradients.

The sequence of species along the salt gradient in a rich halophytic area, as it is in the Central Asian deserts, reveals a typical sequence of the dominating halophyte types. Along the salt gradient (Breckle 1986), which can be derived from salinity measurements in a mosaic vegetation, it is obvious that the stem succulents and then the leaf succulents play the major role close to the saline lakes or basins, where salinity is high. The recreting halophytes (exocrinohalophytes, endocrinohalophytes) dominate in the middle part of the transect, where salinity is more variable as is water supply. This part of the transect is characterized by less water availability and often here a much higher proportion of C_4 plants occurs. This is also the case on the less saline side, where the pseudohalophytes and finally on almost salt-free substrates the nonhalophytes predominate and other ecological factors, such as water availability, water supply and nitrogen source, govern the vegetation mosaic. However, on the desiccated seafloor of the Aral Sea an equilibrium of halophyte types has not yet been reached, the dynamics of changing ecological conditions from year to year is so drastic that only by chance a mixture of more or less adapted species is found, which in part resemble the sequence of the halophyte types discussed.

12.1.3 Ecological Salinity Indicator Values for Plants of the Aralkum Region

The ecological behaviour and adaptation to distinct natural site conditions is the result of the competitive ability of a species. This depends on the floristic pattern of the region and the competitors present. Normally under natural conditions with a fluctuating climate from year to year, a dynamic equilibrium can be observed, and if the main ecological conditions vary within a rather constant range, a set of species will form a rather constant community.

Under saline conditions, the salt content of the soil plays a major decisive role for which species can compete successfully (Adam 1990). By comparing many sites with different salinities, one can evaluate the distinct ecological optimum (not ecophysiological optimum without competition, which can be rather different: many plants grow better under low salinities but are pressed to higher salinity sites by competition, where they can grow, but not optimally). This ecological optimum can be used to grade the ecological salinity tolerance by an indicator value (S value, see Table 12.7). Such indicator values are used rather widely in various regions for various ecological parameters, e.g., pH, nitrogen supply, drought tolerance and heat tolerance (Ellenberg et al. 1991). For salt tolerance a scale from 0 to 9 can be used (Table 12.7), where 9 means the highest salt tolerance. In contrast to many other indicator values, the distribution of the S values over the whole scale is oblique since most species belong to the nonhalophyte group, which has an indicator value of $S = 0$ or $S = 1$.

By long-term observations and comparing many sites, one can define S values for many species. A few species are very variable in their adaptation to saline site conditions, and those species have no definite S value ($S =$ X). For others, their

Table 12.7 Definitions of the *S* value, the ecological salinity indicator value (see Breckle 1985; Ellenberg et al. 1991)

S value	
0	Not salt-tolerant, species never in brackish soils (NaCl content in soil below 0.01%), very sensitive to salt, strong nonhalophytes
1	Almost not salt-tolerant, very rare in brackish soils (NaCl content in soil below 0.05%)
2	Similar to $S = 1$, but more often in slightly brackish soils (oligohaline, about 0.05-0.3% Cl^-), slightly salt-tolerant species, which can withstand some salinity, but most frequently occuring in nonsaline soils ("pseudohalophytes", exhibiting no special morphological or anatomical features, also possible for higher *S* values)
3	Species indicating salinity; however, may also grow in soils with low salinity ("facultative halophyte", "accidental halophytes" in an ecological sense) (ß-mesohaline, about 0.3–0.5% Cl^-)
4	Similar to $S = 3$ (α/ß-mesohaline, about 0.5–0.7% Cl^-), exhibiting some salt tolerance and longer survival under salinity
5	Species normally only in saline soils (α-mesohaline, about 0.7–0.9% Cl^-), can withstand moderate salinities
6	Typical halophytes, indicating salinity, rare in nonsaline soils (α-mesohaline/polyhaline, about 0.9–1.2% Cl^-)
7	Similar to $S = 6$, but very salt-tolerant, never in nonsaline soils (often "obligatory halophytes" in ecological terms) (polyhaline, about 1.2–1.6% Cl^-], species indicating moderate to rather high salinities in soil
8	Typical halophytes, indicating high salinity, very salt-tolerant (euhaline, about 1.6–2.30% Cl^-), typical salt plants, indicating high salinities, only growing on severely saline sites (obligatory halophytes, euhalophytes)
9	Extreme halophytes, in soils with very high, during dry periods extremely high, salinity ("obligatory halophytes" in ecophysiological terms) (euhaline/hypersaline, above 2.30% Cl^-), found only on salt-crust soils and always indicating very strong salinities. Species which can fulfil their whole life cycle on highly saline sites
X	*S* value very variable, broad, indistinct, species found from nonsaline to very saline sites
–	*S* value not yet known, most probably 0 or 1

typical site conditions are not known exactly ($S = –$), and will be revealed only in the future.

It should also be kept in mind that the *S*-value list is only valid for a distinct region; it depends on the whole given flora and the respective competitive plant communities.

The Aralkum flora is very rich in halophytes; thus, the percentage of species with high *S* values (above 4) is rather high in several plant families (see Table 12.8). Other plant families are represented in the Aralkum by a quite high number of species but still mainly prefer sites with low salinity (Polygonaceae, Brassiceae, Fabaceae).

All species of the Aralkum flora are listed in Table 12.9 with their ecological salinity indicator value (*S* value), their halophytic strategy type and their life form. It is easily recognizable that the halophytic type and the *S* value are rather strongly correlated.

Table 12.8 Number of species of halophytic strategy types and related salinity indicator values for the halophytic flora of the Aralkum

Halophytic strategy type	1	2	3	4	5	6	7	8	9	*X*	Σ
Nonhalophytes	42	18	0	0	0	0	0	0	0	0	60
Pseudohalophytes	4	30	42	15	8	4	1	0	0	4	108
Xerosucculents	0	0	0	0	0	0	0	0	0	1	1
Leaf-succulent euhalophytes	0	2	2	5	14	7	22	9	1	0	62
Stem-succulent euhalophytes	0	0	0	1	1	1	1	0	2	0	6
Endocrinohalophytes	0	0	2	5	1	2	0	0	0	0	10
Exocrinohalophytes	0	0	0	0	0	9	7	4	0	0	20
Hydrohalophytes	0	0	0	1	0	0	0	0	1	0	2
Σ	46	50	46	27	24	23	31	13	4	5	269
Not determined strategy type											104
Σ Σ											373

12.1.4 Salinity

Over all the oceans, seawater is rather homogeneous in chemical composition, with a strong preponderance of NaCl. In deserts with their arid climate, salinity is caused not only by atmospheric input (cyclic salt; Teakle 1937; Breckle 1976, 1985), but also by leaching of the rocky material of the hydrotope within the endorheic basin, where the water runoff from the rare precipitation events is collected in the erosion basin, forming salt lakes, which may have accumulated also some other ions besides Na^+ and Cl^-, mainly SO_4^{2-}, HCO_3^-, Li^+, Mg^{2+}, borate, etc. (Breckle 1975a, b, 1990). Thus, in some parts of the world, salinity is caused not only by chloride, but in temperate and cold arid continental regions it may be caused by sulphate or carbonate accumulation (Curtin et al. 1993). In the Aralkum the desiccated substrate of the seafloor is rich in chloride and sulphate. This can change within deeper horizon layers (Fig. 12.5). It can also be seen indirectly by the various water sources in the region (Table 12.10) with very variable ion content and salinities. The ratio between ions is not as similar as in open-ocean water, which is rather constant within narrow limits all over the world. If the Na^+/Cl^- ratio is distinctly higher than 1, the counterbalance is normally by sulphate (sulphate salinity); if the $Mg^{2+}/Na^+{+}K^+$ ratio is distinctly higher than 0.1, the water has a bitter taste. If there is a sufficient portion of potassium and alkali earth ions present, the salinity by sodium is not as severe as with pure NaCl salinity. Plants can adjust to such conditions and are able to absorb nutrients by discriminating ions. Thus, a typical halophytic community is a mixture, and is often composed of several species, where some of these species are not real halophytes. They occur only accidentally in such plant communities of oligohaline marshes, but have their optimal growth and performance in nonsaline vegetation. A typical spatial or temporal niche segregation enables nonhalophytes or pseudohalophytes to migrate and to invade halophytic stands.

Table 12.9 Species of vascular plants from the Aralkum, indicating their salinity indicator values, halophytic character and life form (*Ch* chamaephytes, *G* geophytes, *B* with bulbs, *P* parasitic, *R* with rhizomes, *H* hemicryptophytes, *Hy* hydrophytes, *Ph-m* microphanerophytes, *Ph-n* nanophanerophytes, *T* therophytes). Salinity tolerance is expressed as indicator value *S* (for definitions of *S* values, see Table 12.8; $S = 0$, nonhalophytes, are not indicated here, mainly are within the "not known" group; $S = 9$, extreme halophytes, only growing on strongly saline stands; *X* indifferent, – not known)

Species	*S* value	Halophytic strategy type	Life form
Alliaceae J. Agardh			
Allium caspium (Pall.) Bieb.	1	NoH	GB
Allium sabulosum Stev. ex Bunge	1	NoH	GB
Allium schubertii Zucc.	1	NoH	GB
Amaryllidaceae J. St.-Hil.			
Ixiolirion tataricum (Pall.) Schult. & Schult. fil.	2	Ps	GB
Apiaceae Lindl.			
Ferula canescens (Ledeb.) Ledeb.	–	–	GR
Ferula caspica Bieb.	–	–	GR
Ferula lehmannii Boiss.	2	Ps	GR
Ferula nuda Spreng.	–	–	GR
Prangos odontalgica (Pall.) Herrnst. & Heyn	1	NoH	GR
Asclepiadaceae R. Br.			
Cynanchum sibiricum Willd.	2	Ps	H
Asparagaceae Juss.			
Asparagus breslerianus Schult. & Schult. fil.	1	Ps	H
Asparagus inderiensis Blum ex Pasz.	2	Ps	H
Asparagus persicus Baker	1	Ps	H
Asteraceae Dumort.			
Acroptilon repens (L.) DC.	3	Ps	H
Amberboa turanica Iljin	2	Ps	T
Anthemis candidissima Willd. ex Spreng.	1	NoH	T
Artemisia aralensis Krasch.	2	Ps	Ch
Artemisia austriaca Jacq.	1	Ps	H
Artemisia diffusa Krasch.ex Poljak.	2	Ps	Ch
Artemisia arenaria DC.	–	–	Ch
Artemisia pauciflora Web.	–	–	Ch
Artemisia quinqueloba Trautv.	–	–	Ch
Artemisia santolina Schrenk	3	Ps	H
Artemisia schrenkiana Ledeb.	–	–	H
Artemisia scoparia Waldst. & Kit.	2	Ps	H
Artemisia scopiformis Ledeb.	–	–	H
Artemisia semiarida (Krasch. et Lavr.) Filat.	3	Ps	Ch
Artemisia songarica Schrenk	3	Ps	Ch
Artemisia terrae-albae Krasch.	X	Ps	Ch
Artemisia turanica Krasch.	–	–	Ch
Chartolepis intermedia Boiss.	–	–	H
Chondrilla ambigua Fisch. ex Kar. & Kir.	4	Ps	H
Chondrilla brevirostris Fisch. & C. A. Mey.	–	–	H
Cirsium arvense (L.) Scop.	2	Ps	H

(continued)

Table 12.9 (continued)

Species	*S* value	Halophytic strategy type	Life form
Cirsium ochrolepidium Juz.	–	–	H
Cousinia affinis Schrenk	–	–	H
Epilasia hemilasia (Bunge) Clarke	2	NoH	T
Heteracia szovitsii Fisch. & C. A. Mey.	–	–	T
Hyalea pulchella (Ledeb.) C. Koch	–	–	H
Inula caspica Blum ex Ledeb.	2	Ps	H
Inula germanica L.	1	NoH	H
Karelinia caspia (Pall.) Less.	5	Lsu	H
Koelpinia linearis Pall.	3	Ps	T
Koelpinia tenuissima Pavl. & Lipsch.	–	–	T
Koelpinia turanica Vass.	–	–	T
Lactuca serriola L.	3	Ps	H
Lactuca tatarica (L.) C. A. Mey.	3	Ps	H
Lactuca undulata Ledeb. Pojark	–	–	T
Mausolea eriocarpa (Bunge)	–	–	Ch
Saussurea salsa (Pall. ex Bieb.) Spreng.	5	Lsu	H
Scorzonera sericeolanata (Bunge) Krasch. & Lipsch.	3	Ps	GB
Senecio noeanus Rupr.	5	Lsu	T
Senecio subdentatus Ledeb.	4	Lsu	T
Sonchus oleraceus L.	3	Ps	T
Taktajaniantha pusilla (Pall.) Nazarova	–	–	GB
Tanacetum achilleifolium (Bieb.) Sch. Bip.	2	Ps	H
Taraxacum bessarabicum (Hornem.) Hand.-Mazz.	4	Ps	H
Tragopogon marginifolius Pavl.	3	Ps	GR
Tragopogon ruber S. G. Gmel.	–	–	GR
Tragopogon sabulosus Krasch. & S. Nikit.	–	–	GR
Tripolium vulgare Nees	7	Lsu	T
Berberidaceae Juss.			
Leontice incerta Pall.	1	NoH	GR
Boraginaceae Juss.			
Argusia sibirica (L.) Dandy	6	Ps	H
Arnebia decumbens (Vent.) Coss. & Kral.	1	NoH	T
Asperugo procumbens L.	1	NoH	T
Heliotropium arguzioides Kar. & Kir.	4	Lsu	H
Heliotropium dasycarpum Ledeb.	5	Ps	H
Heterocaryum rigidum A. DC.	–	–	T
Heterocaryum szovitsianum (Fisch. & C. A. Mey.) A. DC.	–	–	T
Lappula semiglabra (Ledeb.) Guerke	2	Ps	T
Lappula spinocarpos (Forssk.) Aschers.	–	–	T
Nonea caspica (Willd.) G. Don fil.	2	NoH	T
Rochelia retorta (Pall.) Lipsky	3	Ps	T
Rochelia leiocarpa Ledeb.	–	–	T
Suchtelenia calycina (C. A. Mey.) A. DC.	–	–	T
Brassicaceae Burnett			
Alyssum dasycarpum Steph.	2	NoH	T

(continued)

Table 12.9 (continued)

Species	*S* value	Halophytic strategy type	Life form
Alyssum turkestanicum Regel & Schmalh.	–	–	T
Capsella bursa-pastoris (L.) Medik.	1	NoH	T
Cardaria pubescens (C. A. Mey.) Jarm.	3	Ps	T
Chorispora tenella (Pall.) DC.	1	NoH	T
Descurainia sophia (L.) Webb ex Prantl	3	Ps	T
Diptychocarpus strictus (Fisch. ex Bieb.) Trautv.	–	–	T
Draba nemorosa L.	–	–	T
Erysimum sisymbrioides C. A. Mey.	1	NoH	T
Euclidium syriacum (L.) R. Br.	3	Ps	T
Goldbachia laevigata (Bieb.) DC.	5	Ps	T
Isatis minima Bunge	4	Ps	T
Isatis violascens Bunge	3	Ps	T
Lachnoloma lehmannii Bunge	4	Ps	T
Lepidium latifolium L.	5	LSu	H
Lepidium obtusum Basin.	3	Ps	H
Lepidium perfoliatum L.	4	Ps	T
Lepidium ruderale L.	4	Ps	T
Leptaleum filifolium (Willd.) DC.	2	NoH	T
Litwinowia tenuissima (Pall.) Woronow ex Pavl.	–	–	T
Matthiola stoddartii Bunge	2	Ps	T
Megacarpaea megalocarpa (Fisch. ex DC.) B. Fedtsch.	2	NoH	GR
Meniocus linifolius (Steph.) DC.	3	Ps	T
Octoceras lehmannianum Bunge	3	Ps	T
Pachypterygium multicaule (Kar. & Kir.) Bunge	3	Ps	T
Sameraria armena (L.) Desv.	3	Ps	T
Streptoloma desertorum Bunge	–	–	T
Strigosella africana (L.) Botsch.	–	–	T
Strigosella brevipes (Bunge) Botsch.	–	–	T
Strigosella circinata (Bunge) Botsch.	–	–	T
Strigosella scorpioides (Bunge) Botsch.	2	NoH	T
Syrenia montana (Pall.) Klok.	–	–	T
Tauscheria lasiocarpa Fisch. ex DC.	3	Ps	T
Tetracme quadricornis (Steph.) Bunge	4	Ps	T
Tetracme recurvata Bunge	–	–	T
Caryophyllaceae Juss.			
Acanthophyllum borsczowii Litv.	1	NoH	Ch
Acanthophyllum pungens (Bunge) Boiss	1	NoH	H
Gypsophila paniculata L.	3	Ps	H
Gypsophila perfoliata L.	3	Ps	H
Silene nana Kar. & Kir.	1	NoH	T
Silene odoratissima Bunge	–	–	H
Ceratophyllaceae S.F.Gray			
Ceratophyllum demersum L.	1	NoH	Hy
Chenopodiaceae Vent. (85)			
Agriophyllum minus Fisch. & C. A. Mey.	2	NoH	T

(continued)

Table 12.9 (continued)

Species	*S* value	Halophytic strategy type	Life form
Agriophyllum squarrosum (L.) Moq.	2	NoH	T
Anabasis aphylla L.	4	SSu	Ch
Anabasis salsa (C. A. Mey.) Benth. ex Volkens	6	LSu	Ch
Anabasis truncata (Schrenk) Bunge	5	LSu	H
Arthrophytum lehmannianum Bunge	5	SSu	T
Atriplex aucheri Moq.	4	NX	T
Atriplex cana C. A. Mey.	6	NX	T
Atriplex dimorphostegia Kar. & Kir.	4	NX	T
Atriplex littoralis L.	5	NX	T
Atriplex micrantha C. A. Mey.	3	NX	T
Atriplex moneta Bunge	2	Ps	T
Atriplex patula L.	2	Ps	T
Atriplex pratovii Suchor.	6	NX	T
Atriplex pungens Trautv.	4	NX	T
Atriplex sagittata Borkh.	4	NX	T
Atriplex sphaeromorpha Iljin	4	NX	T
Atriplex tatarica L.	3	Ps	T
Bassia hyssopifolia (Pall.) O. Kuntze	5	LSu	T
Bassia sedoides (Pall.) Aschers.	5	LSu	T
Bienertia cycloptera Bunge	7	LSu	T
Chenopodium glaucum L.	3	NX	T
Chenopodium rubrum L.	3	Ps	T
Ceratocarpus arenarius L.	2	Ps	T
Climacoptera affinis (C. A. Mey.) Botsch.	7	LSu	T
Climacoptera aralensis (Iljin) Botsch.	8	LSu	T
Climacoptera brachiata (Pall.) Botsch.	7	LSu	T
Climacoptera ferganica (Drob.) Botsch.	8	LSu	T
Climacoptera lanata (Pall.) Botsch.	8	LSu	T
Corispermum aralo-caspicum Iljin	3	Ps	T
Corispermum hyssopifolium L.	3	Ps	T
Corispermum laxiflorum Schrenk	2	NoH	T
Corispermum lehmannianum Bunge	2	NoH	T
Corispermum orientale Lam.	5	Ps	T
Gamanthus gamocarpus (Moq.) Bunge	8	LSu	T
Girgensohnia oppositiflora (Pall.) Fenzl	4	Ps	T
Halimione pedunculata (L.) Aell.	7	LSu	T
Halimione verrucifera (Bieb.) Aell.	7	LSu	Ch
Halimocnemis karelinii Moq.	7	LSu	T
Halimocnemis longifolia Bunge	7	LSu	T
Halimocnemis sclerosperma (Pall.) C. A. Mey.	7	LSu	T
Halimocnemis villosa Kar. & Kir.	7	LSu	T
Halocnemum strobilaceum (Pall.) Bieb.	9	SSu	Ch
Halogeton glomeratus C. A. Mey.	6	LSu	T
Halostachys belangeriana (Moq.) Botsch.	8	LSu	Ph-n
Halothamnus subaphyllus (C. A. Mey.) Botsch.	6	SSu	Ch

(continued)

Table 12.9 (continued)

Species	*S* value	Halophytic strategy type	Life form
Haloxylon aphyllum (Minkw.) Iljin	7	SSu	Ph-m
Haloxylon persicum Bunge ex Boiss. & Buhse	2 (3)	NoH (Ssu)	Ph-m
Horaninovia anomala (C. A. Mey.) Moq.	3	Ps	T
Horaninovia excellens Iljin	3	Ps	T
Horaninovia minor Schrenk	3	Ps	T
Horaninovia ulicina Fisch. & C. A. Mey.	5	Ps	T
Kalidium caspicum (L.) Ung.- Sternb.	7	LSu	Ch
Kalidium foliatum (Pall.) Moq.	7	LSu	Ch
Kirilowia eriantha Bunge	6	LSu	T
Kochia iranica Bornm.	5	Ps	T
Kochia odontoptera Schrenk	5	Ps	T
Kochia prostrata (L.) Schrad.	5	Ps	Ch
Krascheninnikovia ceratoides (L.) Gueldenst.	(2) 3 (5)	(NoH) Ps	Ch
Londesia eriantha Fisch. & C. A. Mey.	4	Ps	T
Nanophytum erinaceum (Pall.) Bunge	5	LSu	Ch
Ofaiston monandrum (Pall.) Moq.	6	LSu	T
Petrosimonia brachiata (Pall.) Bunge	7	LSu	T
Petrosimonia glaucescens (Bunge) Iljin	7	LSu	T
Petrosimonia hirsutissima (Bunge) Iljin	7	LSu	T
Petrosimonia squarrosa (Schrenk) Bunge	7	LSu	T
Petrosimonia triandra (Pall.) Simonk.	8	LSu	T
Salicornia europaea L. S. L.	9	SSu	T
Salsola arbuscula Pall.	4	LSu	Ph-n
Salsola australis (R.) Br.	–	LSu	T
Salsola chiwensis M. Pop.	–	LSu	Ch
Salsola dendroides Pall.	6	LSu	Ch
Salsola foliosa (L.) Schrad.	–	LSu	T
Salsola implicata Botsch.	–	LSu	T
Salsola micranthera Botsch.	5	LSu	T
Salsola nitraria Pall.	6	LSu	T
Salsola orientalis S. G. Gmel.	5	LSu	Ch
Salsola paletzkiana Litv.	3	LSu	Ph-n
Salsola paulsenii Litv.	3	LSu	T
Salsola richteri (Moq.) Kar. ex Litv.	4	LSu	Ph-n
Salsola tamariscina Pall.	5	LSu	T
Suaeda acuminata (C. A. Mey.) Moq.	8	LSu	T
Suaeda altissima (L.) Pall.	7	LSu	T
Suaeda arcuata Bunge	8	LSu	T
Suaeda crassifolia Pall.	9	LSu	T
Suaeda heterophylla (Kar. et Kir.) Bunge	7	LSu	T
Suaeda microphylla Pall.	8	LSu	Ch
Suaeda microsperma (C. A. Mey.) Fenzl.	8	LSu	T
Suaeda physophora Pall.	7	LSu	Ch
Suaeda salsa (L.) Pall.	8	LSu	T

(continued)

Table 12.9 (continued)

Species	*S* value	Halophytic strategy type	Life form
Convolvulaceae Juss.			
Convolvulus arvensis L.	2	Ps	H
Convolvulus erinaceus Ledeb.	1	NoH	Ch
Convolvulus subsericeus Schrenk	1	NoH	Ch
Cyperaceae Juss.			
Bolboschoenus maritimus (L.) Palla	6	Ps	GB
Carex pachystylis J. Gay	2	Ps	H
Carex physodes Bieb.	1	NoH	H
Scirpus lacustris L.	6	Ps	Hy
Scirpus tabernaemontani C. C. Gmel.	6	Ps	Hy
Elaeagnaceae Juss.			
Elaeagnus oxycarpa Schlecht.	4	Ps	Ph-m
Ephedraceae Dumort.			
Ephedra distachya L.	3	Ps	Ch
Ephedra intermedia Schrenk & C. A. Mey.	1	NoH	Ch
Ephedra strobilacea Bunge	2	NoH	Ch
Equisetaceae Rich. ex DC.			
Equisetum ramosissimum Desf.	1	NoH	H
Euphorbiaceae Juss.			
Euphorbia inderiensis Less. Kar. et Kir.	–	–	H
Euphorbia seguierana Neck.	2	Ps	H
Euphorbia turczaninowii Kar. & Kir.	–	–	H
Euphorbia undulata Bieb.	–	–	H
Fabaceae Lindl.			
Alhagi pseudalhagi (Bieb.) Fisch.	X	Ps	H
Ammodendron bifolium (Pall.) Yakovl.	–	–	Ph-n
Ammodendron conollyi Bunge	2	NoH	Ph-m
Ammodendron karelinii Fisch. et Mey.	2	NoH	Ph-n
Astragalus amarus Pall.	–	–	H
Astragalus ammodendron Bunge	–	–	Ph-n
Astragalus brachypus Schrenk	–	–	Ph-n
Astragalus campylorrhynchus Fisch. & C. A. Mey.	2	Ps	T
Astragalus lehmannianus Bunge	2	Ps	H
Astragalus longipetalus Chater	–	–	H
Astragalus ninae Pavl.	–	–	H
Astragalus oxyglottis Stev. ex Bieb.	–	–	T
Astragalus testiculatus	–	–	H
Astragalus villosissimus Bunge	–	–	Ph-n
Astragalus vulpinus Willd.	–	–	H
Eremosparton aphyllum (Pall.) Fisch. et Mey.	2	Ps	Ph-n
Glycyrrhiza aspera Pall.	4	Ps	H
Glycyrrhiza glabra L.	4	Ps	H
Halimodendron halodendron (Pall.) Voss.	5	LSu	Ph-n
Pseudosophora alopecuroides (L.) Sweet	4	Ps	H
Sphaerophysa salsola (Pall.) DC.	–	–	H

(continued)

Table 12.9 (continued)

Species	*S* value	Halophytic strategy type	Life form
Trigonella arcuata C. A. Mey.	–	–	T
Trigonella orthoceras Kar. et Kir.	–	–	T
Frankeniaceae S. F. Gray			
Frankenia hirsuta L.	8	EX	H
Fumariaceae DC.			
Fumaria vaillantii Loisel.	1	NoH	T
Geraniaceae Juss.			
Erodium oxyrhynchum Bieb.	1	NoH	T
Geranium transversale (Kar. & Kir.) Vved.	1	NoH	GR
Hypecoaceae Nakai			
Hypecoum parviflorum Kar. et Kir.	2	NoH	T
Iridaceae Juss.			
Iris longiscapa Ledeb.	1	NoH	GR
Iris songarica Schrenk	3	Ps	GR
Iris tenuifolia Pall.	1	NoH	GR
Juncaceae Juss.			
Juncus gerardii Loisel.	7	Ps	H
Lamiaceae Lindl.			
Chamaesphacos ilicifolius Schrenk	–	–	T
Eremostachys tuberosa (Pall.) Bunge	–	–	GR
Lallemantia royleana (Benth.) Benth.	1	NoH	T
Liliaceae Juss.			
Gagea reticulata (Pall.) Schult. & Schult. Fil.	1	NoH	GB
Rhinopetalum karelinii Fisch. ex Alexand.	1	NoH	GB
Tulipa buhseana Boiss.	1	NoH	GB
Limoniaceae Lincz.			
Limonium caspium (Willd.) Gams.	7	EX	H
Limonium gmelinii Willd. O. Kuntze	7	EX	H
Limonium otolepis (Schrenk) O. Kuntze	7	EX	H
Limonium suffruticosum (L.) O. Kuntze	8	EX	Ch
Malvaceae Juss.			
Malva neglecta Wallr.	3	Ps	T
Nitrariaceae Bercht. & J. Presl.			
Nitraria schoberi L.	6	LSu	Ph-n
Nitraria sibirica Pall.	6	LSu	Ph-n
Orobanchaceae Vent.			
Cistanche salsa (G. A. Mey.) G. Beck	X	Su	GP
Orobanche cernua Loefl.	1	NoH	GP
Papaveraceae Juss.			
Roemeria hybrida (L.) DC.	2	NoH	T
Roemeria refracta DC.	2	NoH	T
Peganaceae (Engl.) Tiegh. ex Takht.			
Peganum harmala L.	X	Ps	H
Plantaginaceae Juss.			
Plantago tenuiflora Waldst. & Kit.	5	Ps	T

(continued)

Table 12.9 (continued)

Species	*S* value	Halophytic strategy type	Life form
Poaceae Barnhart			
Aeluropus littoralis (Gouan) Parl.	7	EX	H
Agropyron desertorum (Fisch. ex Link) Schult.	1	Ps	H
Agropyron fragile (Roth) P. Candargy	–	–	H
Anisantha tectorum (L.) Nevski	–	–	T
Calamagrostis dubia Bunge	–	–	H
Catabrosella humilis (Bieb.) Tzvel.	–	–	H
Crypsis schoenoides (L.) Lam.	7	EX	T
Eremopyrum bonaepartis (Spreng.) Nevski	–	–	T
Eremopyrum distans (C. Koch) Nevski	3	Ps	T
Eremopyrum orientale (L.) Jaub. et Spach.	4	Ps	T
Eremopyrum triticeum (Gaertn.) Nevski	4	Ps	T
Leymus racemosus (Lam.) Tzvel.	–	–	H
Phragmites australis (Cav.) Trin. ex Steud.	X	Ps	H
Poa bulbosa L.	1	NoH	H
Puccinellia distans (Jacq.) Parl.	7	EX	H
Puccinellia dolicholepis V. Krecz.	6	EX	H
Puccinellia gigantea (Grossh.) Grossh.	6	EX	H
Schismus arabicus Nees	3	Ps	T
Stipa caspia C. Koch	1	NoH	H
Stipa sareptana Beck.	1	NoH	H
Stipagrostis karelinii (Trin. & Rupr.)Tzvl.	1	NoH	H
Stipagrostis pennata (Trin.) de Winter	1	NoH	H
Polygonaceae Juss.			
Atraphaxis replicata Lam.	1	NoH	Ph-n
Atraphaxis spinosa L.	1	NoH	Ph-n
Calligonum acanthopterum Borszcz.	–	–	Ph-n
Calligonum alatiforme Pavl.	–	–	Ph-n
Calligonum alatum Litv.	–	–	Ph-n
Calligonum androssovii Litv.	–	–	Ph-n
Calligonum aphyllum (Pall.) Guerke	–	–	Ph-n
Calligonum aralense Borszcz.	–	–	Ph-n
Calligonum borszczowii Litv.	–	–	Ph-n
Calligonum cancellatum Mattei	–	–	Ph-n
Calligonum caput-medusae Schrenk	–	–	Ph-n
Calligonum colubrinum Borszcz.	–	–	Ph-n
Calligonum commune (Litv.) Mattei	–	–	Ph-n
Calligonum crispatum (Litv.) Mattei	–	–	Ph-n
Calligonum cristatum Pavl.	–	–	Ph-n
Calligonum densum Borszcz.	–	–	Ph-n
Calligonum dubjanskyi Litv.	–	–	Ph-n
Calligonum elatum Litv.	–	–	Ph-n
Calligonum erinaceum Borszcz.	–	–	Ph-n
Calligonum eriopodum Bunge	–	–	Ph-n
Calligonum humile Litv.	–	–	Ph-n

(continued)

Table 12.9 (continued)

Species	*S* value	Halophytic strategy type	Life form
Calligonum junceum (Fisch. & C.A.May.) Litv.	–	–	Ph-n
Calligonum lamellatum (Litv.) Mattei	–	–	Ph-n
Calligonum leucocladum (Schrenk) Bunge	–	–	Ph-n
Calligonum macrocarpum Borszcz.	–	–	Ph-n
Calligonum membranaceum (Borszcz.) Litv.	–	–	Ph-n
Calligonum microcarpum Borszcz.	–	–	Ph-n
Calligonum minimum Lipsky	–	–	Ph-n
Calligonum muravljanskyi Pavl.	–	–	Ph-n
Calligonum palibinii Mattei	–	–	Ph-n
Calligonum platyacanthum Borszcz.	–	–	Ph-n
Calligonum pseudohumile Drob.	–	–	Ph-n
Calligonum rotula Borszcz.	–	–	Ph-n
Calligonum rubens Mattei	–	–	Ph-n
Calligonum spinulosum Drob.	–	–	Ph-n
Calligonum squarrosum Pavl.	–	–	Ph-n
Calligonum undulatum Litv.	–	–	Ph-n
Polygonum arenarium Waldst. Ed Scit.	2	Ps	T
Polygonum monspeliense Thieb. ex Pers.	3	Ps	T
Rheum tataricum L.	2	Ps	GR
Rumex marschallianus Reichenb.	–	–	T
Potamogetonaceae Dumort.			
Potamogeton perfoliatus L.	2	Ps	H
Ranunculaceae Juss.			
Adonis parviflora Fisch. ex DC.	2	Ps	T
Ceratocephala falcata (L.) Pers.	3	Ps	T
Ceratocephala testiculata (Grantz.) Bess.	3	Ps	T
Clematis orientalis L.	1	NoH	Ph-n
Consolida rugulosa (Boiss.) Schröding.	2	Ps	T
Myosurus minimus L.	3	Ps	T
Ranunculus platyspermus Fisch. ex DC.	2	Ps	GR
Thalictrum isopyroides C. A. Mey.	1	NoH	GR
Rosaceae Juss.			
Hulthemia persica (Michx. ex Juss.) Bornm.	3	Ps	Ch
Rubiaceae Juss.			
Asperula danilewskiana Basin.	–	–	Ch
Galium spurium L.	2	Ps	T
Rutaceae Juss.			
Haplophyllum perforatum Kar. et Kir.	2	Ps	H
Salicaceae Mirb.			
Populus euphratica Olivier/*Populus diversifolia*	(2) 3 (4)	Ps	Ph-m
Scrophulariaceae Juss.			
Linaria dolichoceras Kuprian.	–	–	H
Veronica campylopoda Boiss.	1	NoH	T
Solanaceae Juss.			
Hyoscyamus pusillus L.	1	NoH	T
Lycium ruthenicum Murr.	4	LSu	Ph-n

(continued)

Table 12.9 (continued)

Species	*S* value	Halophytic strategy type	Life form
Tamaricaceae Link.			
Tamarix aralensis Bunge	6	EX	Ph-n
Tamarix elongata Ledeb.	6	EX	Ph-n
Tamarix florida Bunge	6	EX	Ph-n
Tamarix hispida Willd	8	EX	Ph-n
Tamarix hohenackeri Bge	6	EX	Ph-n
Tamarix karelinii Bunge	6	EX	Ph-n
Tamarix laxa Willd.	6	EX	Ph-n
Tamarix leptostachys Bunge	8	EX	Ph-n
Tamarix litwinowii Gorschk.	6	EX	Ph-n
Tamarix ramosissima Ledeb.	7	EX	Ph-n
Typhaceae Juss.			
Typha angustifolia L.	2	Ps	Hy
Zannichelliaceae Dumort.			
Zannichellia palustris L.	4	HH	H
Zosteraceae Dumort.			
Zostera noltii Hornem.	9	HH	Hy
Zygophyllaceae R. Br.			
Zygophyllum eichwaldii C. A. Mey.	2	LSu	Ch
Zygophyllum fabago L.	5	LSu	H
Zygophyllum macropterum Boriss.	2	LSu	H
Zygophyllum oxianum Boriss.	5	LSu	H

12.2 Conclusions

Investigation of the adaptive mechanisms of the various halophyte types as well as succession processes is essential to obtain an adequate species composition for phytomelioration of the saline soils of the Aralkum. Ion pattern, halophytic strategy to cope with salinity and life form are very variable in halophytes; their distinction from less tolerant pseudohalophytes or nonhalophytes is only gradual. The salinization of the substrate on the dry seafloor varies to a great extent, causing a wide variety of saline soil types. Various solonchaks have developed: marshy solonchaks, crusty and puffy solonchaks, solonchaks slightly covered by sand, degraded coastal solonchaks, takyr solonchaks, etc. Studying natural halophytes is thus very important not only for all those regions where salinity has reached such a level that desalinization techniques are much too costly but also for quasi natural sites with their ecological dynamics. Understanding the adaptation of halophytes to saline sites and understanding their abilities to compete in saline communities is a good precondition for better use of halophytes. The applicability of the ecological salinity indicator value (*S* value) may be also worthwhile for adjacent agricultural areas with salinized fields and weeds for fast characterization of the sites.

Table 12.10 Ion content (g kg^{-1}) of some water samples from the Aralkum

Locality	pH	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	Cl$^-$	Na$^+$/K$^+$	Na$^+$/Cl$^-$	Mg^{2+}/Na$^+$+K$^+$
Water samples from August 1999									
Kambash	7.4	1.33	0.041	–	0.51	1.67	55.1	1.23	0.35
Kaskakulan warm spring	7.6	1.36	0.007	–	0.008	1.25	330	1.68	0.0057
Akbasti (Kokaral), warm spring	6.9	3.54	0.032	–	0.061	3.97	188	1.38	0.016
North Aral Sea, seawater	6.6	6.09	0.26	–	1.61	8.15	39.0	1.15	0.24
Pond for horses	6.9	0.43	0.032	–	0.074	0.31	23.2	2.17	0.16
Water samples from May 2002									
Kambash	7.3	0.26	0.011	–	0.14	0.27	41.1	1.45	0.49
North Aral Sea, Shevchenko bight, seawater	7.1	4.85	0.021	–	1.23	7.59	39.3	0.99	0.23
North Aral Sea, seawater 46°37,48′N 60°07,38′E 45 m asl	7.1	4.85	0.21	–	1.19	7.48	39.2	1.00	0.23
Akespe, warm spring, between 46°44,85′N 60°28,70′E 55 m asl	6.8	6.74	0.073	–	0.26	11.9	157	0.87	0.037
North Aral Sea, Butakov bight west side, seawater 46°46,94′N 60°34,73′E 44 m asl	7.1	7.22	0.29	–	1.80	11.0	42.2	1.01	0.23
North Aral Sea, Butakov bight east side, seawater	7.3	7.26	0.31	–	1.81	10.9	40.6	1.02	0.23
Muddy water sample 46°42.05′N 60°13,77′E 59 m asl	7.1	7.72	0.065	–	0.45	3.97	201	2.99	0.055
Bugun, new fishpond 46°09.83′N 61°11.14′E 55 m asl	7.1	0.46	0.026	–	0.28	0.94	30.0	0.75	0.56
Aralsk, irrigation water, tapwater	7.4	3.63	0.022	–	0.13	6.03	282	0.93	0.031
Aralsk, irrigation water, sandy ditch	7.1	4.53	0.023	–	0.12	5.81	340	1.20	0.026
Syr Darya, river water near Djusali 44° 51.10′N 65°22.89′E 138 m asl	7.4	0.093	0.047	–	0.052	0.041	33.8	3.52	0.51
Kyzyl-Orda, irrigation channel 44°50.41′N 65°30.18′E 135 m asl	7.2	0.11	0.051	–	0.062	0.089	37.9	1.96	0.51
Almaty, Malinki Almaty Djui, for irrigation	7.4	0.0037	0.0012	–	0.0022	<0.005	≈5.7	–	4.6
Water samples from May 2003									
Syr Darya, near Jalagash	8.1	0.11	0.0044	0.089	0.045	0.081	42.4	2.10	0.38
North of Kulandy, artesian spring 46°15.6′N 59°29.1′E	8.9	1.20	0.0067	0.014	0.0052	1.23	306	1.50	0.0040
2 km north of Kulandy, artesian spring 46°08.5′N 59°31.4′E	9.2	0.41	0.0036	0.0077	0.0018	0.57	194	1.11	0.0041
Kulandy spring, 120 m deep	9.0	0.48	0.0039	0.0093	0.0026	0.70	201	1.03	0.0051
West basin of Aral Sea 46°00.55′N 59°16.4′E	8.2	14.3	0.56	0.87	2.90	23.9	43.6	0.94	0.19
West basin of Aral Sea, muddy water sample	8.1	5.13	0.38	0.77	0.83	8.35	23.1	0.95	0.147
West basin of Aral Sea, between reeds	8.2	9.26	0.45	1.23	1.72	15.4	35.3	0.93	0.170
North Aral Sea, Shevchenko bight, seawater	8.2	4.13	0.16	0.27	0.42	5.33	147	1.20	0.092
North Aral Sea, Butakov bight, seawater	8.4	6.10	0.13	0.33	1.45	8.83	82	1.06	0.22
Seawater (for comparison)									
Open ocean water (35 g kg^{-1})	8.0	10.80	0.39	0.41	1.29	19.40	46.0	0.86	0.110

asl above sea level

Ecotypes and biogeography, germination and establishment, competition and nutrient availability under high salinity and alkalinity are subjects on the ecosystems level which have to be investigated further. Investigations of halophytic ecosystems, of the salinity process in agrarial systems and of plant strategies for salt regulation are urgently needed in the Aral Sea region, where salt desertification has become dominant.

References

Adam P (1990) Saltmarsh ecology. Cambridge University Press, Cambridge

Agachanjanz OE, Breckle S-W (1994) Umweltsituation in der ehemaligen Sowjetunion. Naturwiss Rdschau 47:99–106

Albert R (1982) Halophyten. In: Kinzel H (ed) Pflanzenökologie und Mineralstoffwechsel. Ulmer, Stuttgart, pp 33–215

Albert R (2005) Das Physiotypen-Konzept – ein Modell zur Erklärung ökophysiologischer Anpassungen? In Veste M, Wucherer W, Homeier J (eds) Ökologische Forschung im globalen Kontext. Cuvillier, Göttingen, pp 1–23

Balnokin YuV, Myasoedov NA, Baburina OK, Wucherer W (1991) Ion content of Na^+, Cl^-, S and proline in tissues from halophytes from soils with differing salinity on the dry sea floor of the Aral Sea. Probl Osv Pustyn‘, Ashkhabad 2:70–78 (in Russian)

Berger-Landefeldt U (1959) Beiträge zur Ökologie der Pflanzen nordafrikanischer Salzpfannen. Vegetatio 9:1–48

Black RF (1954) The leaf anatomy of Australian members of the genus *Atriplex I. Atriplex vesicaria* Heward and *A. nummularia* Lindl. Aust J Bot 2:269–286

Breckle S-W (1975a) Ionengehalte halophiler Pflanzen Spaniens. Decheniana (Bonn) 127:221–228

Breckle S-W (1975b) Wasser- und Salzverhältnisse bei Halophyten der Salzsteppe in Utah/USA. Ber Dtsch Bot Ges 87:589–600

Breckle S-W (1976) Zur Ökologie und zu den Mineralstoffverhältnissen absalzender und nichtabsalzender Xerohalophyten, Diss. Bot., Cramer, Vaduz 35, 1–176

Breckle S-W (1982) The significance of salinity. In: Spooner B, Mann HS (eds) Desertification and development: dryland ecology in social perspective. Academic, London, pp 277–292

Breckle S-W (1985) Die siebenbürgische Halophytenflora – Ökologie und ihre pflanzengeographische Einordnung. Siebenbürgisches Archiv, 3 Folge 20:53–105

Breckle S-W (1986) Studies on halophytes from Iran and Afganistan. II. Ecology of halophytes along salt gradients. Proc R Soc Edinb 89B:203–215

Breckle SW (1989) Role of salinity and alkalinity in the pollution of developed and developing countries. In: Öztürk MA (ed) International symposium on the effect of pollutants to plants in developed and developing countries in Izmir/Turkey, 22-28 August 1988, pp 389-409

Breckle S-W (1990) Salinity tolerance of different halophyte types. Plant Soil 148:167–175

Breckle S-W (1992) Salinity-stress and salt-recretion in plants. Bielefelder Ökologische Beiträge (BÖB) 6:39–52

Breckle S-W (1995) How do halophytes overcome salinity? In: Khan MA, Ungar IA (eds) Biology of salt tolerant plants. Book Graffers, Chelsea, pp 199–213

Breckle S-W (2002a) Salinity, halophytes and salt affected natural ecosystems. In: Läuchli A, Lüttge U (eds) Salinity: environment – plants – molecules. Kluwer, Dordrecht, pp 53–77

Breckle S-W (2002b) Salt deserts in Iran and Afghanistan. In: Böer B, Barth H-J (eds) Sabkha ecosystems. Kluwer, Dordrecht, pp 109–122

Breckle SW (2005) Naturwissenschaftliche Neugierde, 40 Jahre ökologisch-geobotanische Forschung – Rückblick und Ausblick. In: Veste M, Wucherer W, HomeierJ (eds) Ökologische Forschung im globalen Kontext. Festschrift zum 65. Geburtstag von Prof. Dr. S.-W. Breckle, pp 273–310

Breckle S-W, Agachanjanz OE (1994) Ökologie der Erde, vol 3, 2nd edn, Spezielle Ökologie der gemäßigten und arktischen Zonen Euro-Nordasiens. Fischer, Stuttgart

Breckle S-W, Wucherer W (2007) What will be the future of the Aral Sea? In: Lozan JL (ed) GLOBAL CHANGE: enough water for all? Wissenschaftliche Auswertungen GEO, Hamburg, pp 142–146

Breckle S-W, Wucherer W, Scheffer A (2001) Halophytes on the dry sea floor of the Aral Sea. In: Breckle S-W, Veste M, Wucherer W (eds) Sustainable land-use in deserts. Springer, Heidelberg, pp 139–146

Curtin D, Steppuhn H, Selles F (1993) Plant response to sulfate and chloride salkinity: growth and ionic relations. Soil Sci Soc Am J 57:1304–1310

Dregne HE (1986) Desertification of arid lands. In: El-Baz F, Hassan MHA (eds) Physics of desertification. Nijhoff, Dordrecht

Ellenberg H, Weber HE, Düll R et al (1991) Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica 18:248

Flowers TJ, Yeo AR (1995) Breeding for salinkty resutsnace in crop plants: where next? Aust J Plant Physiol 22:875–884

Frey-Wissling A (1935) Die Stoffausscheidung der Höheren Pflanzen. Springer, Berlin

Geldyeva GV, Budnikova TI, Gobernik IA et al (1998) Assessment of desertification processes in natural complexes of the Syrdarya delta. UNESCO Aral Sea Project, 15–41

Glazovskii NF, Orlovskii NS (1996) The problems of the desertification and droughts in GUS and the ways of their solution. Izv Akad Nauk Ser Geogr 4:7–23 (in Russian)

Hammer UT (1986) Saline lake ecosystems of the world. Junk, Dordrecht

Hedenström Hv, Breckle S-W (1974) Obligate halophytes? A test with tissue culture methods. Z Pflanzenphys 74:183–185

Jacobsen T, Adams RM (1958) Salt and silt in Ancient Mesopotamian agriculture. Science 128:1251–1258

Law JP, Hornsby AG (1982) The Colorado river salinity problem. Water Supply Manage 6:87–103

Metternicht G, Zinck A (2008) Remote sensing of soil salinization: Impact on land management. Taylor & Francis, CRC Press, Boca Raton

Mirazai NA, Breckle S-W (1978) Untersuchungen an afghanischen Halophyten I. Salzverhältnisse in Chenopodiaceen Nord-Afghanistans. Bot Jahrb Syst 99:565–578

Moore RT, Breckle S-W, Caldwell MM (1972) Mineral ion composition and osmotic relations of *Atriplex confertifolia* and *Eurotia lanata*. Oecologia 11:67–78

Munns R (1993) Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. Plant Cell Environ 16:15–24

Munns R, Schachtmann DP, Condon AG (1995) The significance of a two-phase growth response to salinity in wheat and barley. Aust J Plant Physiol 22:561–569

Naik PS, Widholm JM (1993) Comparison of tissue culture and whole plant response to salinity in potato. Plant Cell Tissue Organ Cult 33:273–280

Novikova NM, Kust GS, Kuzmina JV et al (1998) Contemporary plant and soil cover changes in the Amudarya and Syrdarya river deltas. UNESCO Aral Sea Project, 81–91

Oldeman LR (1994) The global extent of soil degradation. In: Greenland DJ, Szabolcs I (eds) Soil resilience and sustainable land use. CAB International, Wallingford, pp 99–118

Pollak G, Waisel Y (1979) Ecophysiology of salt excretion in *Aeluropus litoralis* (Gramineae). Physiol Plant 47:177–184

Popp M (1985) Osmotic adaptation in Australian mangroves. Vegetatio 61:247–253

Ramani S, Apte SK (1997) Transient expression of multiple genes in salinity-stressed young seedlings of rice (*Oryza sativa* L.) cv. Bura Rata. Biochem Biophys Res Comm 233:663–667

Reimann C, Breckle S-W (1993) Sodium relations in Chenopodiaceae, a comparative approach. Plant Cell Environ 16:323–328

Rhoades JD (1990) Soil salinity – causes and controls. In: Andrew Goudie A (ed) Techniques for desert reclamation. Wiley, New York, pp 109–134

Schirmer U, Breckle S-W (1982) The role of bladders for salt removal in some Chenopodiaceae (mainly *Atriplex* species). In: Sen DN, Rajpurohit KS (eds) Tasks for vegetation science, vol 2. Junk, The Hague, pp 215–231

Sheridan D (1981) Desertification of the United States. Council on Environmental Quality, Washington, DC

Shiati K (1991) Salinity management in river basins; modelling and management of the salt-affected Jarreh reservoir (Iran). Proefschrift, Wageningen

Shomer-Ilan A, Nissenbaum A, Waisel Y (1981) Photosynthetic pathways and the ecological distribution of the Chenopodiaceae in Israel. Oecologia 48:244–248

Singh G (2009) Salinity-related desertification and management strategies: Indian experience. Land Degradation Dev 20:367–385

Teakle LJH (1937) The salt (sodium chloride) content of rain water. J Agric Dept W Aust 14:115–133

Tobe K, Li X, Omasa K (2004) Effects of five different salts on seed germination and seedling growth of *Haloxylon ammodendron* (Chenopodiaceae). Seed Sci Res 14:345–353

Tobe K, Li X, Omasa K (2005) Effects of irrigation on seedlings emergence and seedlings survival of a desert shrub *Haloxylon ammodendron* (Chenopodiaceae). Aust J Bot 53:529–534

Ungar IA (1996) Effect of salinity on seed germination, growth, and ion accumulation of *Atriplex patula* (Chenopodiaceae). Am J Bot 83:604–607

Waisel Y (1972) Biology of halophytes. Academic, New York

Waisel Y (2001) Salinity: a major enemy of sustainable agriculture. In: Breckle SW, Veste M, Wucherer W (eds) Sustainable land use in deserts. Springer, Berlin, pp 166–173

Walter H (1968) Die Vegetation der Erde in ökophysiologischer Betrachtung. II. Die gemäßigten und arktischen Zonen. Fischer, Stuttgart

Wichelns D (1999) An economic model of waterlogging and salinization in arid regions. Ecol Econ 30:475–491

Wiehe W, Breckle S-W (1989) Die Ontogenese der Salzdrüsen von *Limonium* (Plumbaginaceae). Bot Acta 103:107–110

Winicov I, Bastola DR (1997) Salt tolerance in crop plants; new approaches through tissue culture and gene regulation. Acta Physiol Plantar 19:435–449

Wucherer W (1986) The spreading of *Suaeda acuminata* (C.A. Mey.) Moq. in Kazakhstan. In: Baitenov MS, Vasyagina MP (eds) Botanical materials of the herbarium of the Institute of Botany. Nauka, Alma–Ata, pp 38–39

Wucherer W, Breckle S-W, Dimeyeva L (2001) Flora of the dry sea floor of the Aral Sea. In: Breckle S-W, Veste M, Wucherer W (eds) Sustainable land-use in deserts. Springer, Heidelberg, pp 38–51

Yang X, Zhang K, Jia B, Ci L (2005) Desertification assessment in China: an overview. J Arid Environ 62:517–531