Vegetation, Climate and Soil: 50 Years of Global Ecology

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Contents

Abstract In this essay, more than 50 years of studies on a broad spectrum of ecological topics is reviewed. Many research questions in desert ecology, in tropical ecology and in stress ecophysiology were studied, mainly in the field but often completed by analysis in the lab.

To keep in mind the complexity of ecological systems, it was necessary to go into detail with very specific approaches but always keeping in mind a synthetic view. More and more it became clear that the biodiversity in many ecosystems plays an important role for the future. Vegetation, climate and soil are interwoven in

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ecosystems; the rapid developments in science – as well as the fast development of methods, techniques and data pools – are a big challenge. Many aspects of global ecology have been studied in the last 50 years. Some examples are demonstrated here. This essay will remain a rather historical treatise. It will give examples of experimental and field work. It will be a look back with great gratitude on what was able to be achieved and experienced.

1 Introductory Remarks and Early Background at Stuttgart, Innsbruck, Hohenheim, Kabul, Bonn, Logan (Utah) and Bielefeld

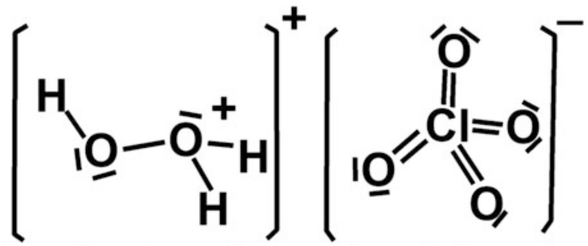
The following review gives a personal overview of some of the scientific topics tackled over the last 50 years and characterizes a somewhat unusual career, which asked many questions on many very different ecological topics. The scientific depth was sometimes limited, and the scientific breadth was immense and always satisfying.

Breadth or depth? I always have had the feeling that, as a scientist, I was lucky not to do research for 25 or 40 years on *Sinapis* seedlings or on one gene of *Arabidopsis*, although it is certainly very important too.

I had the privilege to study three subjects at the University (Technische Hochschule) of Stuttgart (chemistry, biology and geology) for my teacher's exam. Later, geology had to be replaced by geography. But ethnology, astrophysics, engineering, philosophy or even Beethoven piano sonatas could come into lectures. This was fascinating, as was studying for 1 year at the University of Innsbruck with a touch of high mountain ecology. After two obligatory practical courses at schools (each for 4 weeks), the three classes in chemistry were so different that even the teacher had problems in keeping the classes on the same parallel level.

The thesis for the 1963 teacher's exam was in inorganic chemistry at Stuttgart (supervised by Joseph Goubeau). The title was "Preparation of a Compound Between Perchloric Acid and Hydrogen Peroxide" (Breckle 1963). Those who know chemistry would judge that this has something to do with rocket explosives. The questions were: How stable is the ionic compound? Is a salt existent that could be called "perhydronium perchlorate"? (Fig. 1). In fact, this is a very explosive salt, only stable below $-50°C$. By infrared and Raman spectroscopy, the cohesive force and the bond angles could be calculated. However, the monocrystalline sodium chloride (NaCl) cuvette, after several tests, exploded once, and all of the windows of the lab – and also, for some days, my auditory sense and hearing – were damaged. Thus I started writing the thesis and finished my teacher's studies in 1963 with the state examination (inorganic and organic chemistry, zoology, botany, geography and the Philosophicum).

Then I switched back to botany, my old hobby. Instead of becoming a teacher or having a well-paid job at one of the large chemical companies (Bayer, BASF), I preferred to tackle the question: What are the competitive conditions between



Perhydronium-Perchlorate

Scheme on force constants of dimeric hydrid-configurations as bond descriptor						
Free electron pairs-	Force constants [mdyn / Å = 100 N / m] $k_{C\text{-}C}$		$k_{N\text{-}N}$		$k_{O\text{-}O}$	
0	C_2H_2	15.7	$N_2H_6^{2+}$	5.37	.....	
1	C_2H^-	13.1	$N_2H_5^+$	4.65	.....	
2	C_2^{2-}	??	N_2H_4	3.77	$H_4O_2^{2+}$	??
3	.....		$N_2H_3^-$	3.35	$H_3O_2^+$	??
4	.....		$N_2H_2^{2-}$	??	H_2O_2	3.99
5	.....		.....		HO^-	3.7
6	.....		.....		O_2^{2-}	??

Fig. 1 Structure of perhydronium perchlorate and scheme of force constants of dimeric hydrid configurations as a bond descriptor (Breckle 1963)

Quercus suber and *Quercus ilex* in Catalunya in north-eastern Spain? From the University of Hohenheim with an old Volkswagen Beetle and a 1,000 DM fellowship from the Carlos Faust Foundation in Barcelona – the only external funding – I started at the famous Mar I Murta Botanical Garden in Blanes, where they wanted me at once as a gardener! Advice came by letters from my supervisor, Heinrich Walter, in South America, where he was on his sabbatical. It turned out that the cork oak, *Quercus suber*, uses twice as much water as *Quercus ilex* (Fig. 2), with a very large root system (Breckle 1966). And, growing in Germany, young trees of *Quercus suber* were more frost resistant than those of *Quercus ilex* – in contrast to many observations in Spain or in Italy at Lake Maggiore (Sakai and Larcher 1987).

There was some pressure to publish the work, since Heinrich Walter was near retirement. On the other hand, a doctoral thesis at that time was acknowledged as a publication providing more details than a publication in a journal, as Beck (2017) also indicated, and a cumulative dissertation was not known or allowed at that time. The Rigorosum (viva) at the University of Stuttgart-Hohenheim was very comprehensive (one long oral of 90 min), covering botany, ecology and seed science.

My studies at Stuttgart and Hohenheim were a very helpful basis for future research. Teaching at the Chemieschule and during practicals and field trips around Hohenheim made me learn much about plants, their behaviour and ecology. Behind that were chemistry and chemical reactions and pathways. But doing studies and

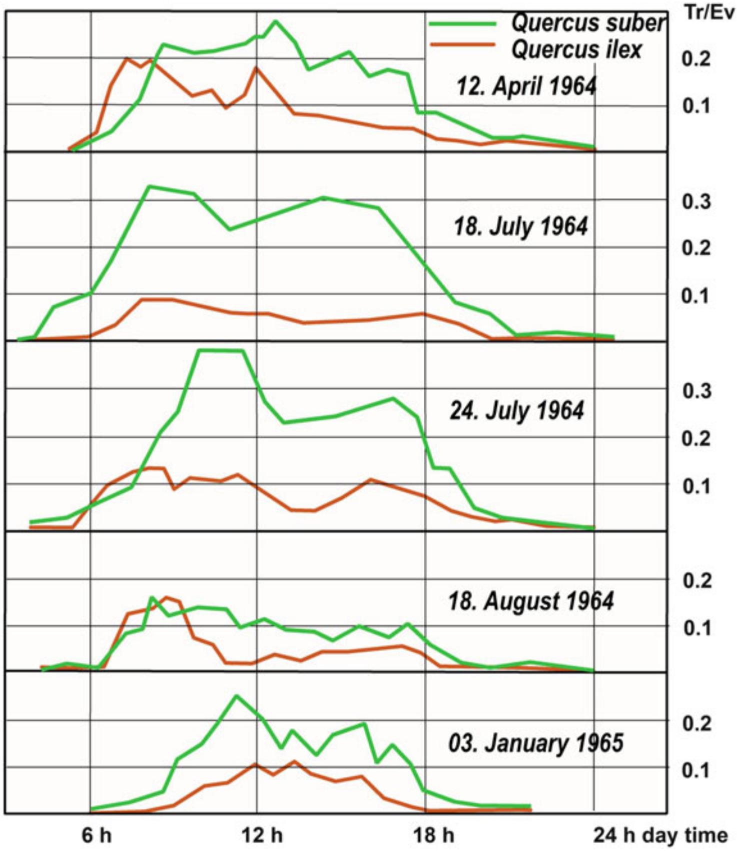


Fig. 2 Daily courses of the transpiration-to-evaporation ratio of *Quercus suber* and *Quercus ilex* in Catalunya (Breckle 1966)

measurements in nature proved to be more complicated; it took many replications to understand diurnal and annual fluctuations.

Parallel to my stays in north-eastern Spain, Helmut Freitag used his Carlos Faust Fellowship for research in the semi-desertic south-eastern Spain. He once mentioned to me the affiliation between the universities of Bonn and Kabul and that there was an existing German team of lecturers in Kabul at its Faculty of Science. We tried and then succeeded in getting a new job in Afghanistan – for us an unknown country. After Freitag's habilitation and my doctorate, we started at the end of 1966 to build up a curriculum for botany, giving lectures, courses, seminars and excursions, jointly for male *and* female students at the Faculty of Science, Kabul. Uta Breckle organized the lab work and the establishment of a herbarium.

Again, there were high mountains. During the summer vacation, when all of the steppe and semi-deserts in the lowlands were dry and arid, the Hindu Kush was an ideal place. One of the many highlights was an expedition to the Wakhan (Fig. 3a), a b

Fig. 3 (**a**) Noshaq (7,492 m), the highest peak in Afghanistan, in the eastern Hindu Kush, near Qazi Deh, Wakhan (photo courtesy of C. Naumann, 2002). (**b**) Base camp at Kotale-Wazit (4,620 m) for microclimatic measurements; data collecting and evaluations with Afghan counterparts (photo courtesy of P. Schneider, August 1968)

with the permission of the Afghan King Mohammad Zahir Shah (deposed in 1973); in August 1968 we spent 1 month in the Wazit area (at an altitude of 4,600 m) as our base camp. Some microclimatic measurements (Fig. 4), not repeatable until now – indicating the specific high-altitude conditions, vegetation surveys and many herbarium collections, etc. – were made (Breckle 1973). Advanced Afghan students who later got fellowships to study in Germany were involved (Fig. 3b).

Other mountain ranges (Koh-e Baba, Safed Koh, etc.) were studied up to the nival region (Breckle 1975; Breckle and Frey 1974, 1976). The number of vascular plants known from above 5,000 m increased from 12 to 40 species. Decades later, many of the data and the photographs (see Sect. 7.2) were used for inventories.

As a member of the German team within the affiliation between Bonn University and the University of Kabul, I had the opportunity to start as an assistant at the Institute of Pharmaceutical Botany at the University of Bonn; the first textbook for students was published in 1978 (Kating and Breckle 1978) and the eighth edition came out in 2014 (Leistner and Breckle 2014).

In Afghanistan, it was very obvious that in dry areas the role of halophytic plant species is very important in many different vegetation types. Evaluation of material and data from Afghanistan, as well as a project comparing two competing halophytic species in the Great Salt Lake area and at the Utah State University in Logan, finally led to my habilitation (Breckle 1976). The question was: Do recreting halophytes have an advantage in the salt desert of Utah, and under what conditions? Mainly, ecophysiological responses of *Atriplex confertifolia* (C_4) and *Ceratoides lanata* (C_3) were compared, and later in Germany cultivation experiments were performed. Sodium (Na) turnover on both sites was calculated from respective analytical data (Fig. 5). *Atriplex confertifolia* exhibited a much higher turnover by litter and salt

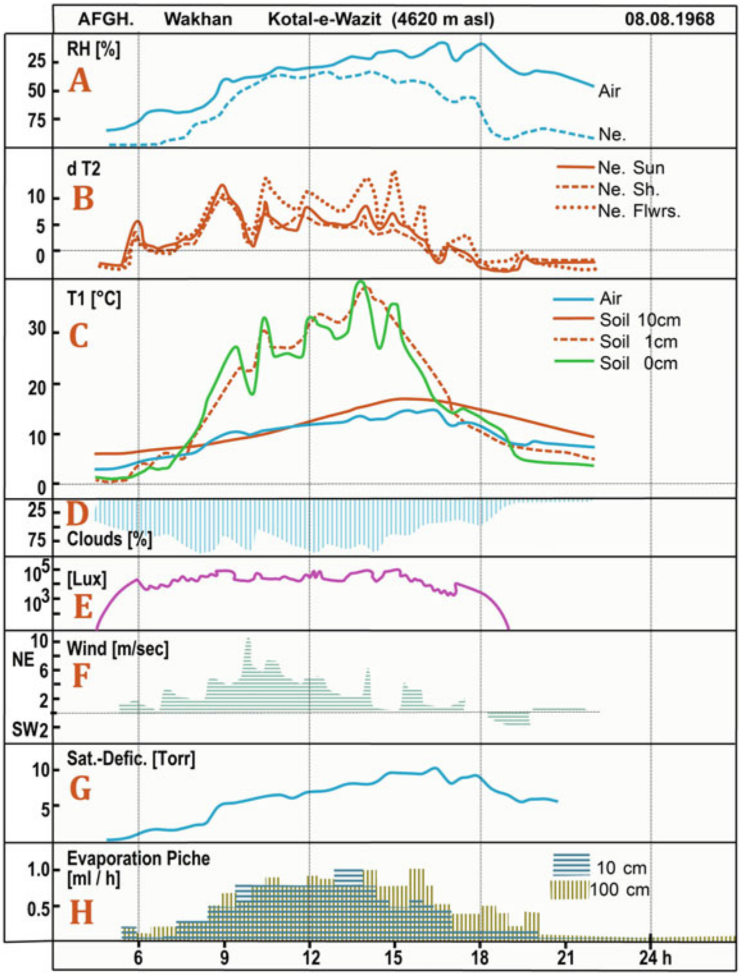


Fig. 4 Daily courses (measured on 8 August 1968) of some microclimatic and ecophysiological parameters at an alpine site at Kotale-Wazit (Wazit pass, 4,620 m; Wakhan) (Breckle 1973). (**a**) Relative humidity (air, 1.5 m; Ne, between *Nepeta pamirensis* [10 cm]). (**b**) Temperature difference (K) to air temperature of *Nepeta* sun leaves, shade leaves and flowers. (**c**) Air temperature (1.5 m) and soil temperatures (surface, 1 cm, 10 cm depth). (**d**) Cloudiness (% of whole sky). (**e**) Radiation (lux). (**f**) Wind speed (north-east or south-west). (**g**) Saturation deficit of air (torr). (**h**) Evaporation (Piche 3 cm) (ml h^{-1}), 10 and 100 cm

bladder hairs than *Ceratoides*, which, however, had a rather high salt content in its roots. Salt is accumulated in the roots of *Ceratoides*; in *Atriplex*, it is in the shoot. The dominant species of the salt deserts are shown in Fig. 6, according to their ecological requirements.

In Nov. 1979, I went to Bielefeld and started to establish the new Department of Plant Ecology. Together with a small team (some co-workers and a technician who came from Bonn), we had plenty of room but almost no equipment at the new

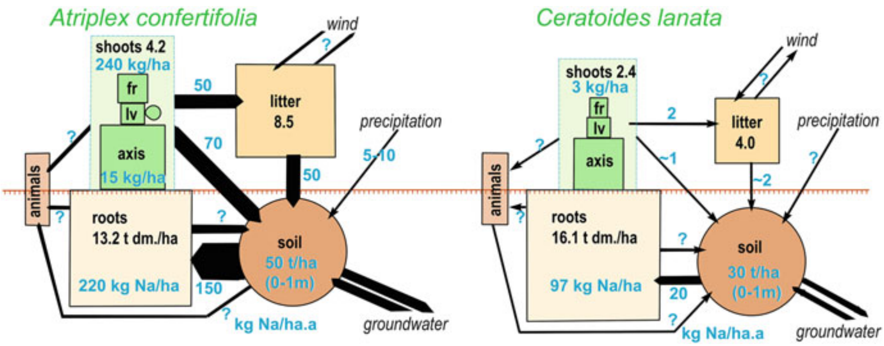


Fig. 5 Estimated sodium (Na^+) turnover (kg ha^{-1} a^{-1}) (*blue figures*) at the *Atriplex confertifolia* site (*left*) and at the *Ceratoides lanata* site (*right*) in the Curlew Valley, Utah; compartmental storage amount of sodium (kg ha^{-1}) and biomass (*black figures*) (total dry mass [tdm] ha^{-1}) (Breckle 1976)

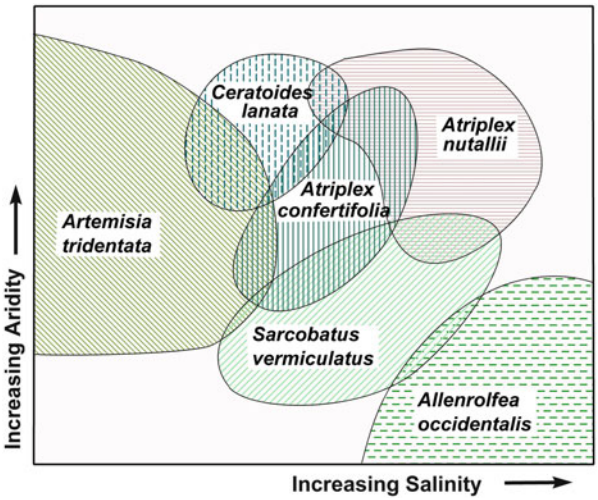


Fig. 6 Aridity/salinity ecogram of the main dominant species in the Great Salt Lake area, Utah (Breckle 1976)

university. Much new material had to be purchased; teaching started with new lectures, seminars, practical lab and field courses, and excursions.

Most of the first studies in Bielefeld had an autecological basis and focused on the effect of plants on distinct stress factors such as salt or heavy metals. Synecology, geobotany and vegetation surveys were later included in several research projects.

During the following years in Bielefeld, many projects and studies were undertaken in various countries abroad. Many candidates asked for a thesis, but we could not take all. We were able to publish some of the results in *Bielefelder Ökologische Beiträge* (BÖB), starting with volume 1 in 1985. After I became a pensioner in 2003, regular editions stopped with volume 20 in 2004, but volume 21 was published in 2017.

2 Halophytes and Salinity

Halophytic research in Afghanistan (1976) and Iran (1977) mainly focused on the question of mineral ion uptake and expression of physiotypes in the various halophytic taxa. The main types (Henkel and Shakhov 1945; Walter 1961) were defined according to salt uptake (Fig. 7), and their occurrence along salt gradients turned out

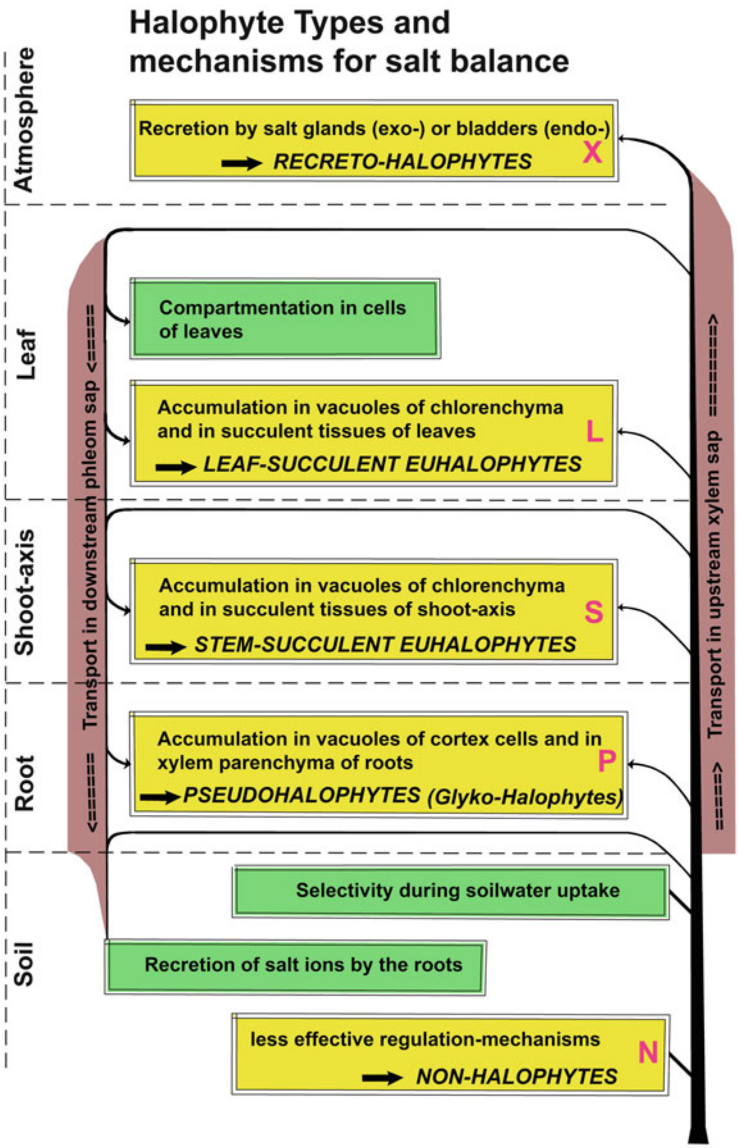


Fig. 7 Main halophyte types and applied mechanisms of salt balance in higher plants (Breckle 1976)

Halophyte-Type

% NaCl in soil

15—10— 5 — 3 — 2 — 1 —0.5—0.2—0.1—0.05—0.02—0.01—<0.01

S	71	63	51	18	3	12	7	4	11	10	0	0
L	29	32	30	72	30	56	51	18	35	18	10	0
X	0	5	19	0	60	27	28	41	4	9	0	2
P	0	0	0	5	7	5	15	23	24	45	68	10
N	0	0	0	0	0	0	0	14	26	24	22	88

Abundance of halophyte types (percentages) along a salinity gradient

Fig. 8 Percentage values of calculated abundances of halophytic plant types (S, L, X, P, N; see Fig. 7) arranged according to the salinity gradient (logarithmic intervals) averaged from eight halophytic zonations in Iran and Afghanistan (Breckle 1986)

to be rather similar at many saline sites. The most salt tolerant are in general the stem-succulent halophytes (Fig. 8), often performing C_4 photosynthesis.

Already in Bonn, one of my first candidates had proved the salt tolerance of whole plants in comparison with tissue cultures in *Phaseolus* and *Suaeda* (Hedenström and Breckle 1974). The big difference that young intact plants exhibit is not mirrored in tissue cultures. To be a successful halophyte requires an intact complex network of storage space and transport systems.

Along ocean coasts, the quality of seawater is rather identical, with about 3.5% NaCl. Other ions such as potassium (K^+) or magnesium (Mg^{2+}) have only low concentrations. Coastal halophytes have thus evolved some kind of salt tolerance by different means. The dominant ecophysiological factor NaCl modifies many processes at all ecological and physiological levels (Fig. 9). It is an excellent example of how many biological processes are interwoven at the various levels of complexity (Breckle 2002a).

In arid desert regions, in contrast to saline coastal areas, the potential evaporation exceeds the water input by precipitation and thus enrichment of various soluble ions takes place (Breckle 2002b). The chemistry is more varied; the pH can be very alkaline, and sulphate (SO_4^{2-}) or bicarbonate (HCO_3^-) can be accumulated. Sometimes K^+ or Mg^{2+} or lithium (Li^+) is enriched. The uptake of those ions is often very specific for different species (thus physiotypes can be defined) (Albert 2005).

Studies on the ecology of halophytes were also done by several of my students over many years. The sodium-to-potassium (Na:K) ratio (Fig. 10), as well as the storage of anions and cations, showed great differences between species (Fig. 11). This has been shown for Iranian halophytes too (Matinzadeh et al. 2013).

In recreting halophytes such as *Limonium* species, one can distinguish between two processes for selecting ions: one is the discrimination of ions by the transport process from the root to the leaf, and the other from the leaves to the salt glands (Fig. 12). Obviously, other species behave rather differently (Wiehe 1986; Wiehe and Breckle 1990).

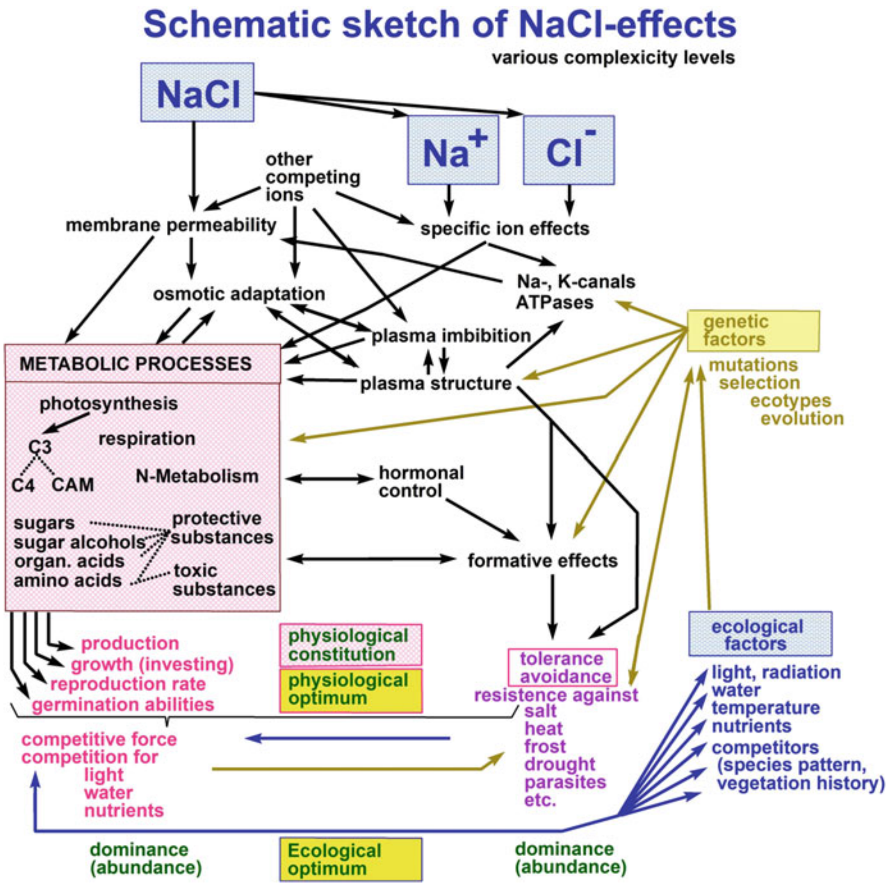


Fig. 9 Scheme of sodium chloride (NaCl) effects on plants at various complexity levels between genetic and ecological factors (Breckle 2005a)

In recreting halophytes such as *Atriplex*, only a few strongly halophytic species exhibit intensive NaCl turnover by bladders (Jones 1970; Lüttge 1971, 2016; Waisel 1972; Breckle 2002a; Osmond 1974; Reimann and Breckle 1988; Schirmer and Breckle 1982). The ratio of total bladder volume to leaf lamina volume in *Atriplex confertifolia* in very young leaves is above 2, keeping young growing tissues low in salt content; with ageing, it declines to about 0.4, and the bladders start to shrink or are blown away, thus eliminating NaCl from the leaves (Breckle 1976). In particular, *Atriplex* was studied very intensively (Tiedemann et al. 1984). Yuan et al. (2016) reported on how recretion in recreto-halophytes may occur. But salt tolerance and the genetic background in halophytes are still not really understood (Song and Wang 2015). Despite major efforts in analysing single genes responsible for salinity tolerance, some old questions (Breckle 1990, 1995) are still unresolved.

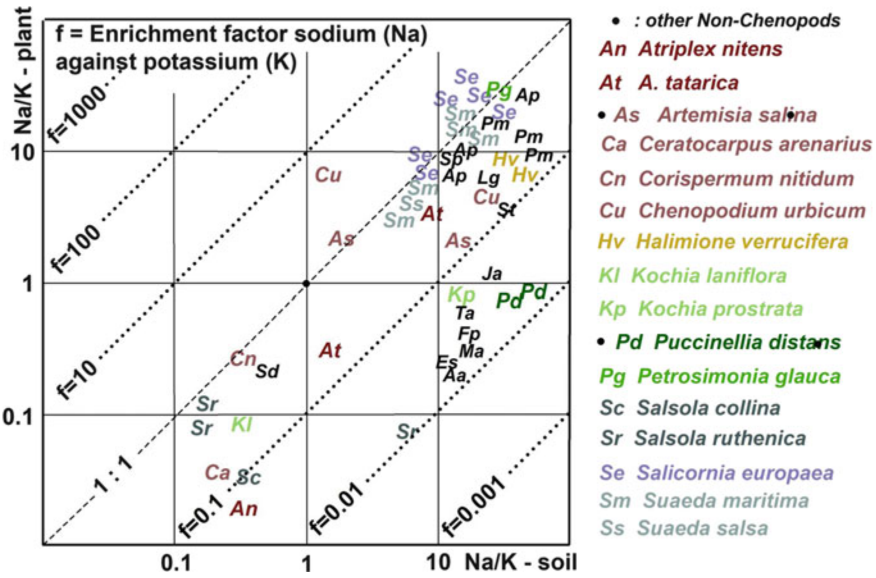


Fig. 10 The sodium-to-potassium (Na:K) ratio in soil is not mirrored in plants (Mirazai and Breckle 1978)

Roots of plants – the invisible half – have also been studied. In collaboration with Yoav Waisel from Tel Aviv [author of volumes on *Plant Roots: the Hidden Half* (Waisel et al. 1991, 1996, 2002; Eshel and Beeckman 2013)], some methods with hydroponics and aeroponics have been tested (Waisel and Breckle 1987). The question was: How do roots behave under salt stress? Large aeroponic chambers (Breckle et al. 2001a), more than 2 m high, were constructed in a new greenhouse in Bielefeld, similar to the Racine lab in Tel Aviv. Yoav Waisel stayed very often with us in Bielefeld. The sophisticated technique for keeping a constant pH and constant temperature of the nutrient solution could be managed for a period of several weeks. Tomato plants grown under different salt stress developed huge root systems in Bielefeld, as well as in Tel Aviv (Fig. 13); cutting of 90% of the roots did not have any effect on the transpiration of the upper plant parts. The architecture of root systems is very adaptive; the ratio of primary and secondary roots exhibits a strong shift to secondary roots with salt stress (Fig. 14). Field studies with mini-rhizotrons (glass tubes of 5 cm diameter) and TV cameras on roots of desert plants in the Negev Desert gave interesting results, but evaluation with automatic processing software is still not sufficiently resolved (Breckle et al. 2001c; Erz et al. 2005; Veste et al. 2005). It is a challenge for all root studies.

An interesting example of salinity effects was studied in the parasitic *Loranthus* growing on various halophytic hosts (Todt et al. 2000). In the southern Arava Valley (Negev Desert), *L. acaciae* was checked on five halophytic and ten non-halophytic host plants. Water content and succulence of mistletoes increased on halophytic

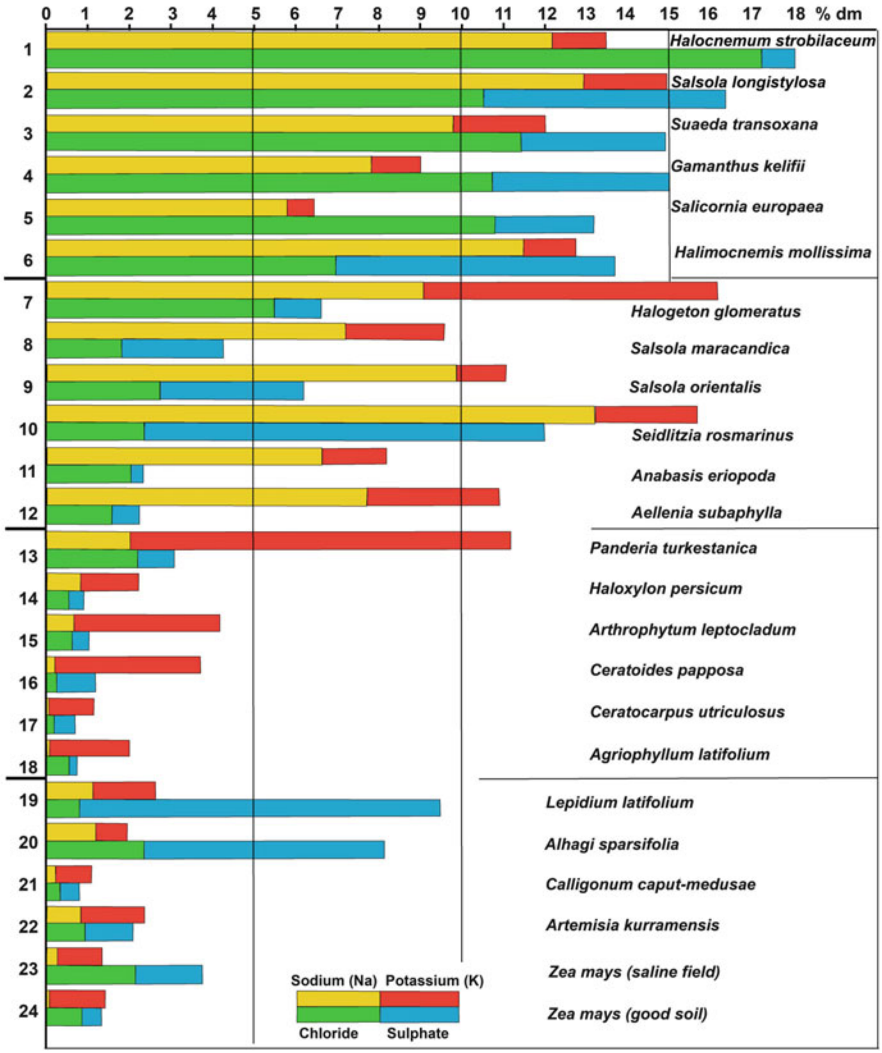


Fig. 11 Ion content in various halophytic and non-halophytic species from northern Afghanistan (after Mirazai and Breckle 1978)

hosts, and the leaf volume increased four to five times in comparison with those on non-halophytic hosts exhibiting typical halo-succulence. It behaves like a typical facultative eu-halophyte (Veste et al. 2014).

Of the world's land surface area, at least 6% is salt-affected land (Flowers and Yeo 1995; Munns 2005). Large areas in drylands and along coasts are naturally salt affected (Breckle 2002c), but with irrigation under arid climatic conditions, secondary salinization (Breckle 1989) is a big threat. Since the work of Boyko (1966), and then Waisel (1972) and Gallagher (1985), the use of seawater for agriculture has very

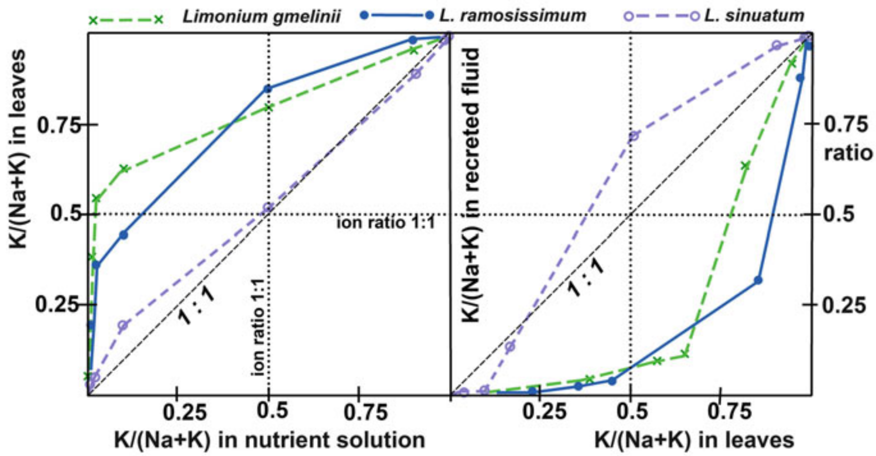


Fig. 12 Potassium-to-alkali ion ratio in leaves and in recreted fluid in three *Limonium* species under different salinities (Wiehe 1986; Wiehe and Breckle 1990)

Fig. 13 Tomato roots grown in aeroponic chambers in the root lab of the Tel Aviv Botanical Garden (photo: S. W. Breckle, 1997) (photo: S. W. Breckle)

often been discussed and studied. But despite intensive research and many projects, only a few organisms have been found that can be grown with seawater. Thus the question was asked: How can we grow plants with seawater? (Breckle 2009). Full-strength seawater can be used to sustainably irrigate only a few special plants, e.g. *Sesuvium*, *Aster*, *Salicornia* (Ventura and Sagi 2013) – maybe now that *Salicornia* salad is becoming quite popular – and *Spartina* along sandy seashores, without impairing soil quality provided that sufficient drainage exists. Intensive agriculture with seawater with high production per surface area is utopian. It was

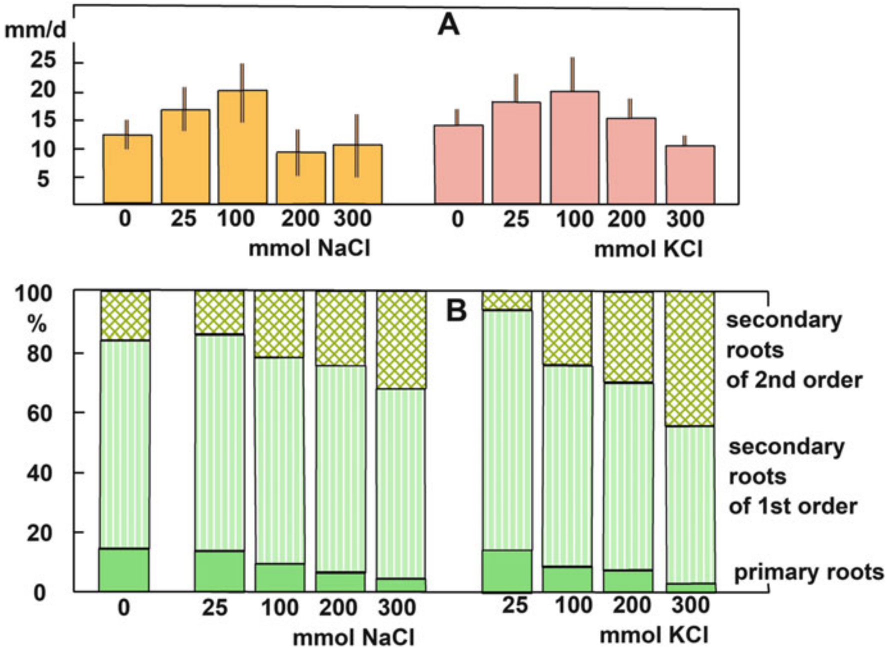


Fig. 14 Root structure of *Chenopodium album* under different salinities of sodium chloride (NaCl) and potassium chloride (KCl) treatments. (**a**) Mean daily growth of main root (mm per day). (**b**) Ratios of lengths of primary and secondary roots after 22 days (Seidel 1988; Breckle 1996b)

often said that greening of deserts, using halophytes, could partially help increase the biomass on the land surface and thus reduce global warming. But it would be much wiser to stop further deforestation in all of the humid climatic zones, especially in the tropics and in the Siberian and Canadian taiga, and to let all secondary forests grow, instead of transforming them from highly biodiverse primary forests into poor McDonald's beef sources (Breckle 2009). Additional costs to maintain sustainable irrigation and leaching systems to keep the salinity of the soil low pay more in the long run. The take-home message "no irrigation without drainage" means that it pays more to invest in desalination systems. This is especially important under very dry climatic conditions (Breckle et al. 2003) and when using urban water, as is done in southern Israel in the Yotvata farming area with brackish sewage water from Eilat.

3 Heavy Metals, Root Growth and Forest Dieback

Stress in plants is not only a result of salinity; many other factors cause stress. One is heavy metals. One of the first studies on lead (Pb) effects started in Bonn; along highways, the accumulation of Pb was checked (Lerche and Breckle 1975). When do trace metals have a measurable effect on the ecological behaviour of plants and trees? Along German highways, the Pb content in and on leaves exceeded the background content in the adjacent forests by 20–40 times. Later, we checked the accumulation of Pb, cadmium (Cd), zinc (Zn) and nickel (Ni) in the annual rings of beech and fir trees; it revealed a rather complex picture. The distribution of heavy metals in annual rings does not give a retrospective picture of the heavy metal stress over time. The physiological mobility of heavy metals within wood along radial pathways in most cases manifested in maximum concentrations of Pb and Cd along the sapwood–heartwood border and the lowest concentrations in the outermost rings, near the cambium (Hagemeyer and Breckle 1986; Hagemeyer et al. 1993; Brackhage et al. 1996). The findings were similar for potassium (K) and calcium (Ca), in contrast to Mg, Ni and Zn, for which the concentrations were lowest at the sapwood–heartwood transition. But both the distribution pattern and the concentrations of minerals in trunk wood were subject to seasonal variations.

Root growth is very sensitive to heavy metals. Reduced root growth, however, can be even overcompensated for when roots reach soil layers with low concentrations (control soil) (Weisser et al. 1990, Fig. 15). There, artificially enriched horizons in root boxes turned out to be very useful. Later also mini-rhizotrons (see Sect. 5.1) were found to be very suitable for experimental sets.

In many papers (Breckle and Kahle 1992; Kahle and Breckle 1992; Breckle 1996a, b), the effects of Pb and Cd on beech were shown. In the early 1990s, there

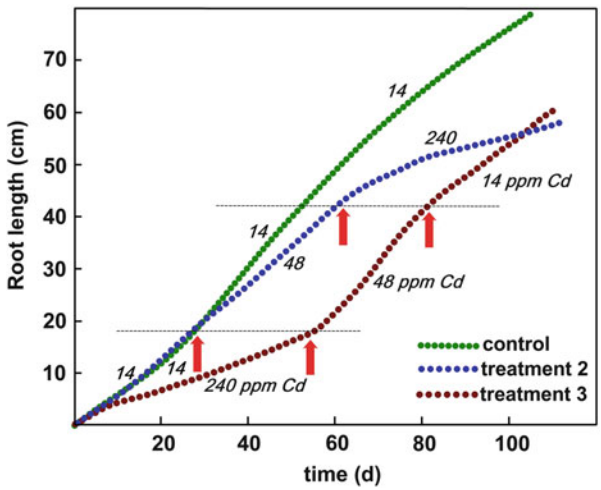


Fig. 15 Root length growth of beech seedlings in root chambers within 3 months. The root chambers were filled with three horizons of soil, differing in heavy metal content: *green*, all three horizons with low cadmium (Cd) (14 ppm); *blue*, increasing Cd content, lower 14, middle 48, upper horizon 240 ppm Cd; *brown*, decreasing Cd content, lower 240, middle 48, upper 14 ppm Cd. *Red arrows* indicate horizon limits (Weisser et al. 1990; Breckle and Kahle 1992; Hagemeyer and Breckle 1996)

was much research on forest dieback, especially in spruce. We started with beech. Later it became clear that deciduous trees also exhibited distinct signs of stress, with lowered soil pH, soluble aluminium (Al) in soil, and ozone (O_3) on leaves. With young beech saplings, it could be shown that in a rather short time of Cd stress, transpiration rates were much reduced (Hagemeyer et al. 1986, Fig. 16).

Only slight synergistic effects of Pb and Cd in beech saplings could be detected (Bertels et al. 1989). Changes in uptake of essential elements were, however, obvious but strongly dependent on soil pH (Kahle et al. 1989a, b). Mg and Ca uptake was antagonistic to Cd uptake, but this was not so with Pb. In general, it became obvious that the concentrations of Pb in exposed acid forest soils in Central Europe were sufficiently high to affect the germination and growth of saplings of beech. The "critical concentrations" could be defined as about 2 ppm of Cd and 25 ppm of Pb (1 N NH_4-acetate extractable fraction, pH 7). The reduction of wood formation seen with heavy metal contamination was distinct in some places of North Rhine–Westphalia (Lammersdorf, Stolberg), causing economic losses (Breckle and Hagemeyer 1992).

Fig. 16 Rapid effect of cadmium (Cd) stress on transpiration rates (mg h^{-1} cm^{-2}) of 2-year-old beech saplings (*Fagus sylvatica*) cultivated in nutrient solution, with indication of the least significant difference (LSD) of 90% (Hagemeyer et al. 1986)

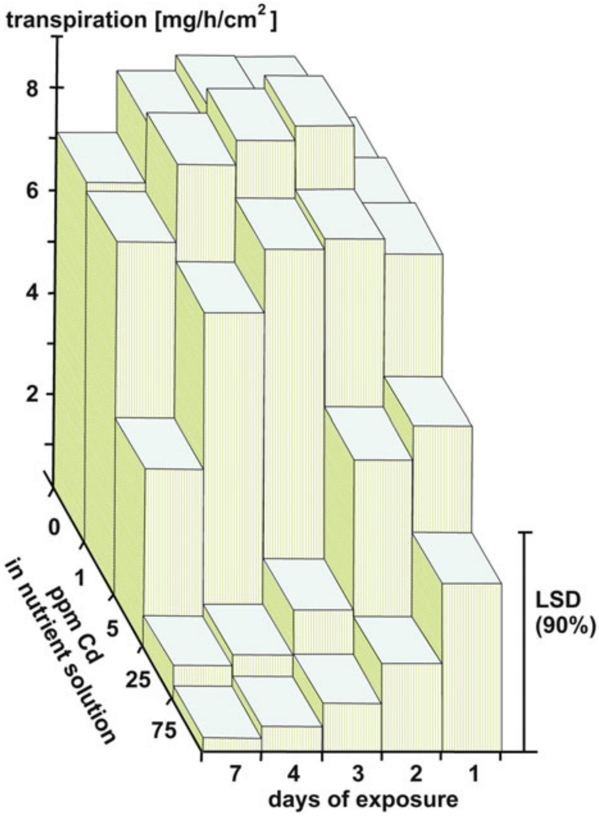


Fig. 17 *Viola guestphalica* (the *blue* calamine *violet*) – the only endemic plant of Westphalia – at the Bleikuhle near Blankenrode (photo: S. W. Breckle)

Metallophytes – plants that are able to withstand high levels of heavy metals in the soil – often accumulate heavy metals in the plant body (Breckle 1997b). They are often very specific and very rare (Fig. 17). As with the idea of desalinating soils by halophytes (Breckle 2009), quite often one finds papers discussing the idea of decontaminating soils containing heavy metals. By simply calculating realistic turnover rates, we often disillusion people, since the desalination times are about 50–500 years; the times required for decontamination of heavy metals (Pb, Cd and Zn) are in the same range. Another purpose would be to use plants for mining (e.g. Ni mining by *Alyssum*) but then again the labour costs would make it inefficient. In the future, maybe better methods can be developed.

Later, during studies in the tropics (see Sect. 6), some heavy metal tests were carried out. We wanted to know in what concentrations essential trace metals are present. As one example, the manganese (Mn) content in tree fern fronds in a montane rainforest in Costa Rica was studied (Weber and Breckle 1994). Volcanic soils are rich in Mn; at the end of the rainy season (December–January), the content is lower than during the dry season (February–March) or at the end of the dry season (end of March) (Fig. 18). Additionally, it is remarkable how the Mn content differs between species.

4 High Mountains and Altitudinal Stress

In the summer of 2002, an expedition to the Pamir area was organized. After 34 years, a view to Afghanistan across the Tajik–Afghan border at the Abe Panj, the upper tributary of the Amu Darya, was again possible (Fig. 19a). This expedition – in the footsteps of my close friend Okmir Agakhanjanz (who had died a few months earlier) – was the first German expedition since the 1935 German Pamir expedition,

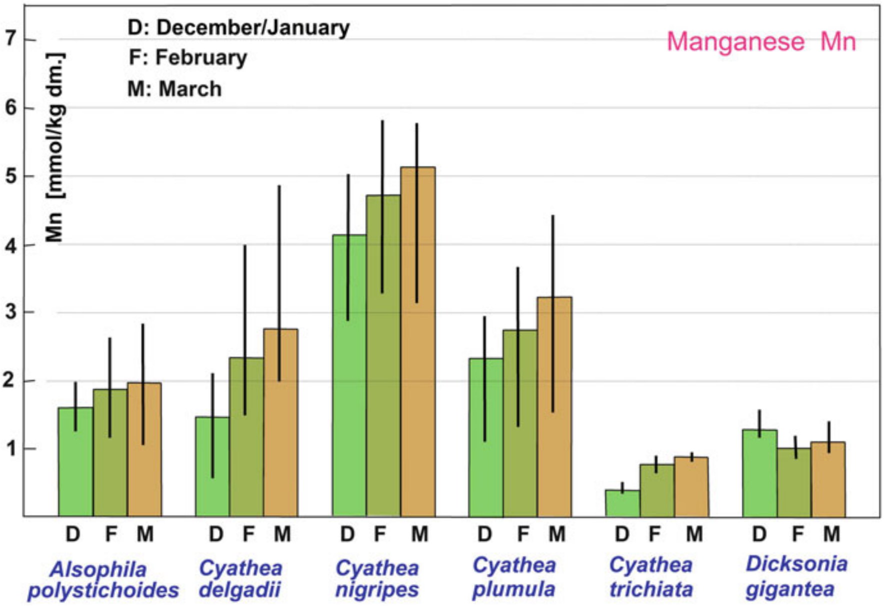


Fig. 18 Manganese (Mn) content (mmol kg^{-1} dm) in six tree fern fronds in the montane tropical forest near Rio Lorenzito in the Sierra de Tilarán, Costa Rica, during the wet season (December) and dry season (March) (Weber 1994; Weber and Breckle 1994)

along the upper Abe Panj and Pamir River, and reaching Zorkul (at an altitude of 4,200 m), the lake being one of the sources of the Amu Darya. The contrasts between western and eastern Pamir in terms of landscape morphology, climate and vegetation were striking. Also the comparison of old vegetation maps (Vanselow et al. 2016) and the present-day situation showed strong desertification.

The expedition to the high mountain deserts of eastern Pamir enabled a survey and comparison of mountain ecological conditions between eastern and western Pamir. This was the last research trip of Clas Naumann, during which he finally clarified the biology of the moth *Zygaena pamira* (Fig. 19b, c); at 4,250 m the eggs were found developing on the lower side of yak cow dung, close to our campsite.

An almost symbolic plant of eastern Pamir is *teresken* (*Ceratoides papposa*, Fig. 19d). This species has an enormous geographical distribution (from the Ebro basin in Spain, the Vienna area and Pannonia to Mongolia and western China) in deserts and semi-deserts. *Teresken* has been the main energy source for the people since the break-up of the Soviet Union and the civil wars in Tajikistan, and is also the main fodder for sheep and goats, for donkeys and camels, and for the famous Marco Polo sheep (*Ovis ammon polii*). But, interestingly, *teresken* is a rather slow-growing dwarf shrub with a shoot-to-root ratio of up to 1:40, thus it is very drought resistant. For fuel, the woody root is used. Old plants have a thick rootstock and can reach 130 years of age (Walter and Breckle 1994).

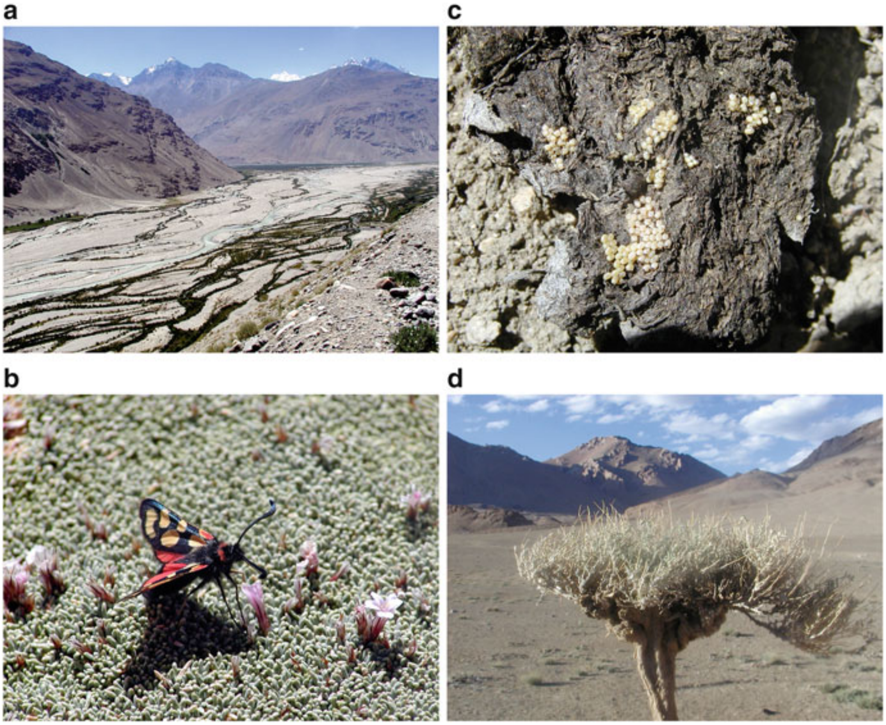


Fig. 19 (**a**) The Pamir River, Tajikistan, with meandering parts and natural gallery forests, joining the Wakhan River in the background (Afghanistan) (photo courtesy of C. Naumann, 2002). (**b**) *Zygaena pamira* on *Acantholimon diapensioides* at Turumtaikul (4,200 m), Pamir (photo courtesy of C. Naumann, 2002). (**c**) *Zygaena pamira* egg layings on the lower side of yak cow dung at Turumtaikul, Pamir (photo courtesy of C. Naumann, 2002). (**d**) *Krascheninnikovia ceratoides* (*teresken*), a middle-aged dwarf shrub, with thick woody rootstock, from eastern Pamir (photo: S. W. Breckle, 2002)

The "*teresken* syndrome" is one of the major problems in the eastern Pamir region and urgently needs a solution through replacement of *teresken* with other energy sources (projects from non-governmental organizations [NGOs] have started). A very similar and astonishingly parallel problem is the "tola syndrome" in the dry altiplano of Bolivia, where, again, people depend on almost only one life form. Again, slow-growing dwarf shrubs of the composite *Parastrephia* are the main source of fuel and fodder for lamas, alpacas and also the wild camelid vicuñas (Breckle and Wucherer 2006; Ahmadov et al. 2006).

Flora of high mountains is derived from floristic ancestors on the plains and in adjacent lower hill areas. In the Central Asian mountains, the migration of species, evolution of new species and extinction of species are leading to new mountain flora (Agakhanjanz and Breckle 1995). The character and speed of orogenesis, the climatic situation, the stages of forest belts and, finally, glaciation are the governing factors. A comparative survey of the phyto-diversity and known species numbers in a b

Fig. 20 (**a**) Combating desertification in Inner Mongolia. By a checker-straw technique, sand movement of mobile dunes is retarded, and diaspores of pioneer plants are able to invade within the straw squares (photo courtesy of C. Wissel, September 2004). (**b**) Nizzana sand dune area with longitudinal dunes (western Negev Desert); meeting of project groups (photo: S. W. Breckle, 1998)

the Eurasian mountains clearly indicates the need for small-scale inventories, especially for the orophytic belt (above the timberline). There endemics reach a high proportion in the subalpine and alpine belts but are almost absent in the subnival and nival belts, where some widespread boreal and even arctic species are present (Agachanjanz and Breckle 2002; Breckle 2004). In contrast, in arid mountains lacking a forest belt, endemics are more common in the lower belts. Concerning the Hindu Kush, the main Afghan mountain range, see Sect. 7.2.

5 Desert Ecology

Stress ecology is certainly very relevant in deserts. Heat stress and drought stress are the prominent ecological factors that organisms have to be adapted to or avoid. All of those questions of desert research have also been part of desertification studies. Only a few examples can be mentioned here. Desertification on a large scale has also been seen in several parts of China (Veste et al. 2006; Gao et al. 2007), with a severe dust situation in Beijing. Large-scale afforestation projects with millions of trees being planted in the loess area and sand-binding actions (Fig. 20a) are under way.

In 1999, a competent network of German scientific institutions was founded in Bielefeld (Desert☼Net) for exchange and planning of innovative joint projects. Close contacts with relevant political institutions were built up. Especially with the Secretary of the United Nations Convention to Combat Desertification (UNCCD) in Bonn, fruitful discussions took place, as well as participation at the Expo 2000 in Hanover. Participating in political discussions on the means necessary for combating desertification was, however, often rather disappointing, e.g. at the Fourth and Fifth Conferences of the Parties to the Convention to Combat Desertification (CCD-COP4 [held in Bonn] and CCD-COP5 [held in Geneva]). So, such political activities lasted only a few years. Then the European Desert☼Net was founded elsewhere, but it seems now just to be one among many other not especially creative or innovative organizations. Scientific desert ecology is more attractive and an important background for applications.

5.1 Negev (Nizzana Sand Dunes)

How do plants survive in deserts? Water availability is reduced in all deserts, but there are many different types of deserts, and generalizations are often misleading. Several projects concerning desert ecology were undertaken. The Namib was studied only randomly [three diploma theses (Veste and Mohr 2005)].

The Atacama had been visited during a 3-month stay in Chile, including study of several *salares* (salt flats) and halophytic sites, and checking of salinity gradients; however, before the return to Germany, all material, notes and samples – about 30 coloured films from all vegetation types between Arica and Chiloe – were lost after being stolen in Santiago just in front of the university library. It happens.

Certainly it was not as tragic as the loss of Alfred Russel Wallace's collection. He was in Amazonia, charting the Rio Negro for 4 years, collecting specimens and making notes on the peoples and languages he encountered, as well as the geography, flora and fauna. The ship's cargo caught fire, and the crew was forced to abandon the ship in August 1852 on the Atlantic Ocean. All of the specimens Wallace had on the ship, mostly collected during the last two – and most interesting – years of his trip, were lost. He managed to save a few notes and pencil sketches, and little else (Raby 2002, note by Lüttge).

The special longitudinal sand dune system of the western Negev, near Nizzana, was studied by a large joint project (Fig. 20b). The area is characterized by an arid typical desert climate with rather strong variability from year to year (Fig. 21). A synthesis of all studied topics was given by Breckle et al. (2008). Those longitudinal dunes were an ideal study system. The very regular ecotopic mosaic of dunes is characterized by the formation of a microbiotic crust (Fig. 22a) (Veste and Breckle 2003; Littmann and Veste 2005; Veste et al. 2011) despite the very arid climate. Within a few years, even on mobile sand (totally protected by the military close to the Egyptian border), it has a rather thick, strong appearance. This organic crust of cyanobacteria, lichens and mosses (Fig. 22b) greatly reduces the infiltration of the scarce rains in winter (Fig. 21) and results in a new pattern of water availability and a vegetation mosaic on formerly mobile sand dunes. This mosaic strongly influences the establishment of seed plants and is also a source of atmospheric nitrogen binding (Russow et al. 2008). The thickness and chlorophyll content along the gradient are shown in Fig. 23. Crust development strongly depends on the water regime, but dew and fog often are the main water sources. Here, just 20–25 fogs per year is one water

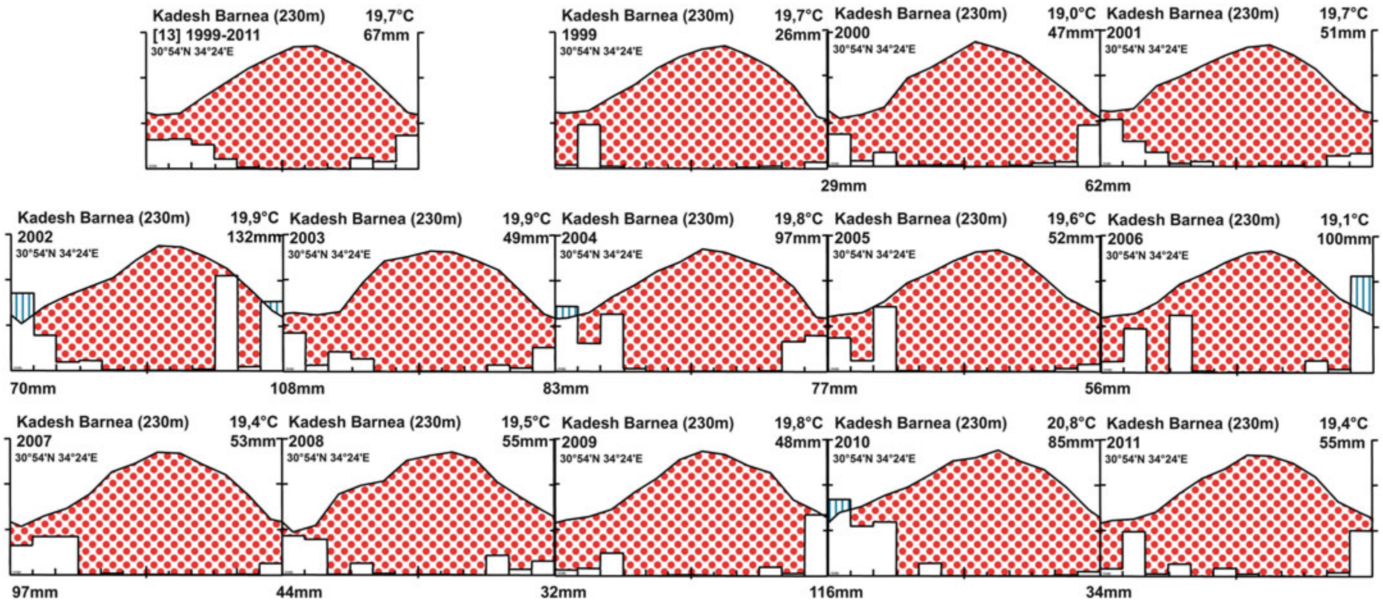


Fig. 21 Ecological climate diagram (*upper left corner*) indicating desert conditions at the Nizzana test site, and climatograms (indicating the conditions of 1 year), thus exhibiting the variability from year to year (during the period from 1999 to 2011). Data from the Barnea Kadesh meteorological station at Nizzana (courtesy of S. Berkowicz)

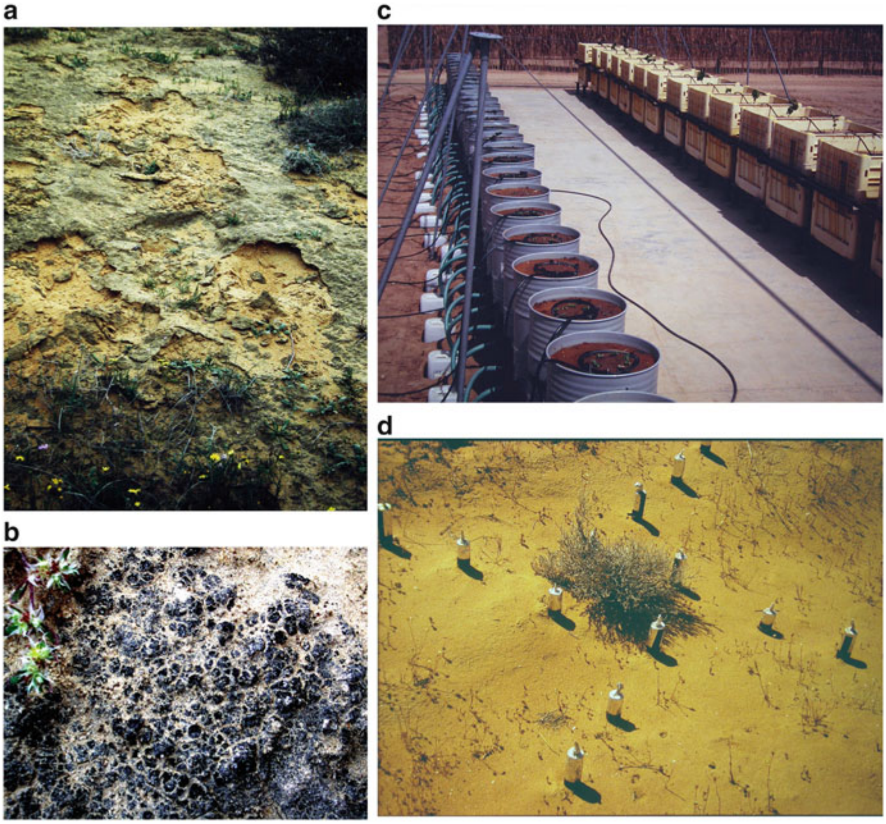


Fig. 22 (**a**) Biotic crusts on mobile sand dunes start with a cyanobacteria cover; this early stage can easily be destroyed by trampling (photo: S. W. Breckle, 1997). (**b**) Close-up view of the well-developed old biological crust on mobile sand dunes, Nizzana, Negev Desert, with cyanobacteria, lichens and mosses (photo: S. W. Breckle, 1998). (**c**) Large lysimeters at the Yotvata test site (southern Negev) with sophisticated nutrient solution supplies (photo: S. W. Breckle, 1996). (**d**) Rhizotron tubes around desert dwarf shrubs in the Nizzana sand dune area, suitable for a small television camera for semiautomatic picture processing (photo: S. W. Breckle, 1994)

source, and dew in the morning is the other – although it provides only about 0.06–0.14 mm of water input per night (Veste et al. 2008) – which could add up to about 26–33 m per year.

In many sand deserts, those biotic crusts are formed, but with strong winds, and even more with grazing and trampling, a closed thick crust normally cannot develop. On rocks, biotic crusts are present everywhere worldwide.

The interdisciplinary approach to the study of this highly complex and dynamic ecosystem mosaic revealed many astonishing details of the processes that form such a dune mosaic. The occurrence of surface run-off on sand dunes is not irrelevant, as is often said, and is seen on mobile sands. The accumulation of a thin cover of fine-grained particles and the existence of the widespread biological topsoil crust change

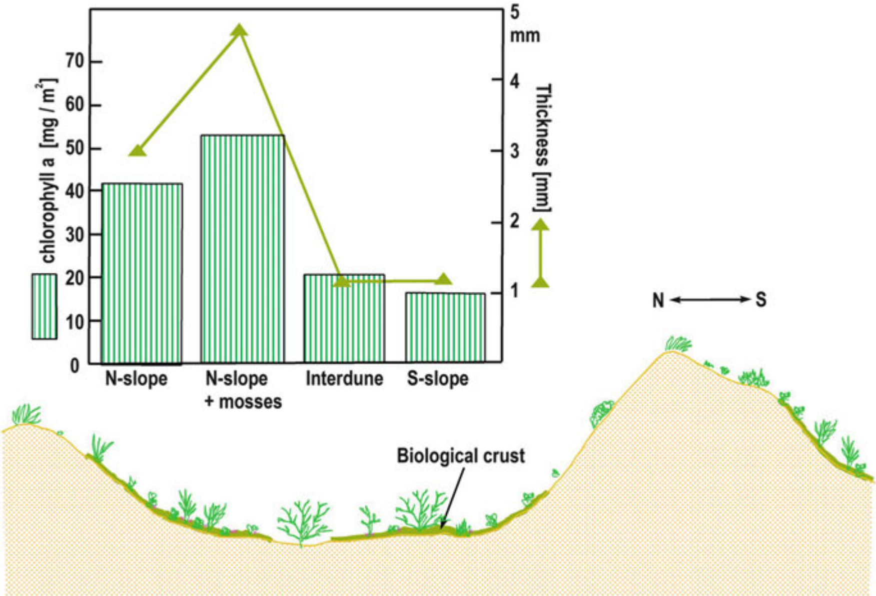


Fig. 23 Profile across dune slopes of the longitudinal dune system of Nizzana (Negev Desert), with formation of a biological crust, their thickness and their chlorophyll content (mg m^{-2}) (Veste et al. 2011)

the whole run-off and erosion processes and thus also the mosaic of vegetation cover (Kidron and Yair 2008; Yair 2008). These are long-term processes and warrant long-term observations. They are, of course, totally dependent on the various human impacts (former land use, grazing, collection, wood cutting, trampling, off-road traffic) and thus the special sand dune area at Nizzana was very suitable for study because it had been protected by the military. The contrast of the different land use systems is seen in satellite images, where the Israeli–Egyptian border exhibits a straight line of differing albedo. On the Egyptian side, the number of perennial shrubs was reduced from about 400 per km^2 (in 1945) to about 100 (in 1989), whereas on the Israeli side, with fluctuations, it increased to more than 600, making the sand dune area spotty green (Tsoar 2008). Another contrasting pattern is given by the steep gradient of aridity from south to north, from about 100 mm to less than 50 mm within a 50 km distance, but local rainfalls are very irregular. These sand dune mosaics are different in the north, where dune movements of the dune crests are lacking, in contrast to the south where more specially adapted sand dune plants are found. Many experiments could be performed to see the effects and recovery, as well as intensive measurements of the main parameters of desert plant life (Breckle et al. 2008), including root growth, by regular checking of rhizotron tubes around dwarf shrubs (Fig. 22c). Small television cameras provided pictures, which were processed by automatic image analysis (Jankowski et al. 1995; Breckle et al. 2001c; Erz et al. 2005).

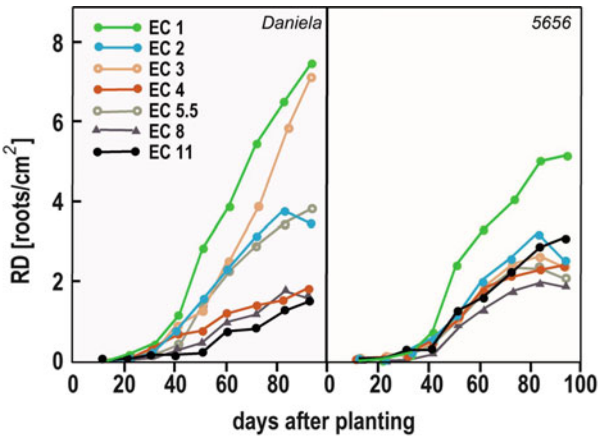


Fig. 24 Root density of tomato plants (breed Daniela and 5656) during 100 days of cultivation under salinity stress (electrical conductivity 1–11 mS) (Veste et al. 2005)

In the southern Negev (Kibbutz Yotvata), the large experimental fields and infrastructure, as well as large lysimeters (Fig. 22d), were used for several experiments to check water consumption under strongly arid and hot conditions. This project, titled "Optimization of Irrigation and Water Use under Desert Conditions", also checked root system behaviour, especially in tomatoes. The root density of tomato plants under irrigation with saline water and grown in large rhizotrons is shown in Fig. 24. Salt reduced the root growth rates, as well as below- and above-ground biomass, in both cultivars (Veste et al. 2005).

5.2 Aralkum (The Desiccated Sea Floor)

At the start of the long-term project titled "Aralkum", there were two main questions. First, what is the present situation on the desiccated sea floor, what flora and vegetation can be found, and what is starting to develop? Second, is there a chance to intervene in the process of primary succession to accelerate the vegetation cover in order to minimize salt and dust storms? The latter was a very important applied approach and was raised by the Federal Ministry of Education and Research (BMBF).

In 1960, the Aral Sea started to disappear because of an unequal hydrological equilibrium of the water balance of this endorheic system, caused by drastically enlarged irrigation areas to produce more than 7 million tons of cotton in Uzbekistan alone. Having been the world's fourth largest lake, today the Aral Sea no longer exists (Fig. 25). The whole larger area around the former Aral Sea became a catastrophic area with a strong social crisis (Fig. 26). Only slowly within the last decade have there been improvements in Kazakhstan by the construction of a dam, which, since 2005, has partly restored the northern Aral Sea. Still in dispute is how the situation can be improved (Breckle and Wucherer 2011; Breckle et al. 2012).

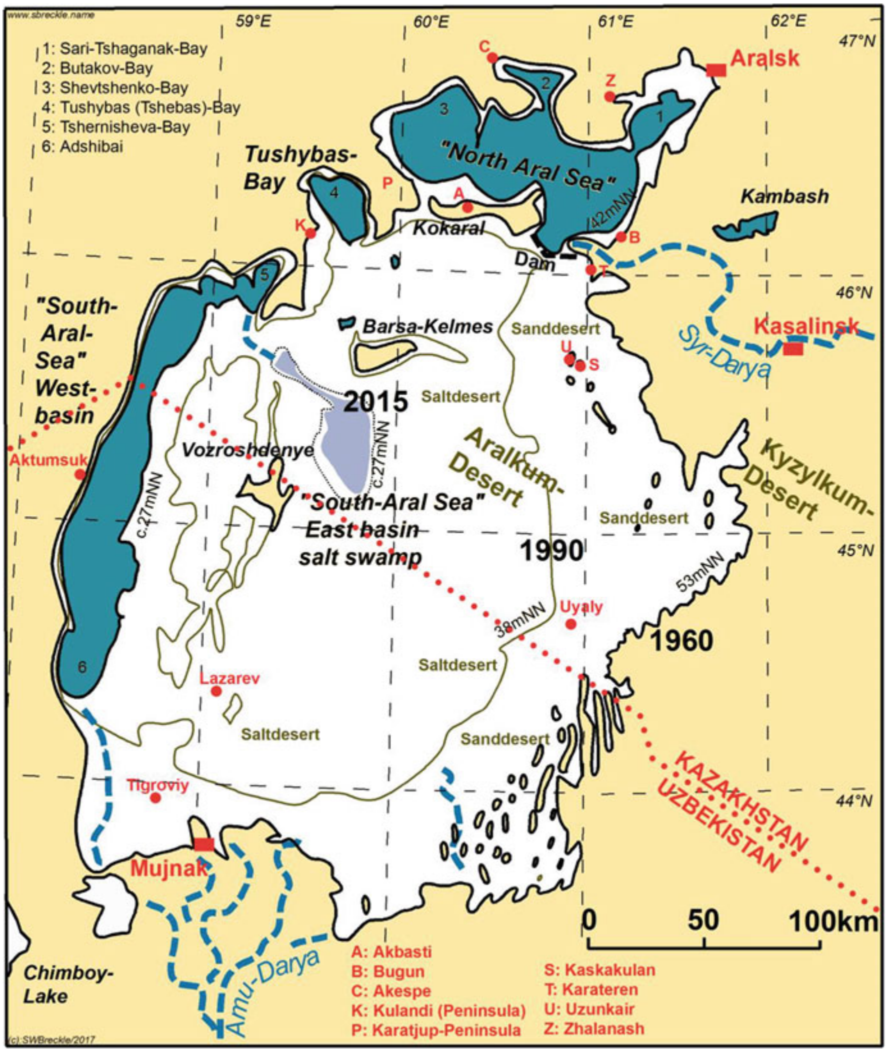


Fig. 25 Aral Sea area: geographical situation and extent of the Aralkum from 1960 to 1990 and 2015

A long-term study on the desiccated sea floor – the Aralkum – as a new desert (Fig. 25) revealed the primary succession (Breckle 2013; Breckle et al. 2012; Wucherer and Breckle 2001, 2012; Groeneveld et al. 2012). This succession often is called mankind's biggest succession experiment. The large new flat area – the desiccated sea floor – was invaded from the surroundings by diaspores. Depending on the substrate (older areas are sandy; younger areas are clayey and more saline), the succession was very dynamic, with species composition greatly varying from year to year. A general scheme for loamy soils is given in Fig. 27, indicating the

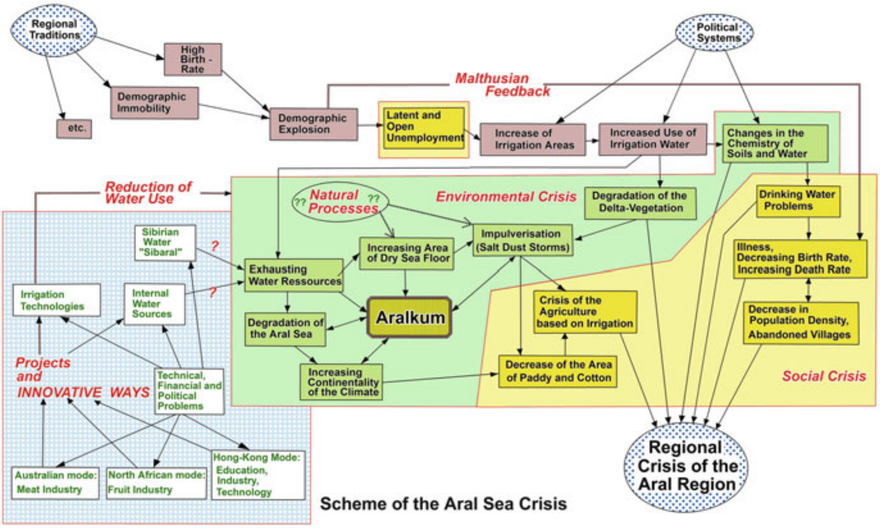


Fig. 26 Scheme of the Aral Sea crisis: environmental and social aspects, and possible future projects (after Breckle et al. 1998)

dynamics between several associations and bare salt desert patches. For the older sandy sea floor, the succession differs considerably because of the better water availability on sand. Small sand dunes can form with various *Calligonum* species but lately also with *Haloxylon aphyllum*.

The desiccation history is not easy to reveal. The changing shoreline from year to year left seeds and saplings, mainly of fast-germinating *Tamarix* species. After a few years, the former shorelines could be seen easily from a distance (Fig. 28a, b). At four transects, Breckle et al. (2014a) did a retrospective dating of the vegetation belts. Also, in the northern Aral Sea basin, the restart of inundation – as a result of the new dam – was visible.

Breckle et al. (2012) brought together the results of international and interdisciplinary studies on the new desert ecosystem. The physical characteristics of the area, mainly geological and climatological aspects and their dynamics, especially the dust storm dynamics, were discussed. There was a strong need to find ways to minimize the destructive salt–dust storms in the area. Phyto-melioration experiments (Breckle 2003) on 250 ha of sea floor with the help of Kazak villagers (financed by the BMBF and the German Society for Technical Cooperation [GTZ]) showed the best potential of *Haloxylon aphyllum* (saxaul) to grow and reproduce under these extreme conditions of continentality (−40°C in winter, +43°C in summer) and salinity. Under natural conditions, *Tamarix* species were the main invaders along the desiccation belts (Fig. 28a) but were not successful in planting experiments; they were always totally destroyed by rodents.

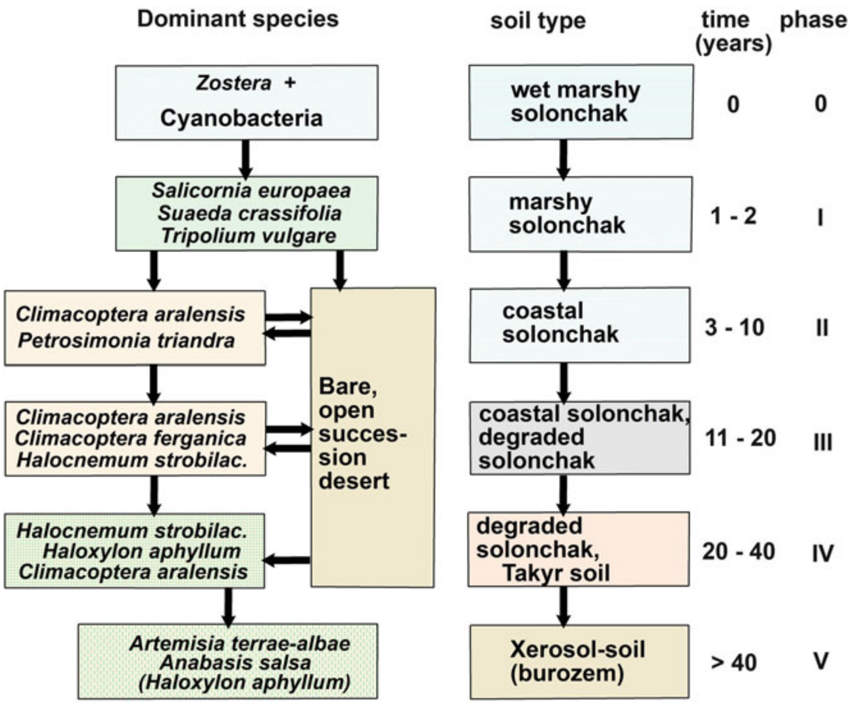


Fig. 27 Primary succession on loamy and clayey soils during the desiccation of the Aral Sea floor (modified from Breckle 2002b; Breckle and Wucherer 2012)

A distinct proportion of all 373 vascular plant species found on the desiccated sea floor are, so far, more or less halophytic. Table 1 gives an overview of the halophyte types and their salinity indicator value *S* (with *S* values from 1 to 9) (Breckle 1985; Ellenberg et al. 1991). Leaf-succulent halophytes play a major role, but non-halophytes and pseudo-halophytes often conquer where the upper soil is already desalinated and sand and dust have been accumulated; thus geomorphological processes are strongly linked with vegetation development.

Several other projects in Uzbekistan used various but similar methods. In Kazakhstan, a huge area was then declared a biosphere reserve (Breckle 2011a, b, 2013), enlarging the former Barsa-Kelmes Island area, partly according to our earlier proposals, parallel to the now open space as far as Kazka Kulan on the former east coast, where there are now herds of onagers (wild asses) and gazelles, often close to the warm springs.

a

b

Fig. 28 (**a**) View from the northern chinks [the steep terraces; see also (**b**)] to the northern Aral Sea basin at the desiccated Chevshenko Bay, with distinct *Tamarix* belts, indicating the desiccation

Table 1 Number of vascular plant species that have spontaneously invaded the Aralkum, their halophytic strategy types and related salinity indicator values (S) for the flora of the Aralkum (Breckle and Wucherer 2012)

Halophytic strategy type	$S = 1$	2	3	4	5	6	7	8	9	X	$\sum$
Non-halophytes	42	18	0	0	0	0	0	0	0	0	60
Pseudo-halophytes	4	30	42	15	8	4	1	0	0	4	108
Xero-succulents	0	0	0	0	0	0	0	0	0	1	1
Leaf-succulent eu-halophytes	0	2	2	5	14	7	22	9	1	0	62
Stem-succulent eu-halophytes	0	0	0	1	1	1	1	0	2	0	6
Endocrino-halophytes	0	0	2	5	1	2	0	0	0	0	10
Exocrino-halophytes	0	0	0	0	0	9	7	4	0	0	20
Hydro-halophytes	0	0	0	1	0	0	0	0	1	0	2
$\sum$	46	50	46	27	24	23	31	13	4	5	269
Undetermined strategy type											104
$\sum\sum$											373

6 Tropical Ecology, Canopy Structure and Growth Dynamics

6.1 Costa Rica

Similar to deserts but very different in appearance, untouched tropical rainforests certainly pose a wealth of open ecological questions. A small research station in the lower montane rainforest on the Sierra de Tilarán at the Rio Lorencito in Costa Rica, as emphasized by Stefan Vogel [in Vienna, formerly in Mainz], was a good starting point for studies on the following questions. How is the high biodiversity in tropical forests maintained? Which habitat structure do we have, and what are its dynamics?

Later, also jointly with other German groups, we used the San Francisco station in the montane rainforest in southern Ecuador, though there were fewer virgin forests than in Costa Rica. We first wanted to know the basic stand structure, the dynamics of the main trees and their growth behaviour. With 1 ha inventories and a large number of dendrometer bands, important basic data on the forest ecosystem could be collected (Homeier 2004; Homeier et al. 2002a, b, 2008; Homeier and Breckle 2004, 2008). Later, members of the department also worked in Kenya (Dalitz et al. 2005, 2011; Gliniars et al. 2011; Table 2).

Fig. 28 (continued) process (photo: S. W. Breckle, 2003). (**b**) The steep chinks provide an excellent view of the remnant of the northern Aral Sea (photo courtesy of W. Wucherer, 24 May 2003)

Table 2 Examples of research and teaching topics at the Department of Ecology at Bielefeld (Breckle 2005a)

Autecology etc.
Halophyte ecology (Breckle, Reimann, Freitas, Sanchez, Herrera, Waisel et al.)
Heavy metal stress (Breckle, Engenhart, Nabais, Pieczonka, Kahle, Dalitz et al.)
High mountain ecology (Breckle, Agakhanjanz)
Dendro-ecology and dendro-analysis (Hagemeyer et al.)
Root dynamics, aeroponics (Anlauf, Breckle, Waisel et al.)
Primary successions (Breckle)
Photosynthesis, biotic crusts (Veste, Breckle et al.)
Tropical ecology and global ecology
Costa Rica (Breckle, Dalitz, Homeier, Wattenberg et al.)
Ecuador (Breckle, Dalitz, Homeier, Oesker et al.)
Kenya (Dalitz, Todt, Uster et al.)
Vegetation and zono-biomes of the globe (Breckle et al.)
Afghanistan: flora, ecology, vegetation (Breckle, Hedge, Rafiqpoor, Keusgen et al.)
Desert ecology
Central Asia: Aralkum project (Wucherer, Breckle et al.)
Inner Mongolia: combating desertification (Breckle, Veste et al.)
Sand dune ecosystems in the Negev: Nizzana project (Breckle, Veste, Yair et al.)
Namib (Breckle, Veste et al.), Atacama
Eastern Pamir and the *teresken* syndrome (Breckle, Wucherer, Trux)
Succulents, Southern Africa, Richtersveld (Veste)
Vegetation and landscape ecology
Riverine vegetation (Stockey et al.)
Nature protection (Breckle et al.)
Applied ecology
Nature sports, e.g. orienteering, ice skating (Breckle)
Desertification (Breckle, Veste, Wucherer et al.)

Gap dynamics play an important role in the future stand structure (Fig. 29). Gaps are the result of natural disturbances in forests, ranging from large branches breaking off, to a tree dying then falling over and bringing its roots to the surface of the ground, to landslides bringing down groups of trees. In the premontane tropical rainforests of the Sierra de Tilarán, the slopes are very steep; thus tree falls and small landslides are common; the same is also true in Ecuador (see Fig. 30b). Because of the range of causes, gaps have a wide range of sizes, including small and large gaps. Gaps allow an increase in light as well as changes in moisture and wind levels, leading to differences in microclimate conditions compared with those below the closed canopy, which are generally cooler and more shaded. Thus, gaps are more or less a special site with altered conditions (Fig. 29); these smaller or bigger islands can be the reason for a dynamic mosaic canopy structure. Gaps provide the ideal location and conditions for rapid plant reproduction and growth (Fig. 39) (Wattenberg 1996).

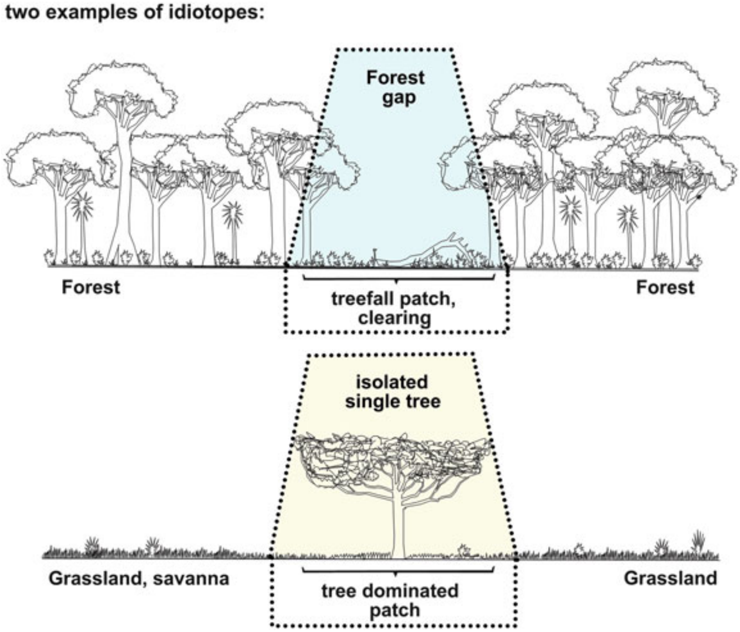


Fig. 29 Comparative structure and effects of idiotopes in a forest area and in savannah (Belsky and Canham 1994; Breckle 1999), indicating the specific island effect of shading from a single tree in the savannah and the opposite effect in a forest by gap formation

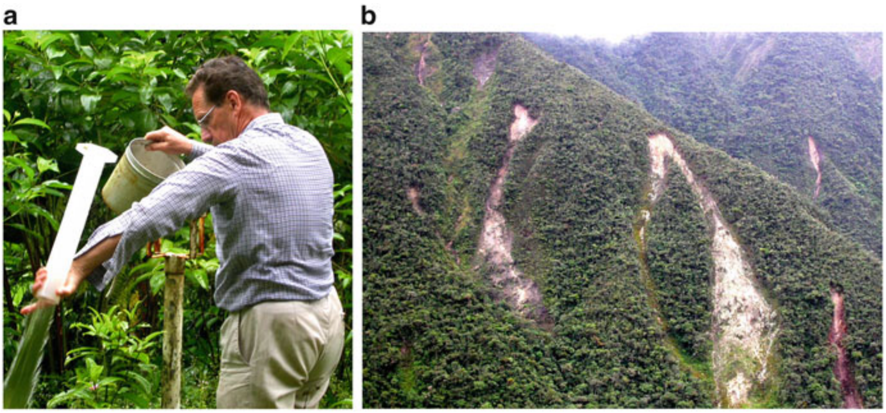


Fig. 30 (**a**) During the rainy season, the rain gauge is full every day and has to be emptied very regularly (photo courtesy of J. Homeier, May 2004). (**b**) Typical landslides on steep slopes of the Rio San Francisco valley, southern Ecuador (photo: S. W. Breckle, 2004)

Working in the tropics, the difficulties were major from the start. Inventories of a beech forest in Germany can take an afternoon, and it is then clear which species dominate and what their cover percentages are. In the tropics, even by restriction to 5 or 10 cm dbh (diameter at breast height), it takes weeks and months of intensive identification work to get reliable species lists. And it is obvious that phytosociological methods and the definition of syn-taxonomic units are senseless, since the main precondition of an existing "minimum area" is not fulfilled (Fig. 31). The very artificial syn-taxonomic nomenclature is useless in the tropics at least, though many syn-taxonomic papers are still published.

In Costa Rica, about 94 tree species per hectare (dbh $\geq$10 cm) were inventoried (Wattenberg and Breckle 1995). If the area was doubled, the number of tree species would be about 130, indicating the lack of an asymptotic minimum area (Fig. 31). The number of tree species in southern Ecuador (dbh $\geq$5 cm) is extremely high and almost a world record (Homeier 2004). At both study sites, the climate is typically a diurnal climate all year round (Fig. 32). Sometimes very large amounts of rain can fall within 1 day (Fig. 30a), regularly causing landslides on the steep slopes and thus dynamic reproduction and establishment processes.

In Costa Rica's 1 ha plot, more than one third of the tree species were present with only one individual tree, and one fifth with only two individuals (Fig. 33). It is still almost a miracle how, under these circumstances, successful pollination is possible. One probable explanation is the process of bird pollination.

Only in species that occur relatively frequently is it possible to delimit an altitudinal belt structure, as was shown for tree ferns. Figure 34 covers only an altitudinal distance of 500 m, but the tree ferns apparently exhibit strong niches (Bittner and Breckle 1995).

What is the growth dynamic of the trees? The growth of tree stems can be checked by study of the annual rings from drilled bore cores, but this method is destructive; furthermore, many tropical trees do not produce periodic annual rings. We used dendrometer bands. Biweekly measurements of 948 trees over several years gave good hints about the growth conditions, the variability within and between species, and the influence of site conditions. This could be shown in Costa Rica (premontane forest between 850 and 1,210 m asl [above sea level]), as well as in the montane tropical forest (1,850–2,450 m) in Ecuador (Homeier 2004; Homeier and Breckle 2004; Bräuning et al. 2008). Diameter growth was highly variable between the 22 investigated species, with annual increments from 0.6 to 5.7 mm in Ecuador and from 1.6 to 12.3 mm in Costa Rica. The maximum growth rates were in the lower diameter classes. Seasonality in growth was seen in the only deciduous tree, *Tabebuia chrysantha*.

The tropical forests in Costa Rica are rich in palm species. Figure 35 shows the growth of three palm species in time, derived from long-term measurements (J. Homeier, personal communication, 2017: Stattegger 2017). Also, the thickness of the palm stems depends on size and thus on age (Fig. 36), despite the fact that monocots are normally described in textbooks as not having a secondary growth of the stem. The two palms reached dbh values of 21 cm (*Euterpe*) and 26 cm (*Iriartea*). Both species start growing with a slender stem and show a limited

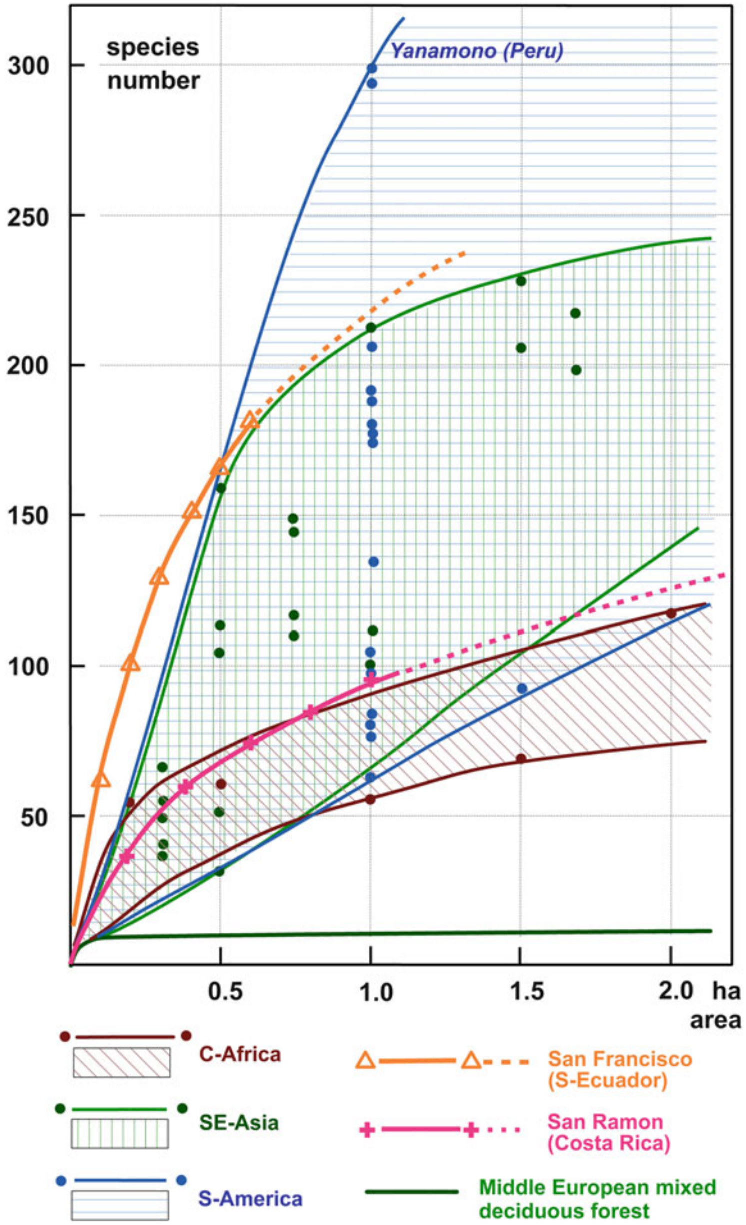


Fig. 31 Species/area curve of the montane tropical forest of San Ramón at Sierra de Tilarán, Costa Rica (diameter at breast height [dbh] ≥10 cm) and San Francisco, southern Ecuador (dbh ≥5 cm) in comparison with some other tropical forest regions and with the middle European mixed deciduous forest (data from Wattenberg and Breckle 1995; Homeier 2004)

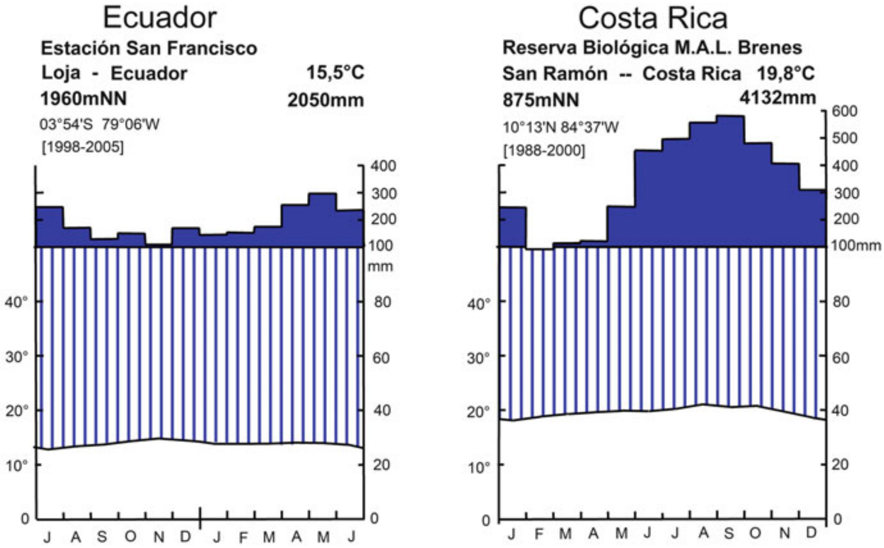


Fig. 32 Ecological climatic diagrams from southern Ecuador (San Francisco Biological Station) and from Costa Rica (San Ramón Biological Station, Rio Lorencito). The climate is typically humid and tropical all year round, with almost no annual temperature oscillation; most months are hyper-humid, with above 100 mm precipitation/month

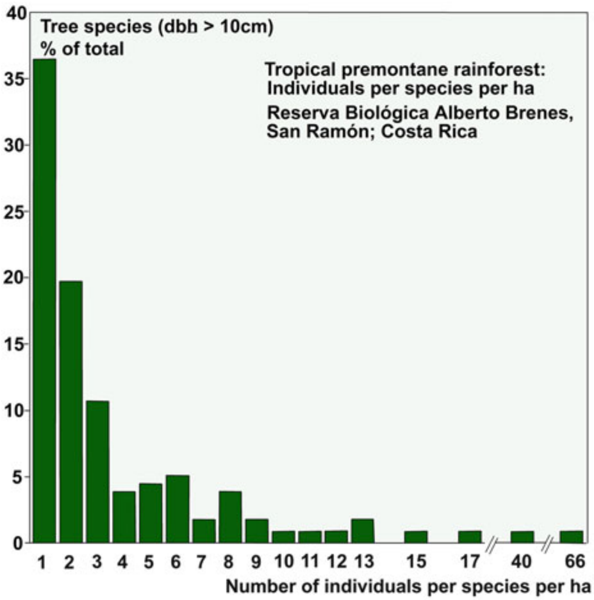


Fig. 33 Number of individuals per hectare of tree species (% of total) in the tropical montane rainforest in the Sierra de Tilarán at Reserva San Ramón, Costa Rica (Wattenberg and Breckle 1995); 37% of tree species are represented by only one individual, 20% of species have two individuals

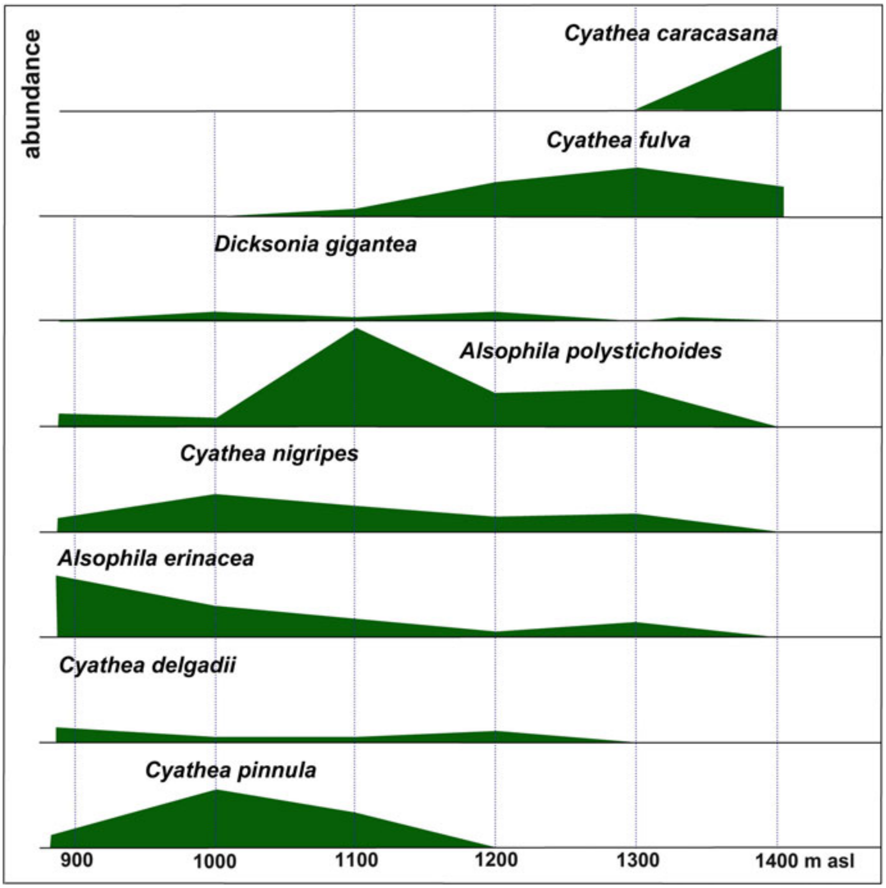


Fig. 34 Abundance of tree fern species along the altitudinal gradient in Sierra de Tilarán, near Rio Lorencito, Costa Rica (Bittner and Breckle 1995)

diameter increment by sustained cell expansion during their development. The relation of height to dbh shows different growth strategies for *Euterpe* and *Iriartea*. *Euterpe* palms grow regularly in height and in dbh (Fig. 35). In *Euterpe* palms, first diameter growth is prioritized up to a dbh of about 20 cm. After almost reaching their final diameter, they then grow mainly vertically. This means competitive strength changes according to age. The smaller *Cryosophila* palms increase their number of leaves during an establishment phase, and the stem reaches the final diameter (Homeier et al. 2002a). After that, the palm continues its vertical growth, with a diameter sufficient to support a maximum height of up to 10 m.

The reproduction and establishment of the various species is a rather complex phenomenon. It was only checked with very few species but is very important for future sustainable soft management of tropical forests, since introduced trees often suffer nutrient deficiencies (Breckle et al. 2005). The population structures of the

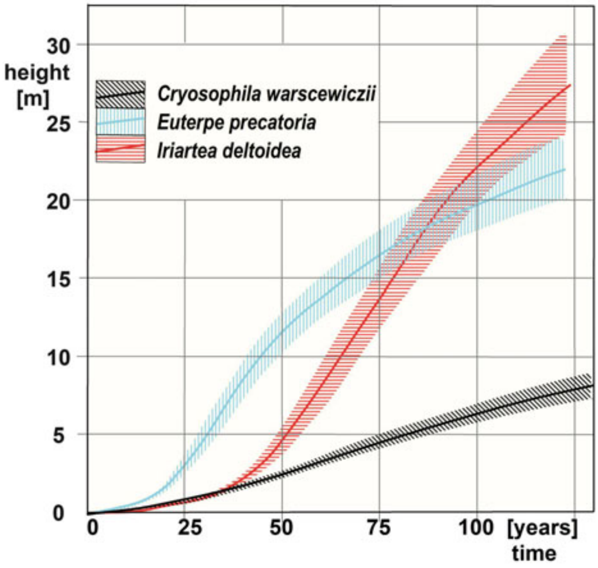


Fig. 35 Height growth of three palm species in the montane tropical forest of Sierra de Tilarán, Reserva Biológica, near San Ramón, Costa Rica, as a function of time (data from Homeier et al. 2002a)

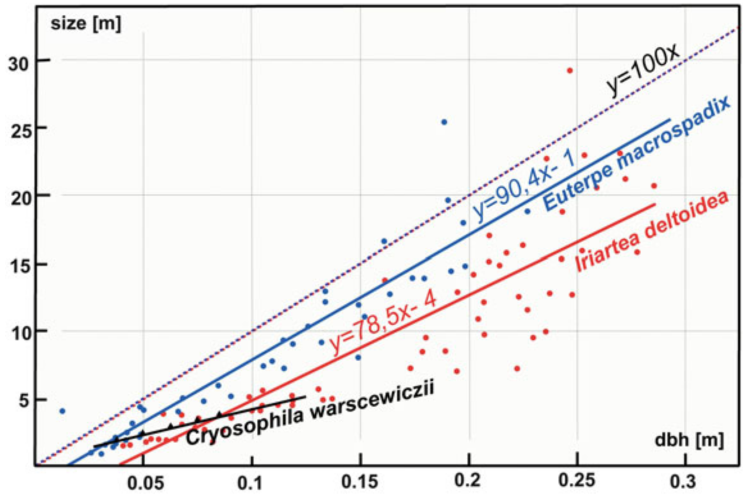


Fig. 36 Correlation of height (m) and diameter at breast height [dbh (m)] of three palm tree species in the montane tropical forest of Sierra de Tilarán, Costa Rica (data from Homeier 2004; Homeier et al. 2002a)

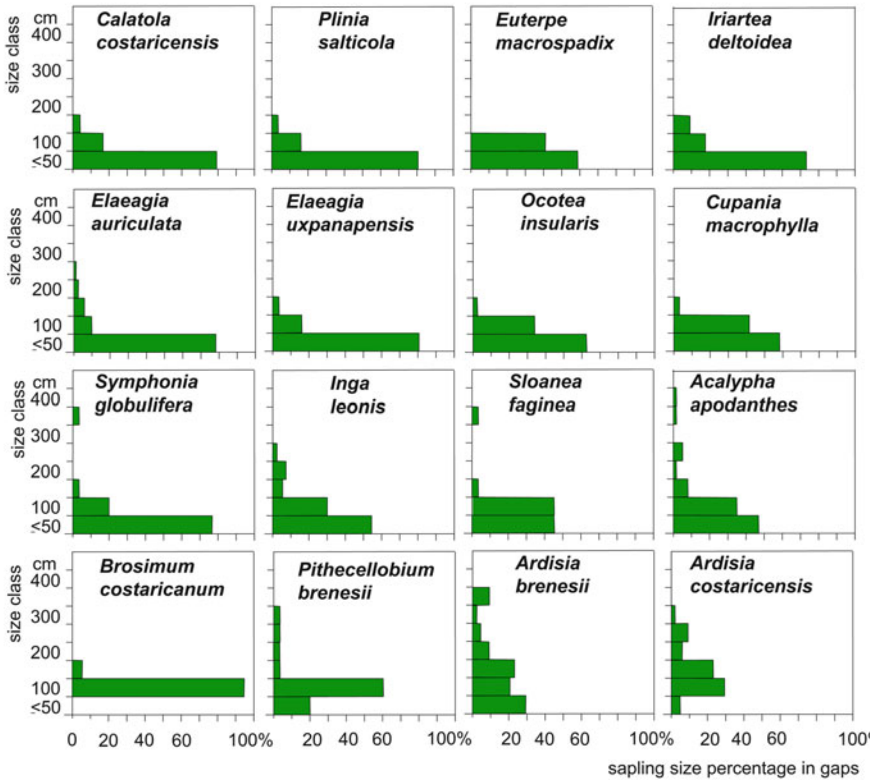


Fig. 37 Comparison of distribution of size classes of saplings and young trees of 16 species from the montane tropical forest of Sierra de Tilarán, Costa Rica (Wattenberg 1997; Breckle 1997a)

various tree species in the Costa Rican mountain rainforest differ from each other. A shortened version (given in Fig. 37) of the size classes of 16 species can also be interpreted as a kind of sapling bank, waiting for an eventual gap to happen. In any case, the number of small individuals in saplings and young trees is much higher than in adult trees, which is demonstrated by the example of *Pterocarpus hayesii* in Costa Rica (Fig. 38). The turnover of young gap trees is very high, with high mortality rates (Fig. 39). In conclusion, it is clear that the shape and composition of tropical forests change rather fast in time.

6.2 Ecuador

The study area covered the moist tropical mountain forests from the valley bottom of Rio San Francisco (1,800 m) up to the treeline at about 2,800 m. The whole area covers mainly northern exposed slopes around the biological station, forming the

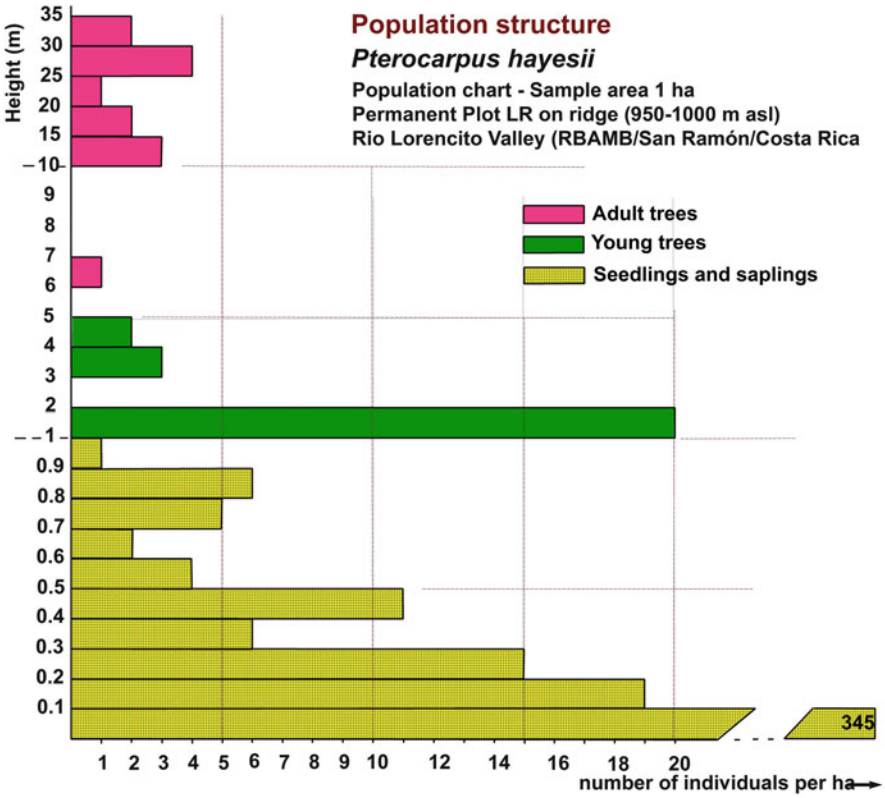


Fig. 38 Population structure of *Pterocarpus hayesii* in the montane tropical forest of Sierra de Tilarán, Costa Rica (Breckle 1997a)

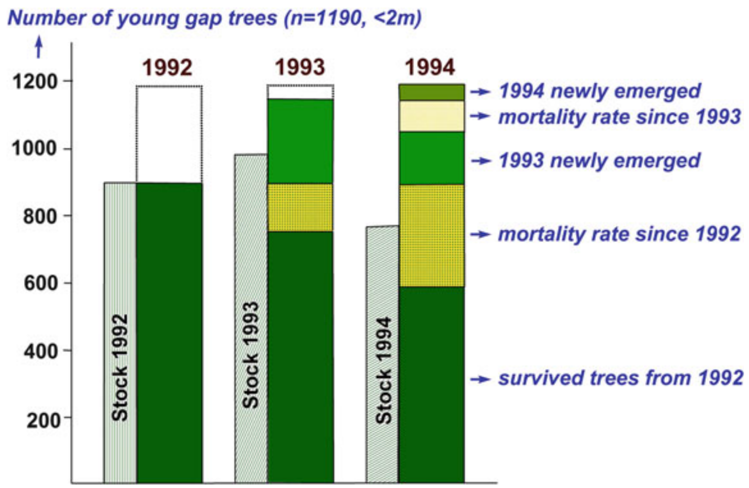


Fig. 39 Mortality dynamics in the montane tropical forest of Sierra de Tilarán, Costa Rica (after data from Wattenberg 1996); number of trees <2 m, per ha

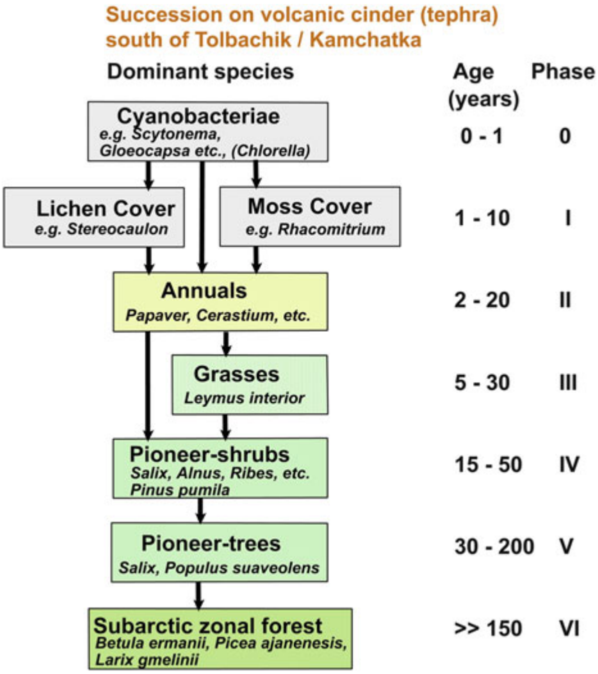


Fig. 40 Primary succession on volcanic cinder (tephra) south of Tolbachik, Kamchatka (Breckle 2002b)

Reserva Biológica San Francisco (RBSF) adjacent to the Podocarpus National Park. On the opposite side of the valley, the forests were cleared about 30 years ago for pine plantations and pastures. Thus, this whole valley – being a hotspot of biodiversity (see Sect. 7.1) – offers great opportunities for comparative studies.

The succession is apparently very dynamic and different in each place, especially in southern Ecuador. There, the long open and steep landslides (Fig. 30b) revealed orchids and ferns as members of the first successional stages (Gross 1998), together with annuals, certainly favoured by their small diaspores. This is rather similar to many examples of primary succession (Breckle 2002b), especially on open cinder slopes of volcanos, e.g. Tolbachik, Kamchatka (Fig. 40), and also in Fogo, Cap Verde; Kilauea, Hawaii; Arenal, Costa Rica; and Piton de la Fournesse, Réunion. But later successional stages seem to proceed very much by chance.

Many basic questions remain. How is the high biodiversity dependent on site conditions? Dalitz et al. (2005) tried to relate it to the spatial heterogeneity, mainly by canopy throughfall of rainwater and leaching of nutrients.

We participated in the priority programme of the German Research Foundation (DFG) on “The Mechanism of Maintaining Tropical Biodiversity”. For a shorter period, we worked at the same time in Costa Rica and Ecuador. Homeier (2004) had carried out extensive comparative studies on tree diversity, forest structure and tree growth in both montane primary forests. In Ecuador on 15 permanent plots (400 m^2

each; in Costa Rica, 13 plots), 1,260 trees (dbh $\geq$5 cm) were inventoried (in Costa Rica, 605 stems). Those trees were identified as belonging to 183 species (in Costa Rica, 147 species) from 53 plant families (in Costa Rica, 55 families). For the whole reserve area in Ecuador, at least 230 tree species were known; four of them were new to Ecuador and nine of them were new to science. At both sites, Lauraceae, Melastomataceae and Rubiaceae were the most common plant families.

The census of biodiversity is a rather full-time job. First, Ingrid Wattenberg and then Jürgen Homeier did basic data collection (Wattenberg and Breckle 1995; Wattenberg 1996; Homeier et al. 2008; Liede-Schumann and Breckle 2008).

Several co-workers continued with their own projects. It turned out that, as in Costa Rica, botanical inventories in Ecuador faced great difficulties. This was because of our ignorance of tropical flora, the frequent lack of flowers or fruits in herbarium collections, or simply because the species have yet to be described (Brehm et al. 2008).

Which are the limiting resources? Are these resources always the available space for growth and species number area-wise? What about the available water in ecosystems? In the Atacama Desert, there are about 50 species and in the Negev Desert about 5–10, but in the tropical rainforests of Costa Rica or Ecuador, only about 1–2 species are found if you calculate them in relation to 1 mm of the available annual precipitation (Breckle 2006).

Nutrient availability is certainly a major factor in plant growth and competitive ability between species (Beck et al. 2008). Jürgen Homeier was able to pursue this question in Ecuador. Especially, the availability of nitrogen (N) and phosphorus (P) to a great degree governs the competitiveness of trees along the elevational gradient, as well as on ridges in contrast to valleys (Homeier et al. 2010).

The question of whether some kind of seasonality can be detected was also tackled. Close to the equator, the weather all year long is more or less rainy and humid, and high annual temperatures fluctuate only between day and night. As has already been mentioned, the wood increment was periodically active annually only for the deciduous *Tabebuia*, but flowering and fruiting also exhibited some annual periods in other species (Cueva Ortiz et al. 2006).

Many groups were also working at the same sites in southern Ecuador. There, strong ties developed between botanists, zoologists, soil scientists, forestry and sociology from both the German and Ecuadorian sides, and many joint studies and projects were carried out and many publications produced (Beck et al. 2008; Bendix et al. 2006, 2013).

7 Wealth of Biodiversity

7.1 Tropics

The question of wealth – what is the price for biodiversity – is a totally anthropocentric question. Do we need to know it? What can we conclude? If biodiversity is lost, it is irreversible; if climate changes, it is reversible. Natural biodiversity cannot easily be judged monetarily; it is an indefinite wealth. The global initiative TEEB (The Economics of Ecosystems and Biodiversity; teebweb.org) is focused on "making nature's values visible" in economic terms. It helps decision makers to recognize the wide range of benefits provided by ecosystems and biodiversity. In anthropogenic agro(forestry) systems, biodiversity stabilizes and sustains productivity. In such cases, via productivity, biodiversity can be better judged monetarily (note by Beck).

Though we were mainly tackling ecological questions, the problem of extremely high biodiversity was always present. In both regions (Costa Rica and Ecuador), the documentation of biodiversity was a necessary part, parallel to all other studies, and time consuming.

In southern Ecuador, one of the hotspots of biodiversity was investigated by many individual projects and research units. From this Ecuador group, as mentioned above, books (Beck et al. 2008; Bendix et al. 2013) and more than 600 papers were published, covering many aspects of natural and social sciences.

The checklists for various groups of organisms (Liede-Schumann and Breckle 2008) bring together earlier knowledge.

The checklist for spermatophytes has 131 plant families, 425 genera and 1,208 species in the RBSF. The pteridophytes have 250 species; the bryophytes have 320 liverworts, 204 mosses and three hornworts (altogether 527 species); the lichens list has 323 species, but many specimens are still unidentified. A very special list is that of the mycorrhizal fungi, where the only way of sure identification is direct sequencing of the associated fungi. Those ribosomal genotypes can rarely be related to morphological or biological species. The mammals are very incompletely known, and only the list of bats, with 35 species, may be rather complete. The birds list has 271 species in the RBSF, but there may well be close to 800, half of the 1,600 in Ecuador. The list of papilionoid butterflies has 245 species, which is estimated to be less than 50% of the existing fauna. The moths are extremely rich; 2,547 species have been recorded in the RBSF and in the close vicinity, including 42 Saturniidae and 36 Sphingidae. The checklist of Tettigoniidae has about 100 species. One hundred and ninety-three species from Oribatidae have been recorded, again including several ones new to science, as in other organismic groups. The checklist of amoebas has 135 species. Finally, also included is a list of useful plants and weeds, with about 360 plants in the Shuar and other indigenous communities.

It was, at that time, a wonderful experience to bring together so many different lists of organisms. Though several groups are still lacking, those lists are very important for future studies. Certainly the inventories may soon be outdated by the tremendous wealth of biodiversity, guaranteeing new finds for many years to come.

Documenting high plant biodiversity certainly always requires good herbarium material, but with new sophisticated digital cameras, photographs of plant portraits can also be used for image-based plant databases (Homeier 2004). With Visual Plants (http://www.visualplants.de/), one has access to records of digitized plant images, herbarium specimens and illustrations of plants from Kenya, Uganda, Costa Rica and Ecuador, and many additional data. This is a helpful tool for the determination of plants; it can be used in the field on laptop computers and also for the training of students before travel in tropical regions. In 2017, the collection included 27,100 images of 288 families, 1,855 genera and 4,215 species.

In 1990, we could study the elevational gradient not only on the tropical high volcano peaks of Mt Kenya and Mt Elgon but also in one of the rather untouched rainforests at Kakamega. Former co-workers of the Department of Ecology later participated in the large BIOTA consortium, where not only the dry vegetation gradients in Namibia and South Africa were studied but also (BIOTA-East) the area of the Kakamega Forest (1,460–1,760 m) in Western Kenya. Dalitz et al. (2011) provided basic data and a very valuable field guide on the woody plants of the area, with about 300 species of trees, shrubs, lianas and palms, indicating the high biodiversity but also the threats of logging and firewood collecting.

7.2 Afghanistan

Studying biodiversity in an arid country is another endeavour. After many years, in 2005, work on Afghan flora and ecology could be resumed after more than 30 years of war and destruction. It became my second home after 3 years of work, studies and teaching there. In Bielefeld, together with Clas Naumann (also infected by the "Afghanistan virus", but as a zoologist), we were able to organize an interesting symposium (Breckle and Naumann 1982) at a really bad time for the country after the Soviet occupation.

In the continental semi-desert of Afghanistan, the cold winters and the hot summers force plants and animals to use the underground. In the Dashte-Kushi, south of Kabul, we had an interesting phenomenon to observe (Breckle 1971). There were small anthills, sometimes only an opening and an underground nest of ants (*Cataglyphis bicolor*). Around them there were large circles devoid of vegetation but surrounded by a ring, about 4–6 m in diameter, of a therophytic flora rich in species and with distinctly favoured growth. In this belt, N and P content was distinctly higher than in samples from outside the belt. The additional source of nutrients is the underground waste chambers of the ants (garbage zone). Another ring, located outside the garbage zone, poor in small stones, shows vegetation more negatively influenced by the plant- and seed-collecting activity of the ants. This myrmecophilous dissemination varies within different plant species. In the course of several years, there evolves a typical weedy plant community, exhibiting the changed availability of nutrients and water. We saw a rather similar mosaic of plant-free rings later in Arizona, caused by ants (*Pogonomyrmex*). From Namibia, recently several papers described a similar pattern (called "fairy circles"), most probably caused by underground termites (Tarnita et al. 2017) as a multi-scale patterning.

Exactly at Christmas 1979, the Soviet troop invasion in Afghanistan started. Field research had been blocked for a few years even before then because of internal unrest and turmoil. After many years of war and destruction in Afghanistan, and after terrible civil war times, many of our old coloured slides of landscapes and plants

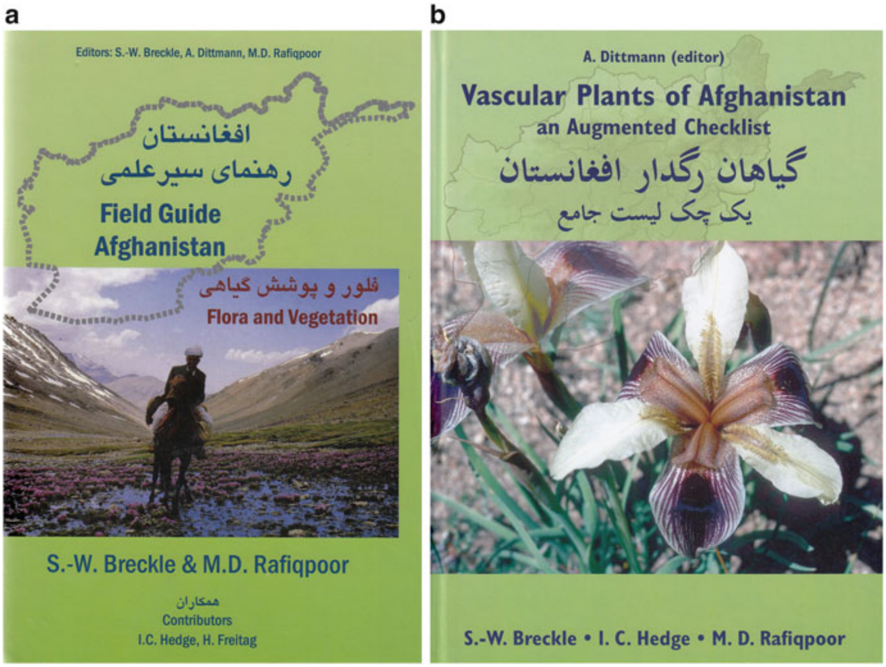


Fig. 41 (**a**) Title page of the *Afghan Plant Atlas* (Breckle and Rafiqpoor 2010). (**b**) Title page of the *Afghan Checklist* (Breckle et al. 2013)

became valuable historical documents. How were we to use them? By developing a "snowball system", after 2005 we were able to use photographs from many colleagues all over the world. This was the starting point for collecting photos for an illustrated flora. An easy-to-use botanical field guide was, for a long time, much needed. The *Field Guide Afghanistan* (Breckle and Rafiqpoor 2010, Fig. 41a) fulfilled that need for school teachers and university lecturers. It is also a basic reference source for forestry, horticultural and agricultural projects, for nature conservation and anyone interested in the very rich flora of Afghanistan. The idea of bringing together old slides – photographed by both the German team and others from Austria, Britain and Scandinavia working there during the 1960s and 1970s – had been discussed during the 6th Plant Life of South West Asia Symposium (PLoSWA) in Van, Turkey, in 2002. Modern communication facilities, especially e-mail, enabled us to complete it in a relatively short time, as well as intensive cooperation in a perfect "symbiosis" between the authors and contributors.

Many colleagues from all over the world contributed photographs, old slides (which we scanned) and digital photographs. Five thousand copies of the book were printed, with German Academic Exchange Service (DAAD) funding, to be distributed all over Afghanistan, and 500 additional copies, funded by the Sibbald Trust, Edinburgh, were distributed cost free to libraries and herbaria all over the world. The main part of this pictorial flora includes 2,000 colour photographs of approximately 1,200 plant species with short descriptions, all bilingual (in English and Dari). The general chapters give an introduction to the overall physical geography of Afghanistan (see also Breckle 2007; Djamali et al. 2012), including its geology, soils, climate and vegetation, but also the plants and their structure, morphology, anatomy, taxonomy and systematics are described.

During the acquisition of photographs, we got (from a private development project by Marga Flader) some digital photographs from a tree in a village in north-western Afghanistan and, after a short time, another one from the German Embassy in Kabul. It was immediately clear: this tree was *Ailanthus altissima*. The plant family Simaroubaceae, it turned out, had been forgotten in the Flora Iranica (Rechinger 1963 ff). Thus, after we contacted Iranian and other colleagues in the whole area, it became obvious; *Ailanthus* is very widespread (Breckle et al. 2015). An additional delivery for Flora Iranica could be prepared to make the series with 181 deliveries complete (still lacking only the pteridophytes).

Germany, especially, has long-lasting ties with Afghanistan (Breckle 2008). In 1966, the Scientific Working Group on Afghanistan (Arbeitsgemeinschaft Afghanistan [AGA]) was founded in Heidelberg by Karl Jettmar, Willi Kraus and Carl Rathjens. Coming back from Afghanistan at the end of 1969, I became a member of that group. This group organized symposia, edited books on Afghanistan and was an ideal information platform between both countries. From 1990 until 2001, I was the chairman of the group, which had more than 250 members from about 12 countries. From the beginning, there was close cooperation with the excellent Swiss archive Bibliotheca Afghanica in Bubendorf and the Swiss Afghanistan Foundation.

The next step was to give an answer to the simple-looking question: How many vascular plant species are known in Afghanistan? What proportion do we have illustrated in the *Field Guide Afghanistan* (Breckle and Rafiqpoor 2010)? It was necessary to produce a definitive checklist. All available floras and papers on taxonomy had to be evaluated. A checklist of a region enables one to quickly become familiar with the richness of its flora. Dr Souza Dias (executive secretary of the Convention on Biological Diversity, Montreal) wrote in the preface: "The book 'Vascular Plants of Afghanistan – An Augmented Checklist' (Breckle et al. 2013, Fig. 41b) provides the most accurate and up-to-date account of the plant biodiversity of this region. It complements the colourful 'Field Guide Afghanistan – Flora and Vegetation' by Breckle and Rafiqpoor (2010) during the International Year of Biodiversity".

The estimations of species numbers were about 3,500 species and 30% endemism. The more precise answer from the checklist is now approximately 5,000 species and about 25% endemism. The genus *Astragalus* has the most species, and the family Asteraceae has the most genera and species. And we know that the Hindu Kush has distinctly higher elevational belts than the Alps or the Caucasus (Breckle et al. 2017, Fig. 42).

Both books are scientifically as correct as possible on one side but also are an important tool for education on biodiversity topics for a wider audience (Breckle and

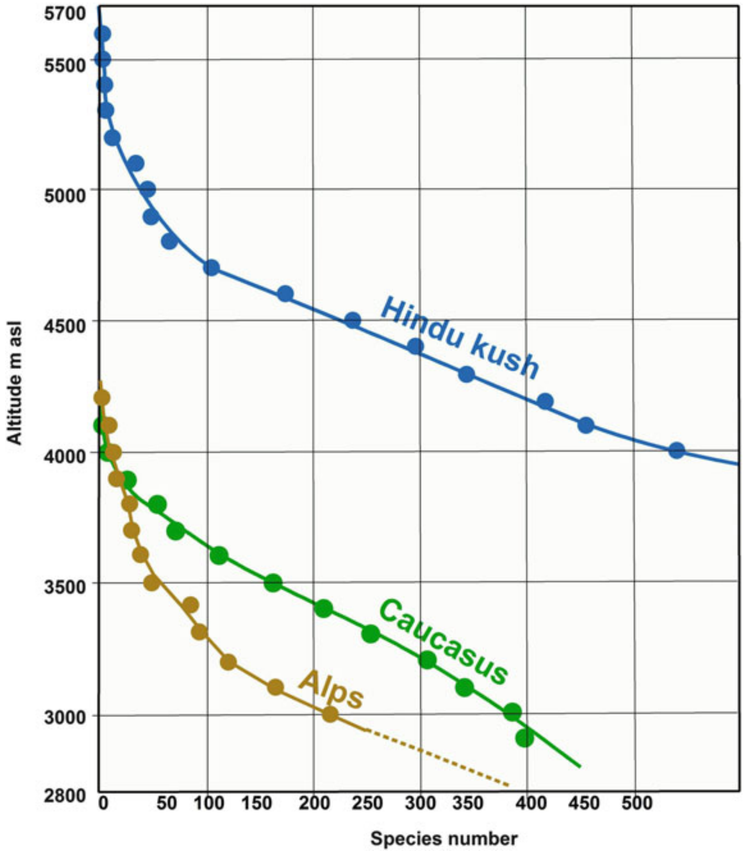


Fig. 42 Floristic "drainage" (decrease) in species numbers with increasing altitude in the Hindu Kush, Caucasus, and the Alps (Breckle and Rafiqpoor 2010; Breckle et al. 2017)

Rafiqpoor 2016; Lozan et al. 2016). Older studies on useful plants (Breckle and Unger 1977; Breckle 1979; Breckle and Koch 1982) were a good starting point.

A continuation is planned. The *Field Guide on Mosses and Liverworts of Afghanistan* is in press (Kürschner et al. 2017), a field guide on lichens is planned (Mayrhofer et al. 2019) and an updated treatise on Afghan medicinal plants is also planned (Keusgen et al. 2015), as well as a general treatise of Afghan biodiversity (Breckle et al. 2018).

8 Ecosystems of the Earth

The two volumes on the vegetation of the earth (Walter 1968, 1973, short version: Walter 1986, 1990) give, in approximately 2,000 pages, a survey of the vegetation and climate of the globe. A totally new edition, including ecological processes in the various ecosystems and ecozones, was much needed, so Heinrich Walter invited me to be a co-author. A new rather comprehensive and strictly hierarchical content of all of the necessary ecologically ranked units, and including relevant recent literature, led to the four volumes *Ökologie der Erde* (*Ecological Systems of the Geo-biosphere*) (Walter and Breckle 1983, 1984, 1986a, b, c, 1989, 1991a, b, c, 1994, 2004), including revised new editions. Mainly the third volume, with all of the Russian literature, needed another co-author after Heinrich Walter's death on 15 October 1989. Independently, we had the same solution: Okmir Agakhanjanz was the ideal partner, having been a DFG guest professor in Bielefeld in 1992 and a future close friend. His long-term studies in the Pamirs and many other Asian mountains were the incentive for the Pamir expedition in 2002 [with the help of GTZ-UNCCD (Bonn) and DAAD (Bonn) funding (Figs. 3a and 19a–d)], with all aspects of biological and geographical highlights (including Bavarian Television). All of the curious conditions and adventures of scientific work were illustrated by Agakhanjanz (2002).

In order to describe all of the various ecosystems of the climatic belts of the whole geo-biosphere, it seemed necessary not only to check all relevant literature but also to become personally familiar with most ecosystems. Examples from the tropics, lowlands, mountains and islands (see Fig. 44c) and the various hot deserts could be enlarged by experience and examples from savannah ecosystems, from the various Mediterranean biomes, from high mountains on most continents and from taiga and tundra. There are still many blank areas (on the global map) concerning our own experience. However, I am sad to say, there are increasing difficulties in studying ecological systems abroad, for political reasons and because of bureaucracy, civil wars and the ongoing destruction of natural ecosystems. Despite better possibilities to travel across continents, it has become more complicated to study natural ecosystems – often isolated in national parks – as a basis for comparison of the natural processes of ecosystems of the various zono-biomes.

Heinrich Walter had initiated a book series titled *Vegetationsmonographien der einzelnen Großräume* (*Vegetation Monographs of the Major World Regions*). The series was funded in 1965. In his survey (Walter 1976), he explained the whole concept of hierarchical ecosystems of zono-biomes, biomes and ecotones. After Heinrich Walter's death in 1989, I continued as the editor of this monograph series. The concept includes nine world regions. After volume 1 (North America, Knapp 1965), volume 2 (South American forests, Hueck 1966), volume 3 (Africa, Knapp 1973), volume 7 (North and Central Asia, Walter 1974) and volume 10 (climate diagrams of all continents, Walter et al. 1975), additional volumes to be published were volume 4 (Australia, Beadle 1981), volume 9 (Pacific Islands, Mueller-Dombois and Fosberg 1998) and volume 8 (not indicated as such: Europe, only open vegetation types, Klötzli et al. 2010). I was only partly successful in continuing this monograph series, despite many attempts to convince possible authors. Volumes 5 and 6 (East Asia, South Asia) are still lacking. The assembling of the huge existing information into an integrated comprehensive book is a major magisterial synthesis and a challenge to attempt. It requires long experience (Walter 1989).

The continuation of the aims of the AFW Schimper Foundation, founded by H. and E. Walter in 1968 to promote ecological research outside of Europe, was documented by the proceedings of the first symposium in October 1998 and a second in October 2002. From 1968 till now, almost 100 fellowships have been given. The fellows (the “Schimper Family”) have presented many interesting results of their research, which quite often were a starting point for more detailed studies. The proceedings volumes (Breckle et al. 2000, 2004) document a broad wealth of worldwide ecological studies and, in part, up-to-date research data on specific subjects.

9 Applied Biology and Ecology

On my return from Afghanistan at the end of 1969 to the Institute of Pharmacognosy in Bonn (later the Institute of Pharmaceutical Biology) it became clear that my ecological interests should be combined with the chemistry of secondary compounds and also studies on nutrients and trace elements. A heavy load of teaching on the morphology and anatomy of plants, as well as on biochemical pathways of active principles in medicinal plants, led to the edition of a textbook on *Pharmazeutische Biologie* (Kating and Breckle 1978, 1981), with several subsequent new editions – the third in 1988 and now, in collaboration with Eckhard Leistner, the 8th edition (Leistner and Breckle 1988, 1992, 1997, 2000a, b, 2008, 2014) with new authors (Drews et al.).

When I started in Bielefeld in 1979, botanical ecology was becoming a dominant topic. There were also applied projects on nature conservation, mainly documentation of specific sites for future nature protection. They were the topic of many diploma theses. Numerous phytosociological and floristic studies were carried out around Bielefeld. Often, the documentation of the ecology of a distinct area led, sometimes many years later, to the declaration of such an area as a nature reserve – sometimes with unnecessary prohibitions on entering the area, since not all official flora–fauna habitat (FFH) regions (as declared by the European Union [EU]) were really worth nature protection. Many former diploma candidates are now working at biological stations and in communal environmental administration, or have founded private consulting agencies.

This scientific curiosity was not directed only towards purely ecological problems but also towards other scientific topics. One interesting question has been how much influence on – or damage to – nature has been caused by nature sports such as orienteering, which is very common in Scandinavia.

An anecdotal event should be narrated. In 1984, the German university championships in orienteering (O) were organized by the University of Bielefeld. The sandy Senne area, with a pine forest and fossil glacial sand dune hills, was an ideal competing ground. But what would be the impacts of such an event, where runners would go all over the forests, to find controls as fast as possible with the help of a special O-map? Three control sites were mapped and photographed before and after the event (Breckle et al. 1989, 2014b).

Some weeks later, because I was responsible for the event, I got a letter, which accused me of having partly destroyed the small Ölbach Valley. Apparently this had been a small nature reserve, though it was not marked as such. Several letters went to and fro; as an ecologist I was being charged with destroying a nature reserve. Finally, it could be clarified that there was not one official indicator plate in the area that indicated the borders of the nature reserve (as is necessary according to the law), that there was no damage (the few visible steps had disappeared after a few weeks) and that in such a sandy area, disturbances from time to time enhance the biodiversity and recovery of plant species; however, they were much less than the large military tanks were doing nearby. Thus, the penalty of a 3-month jail sentence (or 50,000 DM fine) for such an offence was not imposed. The area is in close proximity to the British and German military exercising area in the Senne. It has been a military area for about 120 years and now exhibits rare flora and fauna maintained by continuous special disturbances (Breckle 1993) – maybe in future it will be part of a national park?

Long-term studies of observation squares at former control sites since then revealed that the natural dynamics are very obvious but have nothing to do with any anthropogenic influences. The number of shoots of *Trientalis* and of *Maianthemum* oscillated tremendously (Fig. 43) according to ice/rain, growth of shading *Frangula* or the natural death and decay of pine trees.

10 Teaching

The topics mentioned in Table 2 illustrate the breadth of teaching but also various research projects, which, in most cases, were characterized by an interdisciplinary approach. The philosophy behind it was the rather important feedback between field research and lab studies and controlled experiments where students could participate. The importance of such an approach was also stressed by Beck (2017).

Starting in Bonn and continuing in Bielefeld, I was always engaged in preparing textbooks and their new editions, not only in ecology (see above, Breckle 1999, 2002a, b, c, d) but also in pharmaceutical biology (Kating and Breckle 1978, 1981; Leistner and Breckle 1988, 1992, 1997, 2000a, b, 2008, 2014).

The ongoing research projects were done in close cooperation with local people and institutions. We used all opportunities to inform relevant stakeholders, to raise capacity building and to improve resource management by organizing small meetings and symposia and, of course, by participating in talks and posters at relevant

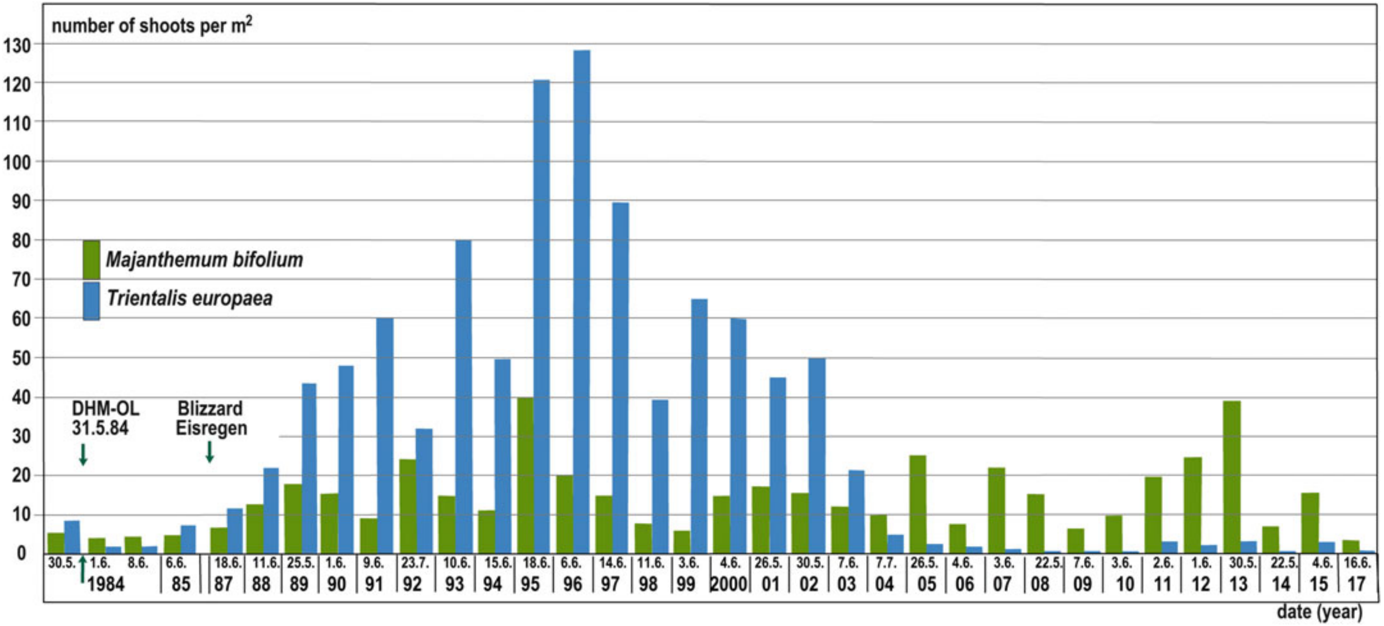


Fig. 43 Number of shoots during the last 33 years from *Maianthemum bifolium* and *Trientalis europaea* in sandy pine forest in the Senne area, Augustdorf, south of Bielefeld (Breckle and Breckle 2014) – the site of the German championships in orienteering (DHM-OL) in 1984

regional, national and international workshops and meetings (Breckle et al. 2001a, b, c, 2008, 2012; Breckle 2005b).

Since I retired in 2003, I have had more time to work constantly on specific interests. There were not only the books on Afghan flora and vegetation or new editions of textbooks, but also many older studies mainly on dry land ecology and desertification (e.g. Breckle et al. 2001a, b, c, 2008, 2012; Khan et al. 2016) and again on the effects of orienteering (Breckle et al. 2014b, Breckle and Breckle 2014) or even several editions of a basic treatise on ice skating (Breckle 2016).

11 Some Final Remarks

Ecology deals with the environment of organisms. Scientific ecology has many aspects; it depends on the scale. At the level of cells and tissues, many processes are important for the whole plant. Structure and function are closely related. One incredible type of structure is bladders in Chenopodiaceae (Fig. 44a).

At the level of the whole plant, there are fantastic adaptations to hostile environments but also aesthetic structures and an incredible variety of flowers, governing pollination and preparing for the next generation. Some plants are very common weeds, and others are extremely rare; one example is shown in Fig. 44b.

At the next structural level, very complex plant associations and their basic ecological factors can be comparatively studied from deserts to tropical rainforests (Fig. 44c).

At the next structural level, landscapes and vegetation belts are a striking feature, again demonstrating effects of ecological factors, climate, soil, etc. The treeline in mountains – under natural conditions – gives us an idea of the importance of forests worldwide. The highest treeline on the globe – that of the rosaceous *Polylepis tarapacana* on the Sajama slopes in Bolivia – is an incredible example of the struggle of plants (Fig. 44d).

Figure 44a–d is used here in a symbolic way, indicating the broad amplitude of ecology (along scales) and its fascination and beauty.

It is the privilege of university professors to work on topics that they find especially interesting and that are satisfying (at least part of the time). It is not only a job but also like a hobby. However, administration and ministries sometimes seem to have another opinion. Administration and management become increasingly dominant.

Good and basic knowledge, good education and outstanding science have to be offered to students. Information is not equal to knowledge; the latter must be followed by understanding. What can we do against the atomization of scientific subjects? Should we not always try to stay on the diagonal line in Fig. 45? Should students not be offered a broad spectrum of science in future too? University faculties are not small Max Planck Institutes with specialized research topics; they should not have only two or three main research centres. What is the important role of biology and ecology? Ecology is green; it is almost a religion, if you follow

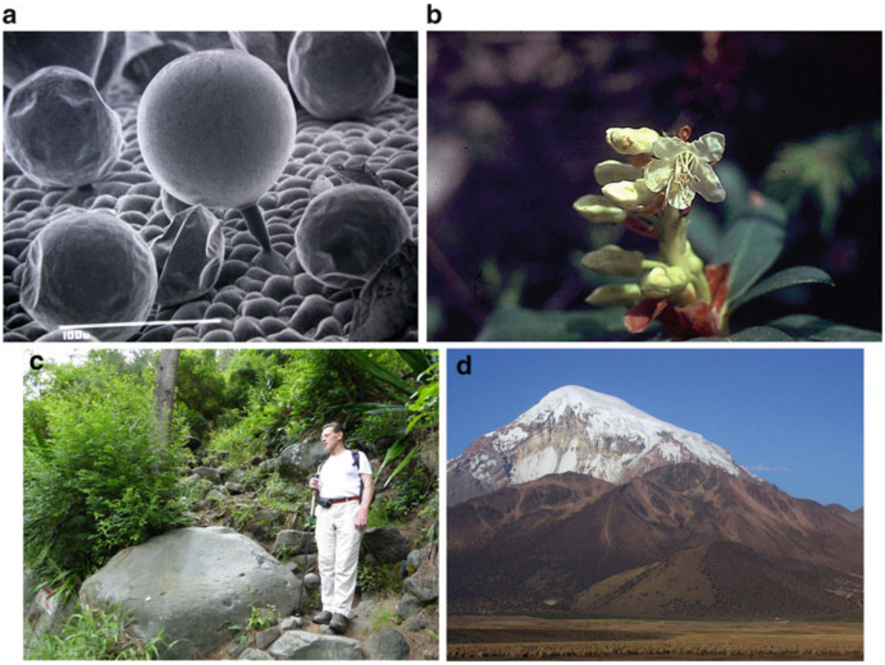


Fig. 44 (**a**) Cell level: scanning electron micrograph (SEM) from the surface of a mature leaf of *Atriplex hastata*, showing various stages of development from fully turgid bladders to totally shrunken remnants (Schirmer and Breckle 1982). (**b**) Plant level: *Rhododendron afghanicum*, an extremely rare plant, formerly known only in two localities at the south-eastern Hindu Kush treeline, now most probably extinct; the collecting history from our excursion with Ian Hedge and Per Wendelbo can be found in Larsen (2009) (photo: S. W. Breckle, 1969). (**c**) Ecosystems biocoenosis level: tropical mountain canopy at Réunion with volcanic boulders (photo: U. Breckle, 2017). (**d**) Ecosystems landscape level: arid tropics in Bolivia, altiplano on the Sajama peak (6,542 m) and the very high forest belt with *Polylepis tarapacana* between 4,350 and 4,800 m, with the highest individuals at up to 5,300 m (photo: S. W. Breckle, 2003)

statements on television and in politics. At least now everybody knows: “Trees produce oxygen!” But the stoichiometry of carbon dioxide (CO_2) and global warming is something none of the public understand. Basic knowledge of natural science topics (MINT) urgently needs to be pushed in schools.

What is kept in mind by former students? These are mainly the “big excursions” of 1 or 2 weeks, the many coloured slides in lectures and the joint efforts in ice skating. What else? Why are almost no excursions offered for students today? The advice I gave students often included the following:

> Have clear aims about what you want to achieve. Specialize as late as possible. Have at least one or two hobbies. Biologists need good knowledge and understanding of chemistry. Use the internet and software critically; use it to make work easier. Always try to optimize applied methods. If something works well, keep it; be conservative and innovative. Set scientific rationality against irrationality and esotericism, fake news and fundamentalism; it

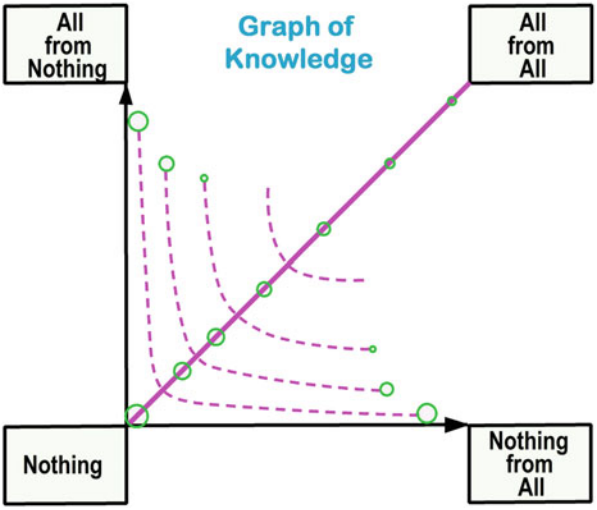


Fig. 45 Knowing and understanding everything from nothing and nothing from everything

is better to think before talking. Use international contacts and try to be able to communicate in more than one foreign language. Visit foreign countries and realize how small Germany is. Be aware of the short lifetime and the limited size of humans – in comparison with our planet, our sun, and our galaxy.

Acknowledgements Scientific curiosity has to be animated, by parents and by teachers. To both, I say thanks.

If university faculties offer excursions for students, they firstly have to be attractive and secondly worth the price. If, during the time of study, it is possible to join about ten 2-week excursions (soil science, botany, geography, geology, limnology, palaeontology, ethnology, zoology), then this is the most intensive learning process and best way of scientific mediation – though also a strain. I say thanks.

Personally, I would like to mention and acknowledge a few scientists and university teachers: Prof. Hermann Aldinger, Stuttgart (geology); Prof. Max Bense, Stuttgart (philosophy); Prof. Hellmut Bredereck, Stuttgart (organic chemistry); Prof. Heinz Ellenberg, Göttingen (ecology); Prof. Theodor Förster, Stuttgart (physical chemistry); Prof. Helmut Gams, Innsbruck (botany); Prof. Josef Goubeau, Stuttgart (inorganic chemistry); Prof. Emil Greiner, Ludwigsburg (physics); Prof. Helmut Heuberger, Innsbruck (geography); Prof. Johannes-Erich Hiller, Stuttgart (crystal chemistry); Prof. Herfried Hoinkes, Innsbruck (climatology); Prof. Karl Ilg, Innsbruck (ethnology); Prof. Helmut Kinzel, Vienna (ecophysiology); Prof. Hans Kinzl, Innsbruck (geography); Prof. Hermann Lautensach, Stuttgart (geography); Dr Werner Marten, Blanes (entomology); Prof. Wolfgang Meckelein, Stuttgart (geography); Prof. Otto Pflugfelder, Stuttgart-Hohenheim (zoology); Prof. Arthur Pisek, Innsbruck (ecophysiology of plants); Prof. Hans Pitschmann, Innsbruck (botany); Prof. Herbert Reisigl, Innsbruck (botany); Prof. Ernst Schlichting, Stuttgart-Hohenheim (pedology); Prof. Maximilian Steiner, Bonn (pharmacognosy); and Prof. Heinrich Walter, Stuttgart-Hohenheim (geobotany/ecology). I say thanks.

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I never tried to publish in nature or science or sought impact factors. But often, over the years, we received complimentary comments. Senckenberg's director (Dr Mosbrugger) wrote concerning our *Field Guide Afghanistan* book: "a marvellous book, even if there are no impact- or Hirsch-factors improved, this book has certainly a much longer value than most of the Nature or Science papers". I say thanks.

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