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ZONATION AND ESTABLISHMENT OF VEGETATION IN SELECTED UNINHABITED EGYPTIAN AND SUDANESE OASES

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SUMMARY

Flora and vegetation of uninhabited Egyptian and Sudanese oases have been surveyed to obtain more knowledge about their groundwater-dependence, distribution and establishment. Similarities in the floristic composition and distribution pattern are assumed to be dependent on the gradients of salt-contents in soil, depth of groundwater table and additionally on salt-tolerance, reproduction behaviour and development of different root systems of the taxa concerned. The vegetative reproduction has an essential function for the preservation of the oases vegetation. Under extreme arid conditions the generative reproduction takes place after sufficient rainfall. Germination and stable establishment of species on the outer margin of the oases need a larger amount of rainfall than the vegetation in the centre.

ZUSAMMENFASSUNG

Flora und Vegetation unbesiedelter ägyptischer und sudanesischer Oasen werden im Hinblick auf ihre Grundwasserabhängigkeit, Verbreitung und Etablierung untersucht. Die Übereinstimmungen in ihrer floristischen Zusammensetzung und zonalen Gliederung werden im wesentlichen zurückgeführt auf die Versalzungs- und Grundwasserabstands-Gradienten sowie auf Unterschiede in der Salztoleranz, dem Vermehrungsverhalten und Bildung der Wurzelsysteme der beteiligten Taxa. Die vegetative Vermehrung ist von primärer Bedeutung für die Erhaltung der Oasenvegetation. Unter den extrem ariden Bedingungen ist eine generative Vermehrung nur nach ausreichendem Regen möglich, wobei Arten am Rande der Oasen höhere Niederschläge zu ihrer Etablierung benötigen.

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1 INTRODUCTION

Althoug some investigations have been carried out on the distribution of vegetation in the large oases of Egypt, e.g. Kharga and Dakhla (MIGAHID et al. 1960, ABU-ZIADA 1980), the results have been inconclusive regarding the pattern and process of groundwater-dependent natural vegetation. Especially the question of natural vegetation zonation for large oases which contain historical settlements cannot be answered due to the fact that oases vegetation have been adversely affected by agricultural measures (KASSAS 1971, 491). A belt of waste land now very often surrounds this type of oasis and characterizes the outer vegetation border.

In order to obtain more knowledge about the distribution and establishment of more or less unaffected groundwater-dependent vegetation under extreme arid conditions (episodical rainfall with an annual average of <1 mm in the central parts of the Western Desert and appr. 10 mm in the northwestern research areas of Egypt and northern parts of Sudan), research has been carried out in selected uninhabited Egyptian and Sudanese oases. The data were collected during several field trips, esp. in March/April 1985 between the Qattara depression and the Abu Tartur plateau and in February/March 1984 to S-Egypt and the northern part of Sudan [1].

2 MATERIALS AND METHODS

For purposes of comparison it is first necessary to briefly describe different types of vegetation distribution in the desert. Generally, rainfall- and groundwater-dependent vegetation can be separated into two groups (tab.1). One type of vegetation occurs

(A) where groundwater reaches the surface or

(B) where groundwater is more or less near the surface.

A second type of vegetation occurs as accidental vegetation as defined by KASSAS (1952), where an accumulation of episodical rainfall builds a temporary water body under the surface, and where the moisture is available to the root systems of perennials and ephemerals during their growth cycles.

Oases selected for this study had a clearly recognizable centre and a gradient of decreasing groundwater closeness to the surface could be hypothesized. Two oases with open water in their centre and another two with groundwater more or less near the surface were chosen. An artificial oasis of northwestern Egypt (cp. fig.1) was investigated for comparison.

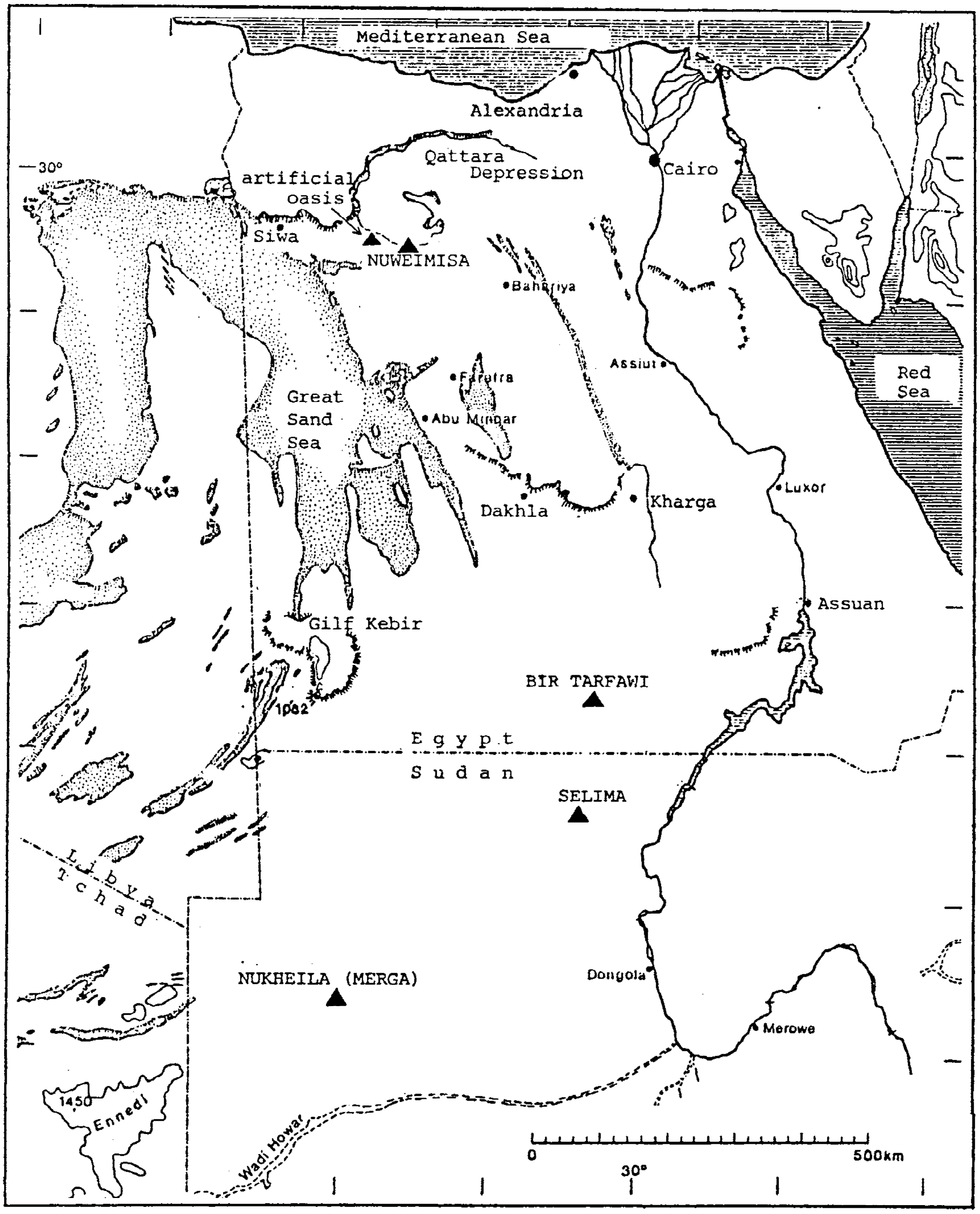
The taxonomic nomenclature is mainly taken from TÄCKHOLM (1974), the *Tamarix* spp. were determined according to BAUM (1978) and the method of vegetation studies is adopted from BRAUN-BLANQUET (1964) and WHITTAKER (1982).

The vegetation relevés were distributed along transects which were laid from the outer margin of the oases to the centre. The sample plots were generally not located in homogeneous vegetation stands as required by the school for BRAUN-BLANQUET, but were located between the transition spaces of different populations.

3 RESULTS

The oasis richest in species and the most distinctive zonation of vegetation is **Nukheila** (Merga) in the northwestern part of Sudan (tab.2). Compared with the other investigated oases, the above mentioned is located in the most southern area with sporadic summer rainfall. The vegetation outside of the depression is mostly accidental and occurs in

[1]The investigations were carried out within the Special Research Project "Geoscientific Problems in Arid Areas" (SFB69), supported by the German Research Foundation.



▲ Investigated oases in Egypt and in the northern part of Sudan

Figure 1: *Sites of the investigated uninhabited oases.*

Type of vegetation	groundwater-dependent permanent vegetation (A)	groundwater-dependent permanent vegetation (B)	rainwater-dependent accidental vegetation
Water supply	groundwater reaching the surface, oases with lakes, water pools	groundwater more or less near the surface oases with open water, often with wells	storage of rainfall as surplus water in sediments, above clay layer (perched groundwater), etc.
Distribution of vegetation	contracted vegetation, clearly recognizable centre and zonation, shallow depressions, between the deepest point and the outer margin of the oases	mainly contracted vegetation often without zonation, monotypic stands, sometimes single chamae- or phanerophytes, not strongly bound on depressions	mainly contracted vegetation patches in runnels, old dunes with coarse sand, sand filled notches and crevises with impermeable underground
Establishment and life forms	perennials (eventually after rainfall events annuals), in the immediate vicinity of the open water probably propagation by germination without precipitation and at the outer margins establishment of vegetation only after rainfall events, normally vegetative reproduction	perennials (eventually after rainfall events annuals), germination and establishment only after sufficient rainfall, and after the roots have reached the capillary fringe of the groundwater, reproduction of the vegetation mainly vegetative	perennials and ephemerals grow after occasional showers and perennials continue to grow forweeks to several years until the plant available water-content is used up by the root system

Table 1: *Types of vegetation distribution in the extreme desert of Egypt and N-Sudan.*

shallow depressions and runnels. The species found are *Cornulaca monacantha* (mostly dead), *Stipagrostis acutiflora* (only few living individuals), *Stipagrostis vulnerans* (dead) and very rare *Fagonia arabica* (flowering). The latter points to a slight increase of rainfall. This is confirmed by the presence of some Sudanian floral elements as *Capparis decidua, Acacia ehrenbergiana* and *Maerua crassifolia*, which appear in great distance of the large Nukheila-depression in lower playas and very often in rock crevices.

The difference in altitude between the lake surface and the outer margin of the oasis vegetation is approx. 10 m and the groundwater at the real depression "appears to be no more than 1.5 m below the floor and varies from brackish a few metres from the edge of the lake to quite fresh (water) elsewhere" (HAYNES et al. 1979, 441).

In the immediate vicinity of the lake shore, *Phragmites australis ssp. altissimus* and *Phoenix dactylifera* dominated in the vegetation. *Phragmites* built a very dense fringe and reached nearly 15 m into the more shallow water on the western site of the lake. In this high density the plants grew over 4 m tall. The most common companion of the reed, *Phoenix dactylifera*, which occurs mainly 0.5 to 1.5 m above lake level was represented as well by a large number of young plants. Although this species had its centre of distribution at the deepest points of the depression, single species are scattered between shallow dunes in the southeastern area 5 to 8 m above lake level. Very few palms in the shallow water near the

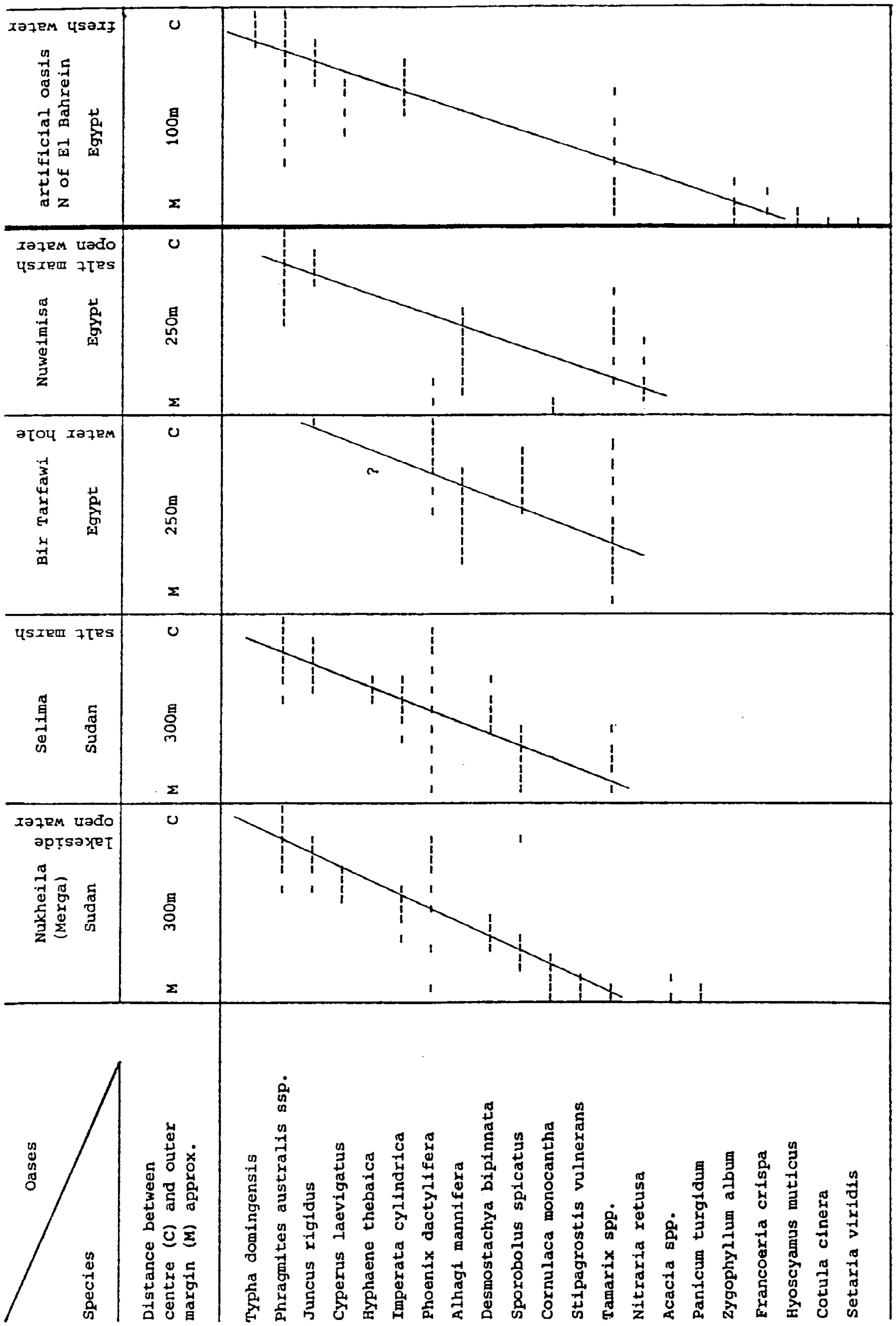


Table 2: *Distribution and zonation of plants in the selected uninhabited oases of Egypt and N-Sudan.*

shore indicated variations in the ground water level, as HAYNES et al. reported in 1979. The subsequently following species on the western transect *Juncus rigidus* and *Cyperus laevigatus* occurred in the moister conditions of the sea shore, where the salt crust was nearly 3 cm thick. The grasses *Imperata cylindrica* and *Desmostachya bipinnata* were recognized as clearly avoiding the gleyic solonchak with salt crust.

From the following species only *Sporobolus spicatus* (which could additionally be found as a single tussock on a dune reaching to the eastern lake shore), *Tamarix* and *Acacia raddiana* were evidently connected to the depression.

Selima, the largest oasis in northern Sudan, had no water pools in its deepest areas, but salt marshes. This area was covered almost completely by *Phragmites australis*, reaching heights of around 5 m in its most dense stands. On smaller openings with less reed density, *Juncus rigidus* was present. The groundwater level in the area of the *Juncus*-stands was appr. 40 cm below the surface. Palm groves with *Phoenix dactylifera* and *Hyphaene thebaica* were restricted to the main distribution area of *Phragmites* and several young plants could be found there as well. *Hyphaene* kept away from the moister soil conditions and settled on areas with more than 150 cm above the groundwater table. They could not, however, be found with single individuals of *Phoenix* on the outer margin of the oasis.

Although the halfa-grasses *Imperata cylindrica* and *Desmostachya bipinnata* occurred in the same area, the latter grew on shallow dune ridges and the former was mainly distributed in the spaces between the shallow dunes.

Towards the periphery of the oasis the landscape rose slightly to reach the surrounding dunes and sand formations. The outer margin of the oasis, covered sporadically by vegetation, was approx. 10 m above the deepest points of the depression. The area between the outer margin of the oasis and the *Imperata cylindrica*-stands was occupied by large *Sporobolus spicatus*-tussocks and *Tamarix*-hillocks. The phytogenetic sand mounds of *Sporobolus* were more oriented to the deeper parts and interrupted in a mosaic pattern by large *Tamarix*-hillocks with a diameter of sometimes 15 m and a height of 5 m.

The small S-Egyptian oasis **Bir Tarfawi** is located in the centre of a morphological depression near the edge of basement outcrops. This oasis was characterized by large *Tamarix*-hillocks reaching a height of sometimes 12 m and a diameter of nearly 40 m. A palm grove in the centre of the oasis marked the deepest point of the depression (fig.2). A small artificial water hole was located in the area of the palm grove indicating a groundwater table 70 cm below the surface in November 1982. Directly at the waterhole with favourable moisture conditions a small *Juncus rigidus*-stand could be observed.

It can be assumed that a variation of the groundwater table is present, because measurements during spring of 1986 indicated a depth of 40 cm below the surface (U. SCHNEIDER, unpublished data).

Near the *Juncus rigidus*-stand, extensive *Sporobolus spicatus*-hummocks formed large polycormons, which reached into the belt of *Alhagi mannifera* plants, sometimes displacing this species. *Alhagi* covered large areas between the *Tamarix*-hillocks and often reached the lower parts of its dead hillocks. The frequent occurrence of fruit and leaf rem-

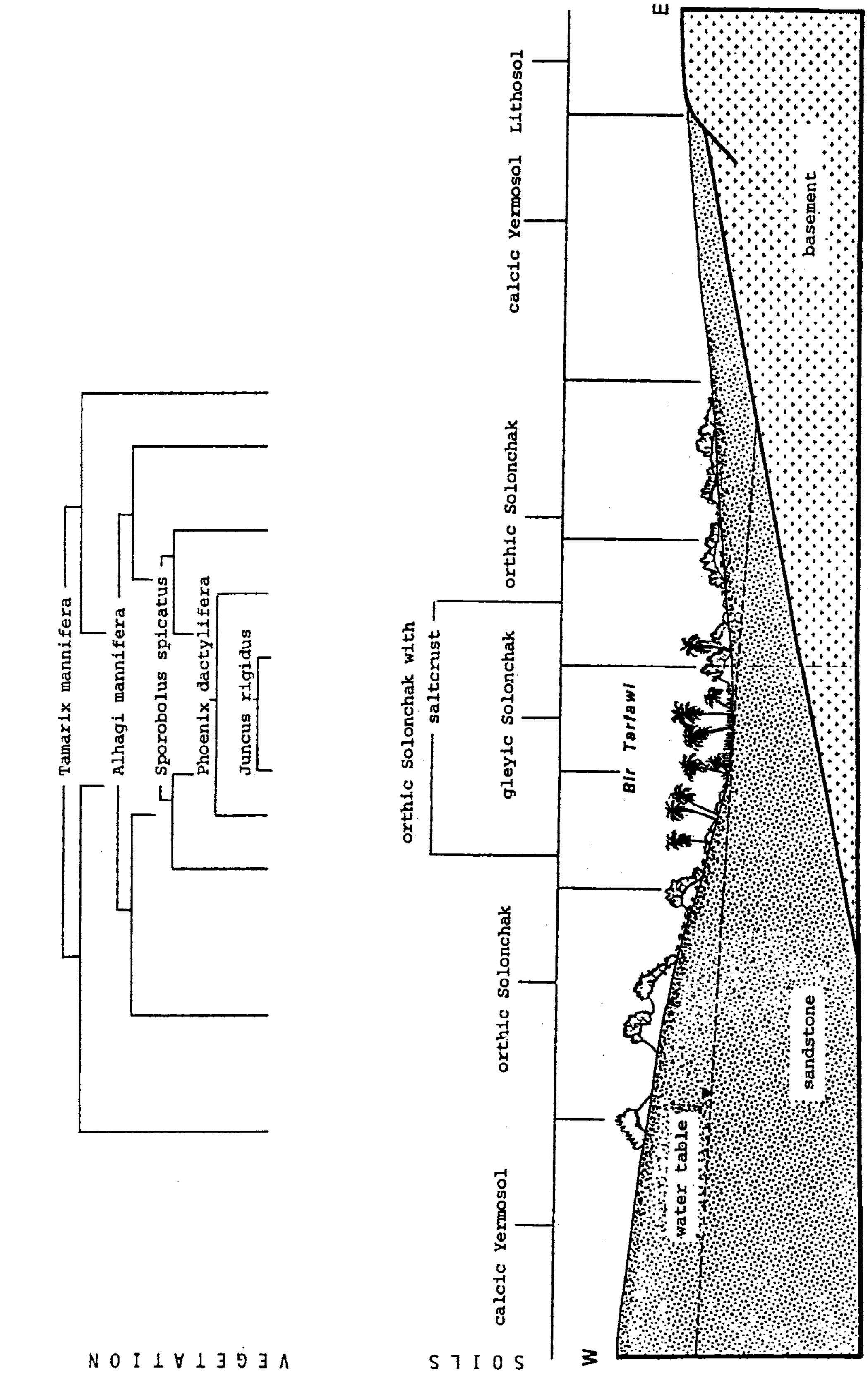


Figure 2: *Plant-soil-zonation of the uninhabited oasis of Bir Tarfawi, S-Egypt.*

nants of *Hyphaene thebaica* led to the assumption, that this species was established in the oasis of Bir Tarfawi as well as in the neighbouring oases (BORNKAMM 1986). The differences in altitude between the deepest point near the water hole and the outer margin of the oasis was approx. 8 m.

Nuweimisa as the northern most oasis with groundwater-dependent vegetation taken for comparison, is located in the northwestern part of Egypt and belongs to the chain of oases at the southern edge of the Qattara-Depression near the oases of Sitra and Bahrein with its large lakes. The centre of the investigated oasis was characterized by a broad saltmarsh with a mosaic pattern of shallow brackish water and sand mounds.

The surveyed transect at the southern part of the oasis included only the edge of the salt marsh and the outer belt of the vegetation. The salt marsh was occupied by a homogeneous *Phragmites australis*-stand. A single species of the hydrohalophyte *Arthrocneum glaucum*, growing on a shallow sandy mound, should also be mentioned here.

The edge of the *Phragmites*-stand with shallow mounds of well moistened sand supported a rich population of *Juncus rigidus*, which was sharply restricted by a steep sandy shore line. Like a belt, *Tamarix*-shrubs appeared immediately after *Phragmites* and had their main distribution area on the shore line with deep sand strata. *Alhagi mannifera* occupied only the sandy places approx. 1 m above the salt marsh level and covered the area between the large *Nitraria retusa*-hillocks with a height of 3 m and a diameter of 15 m. Very seldom *Tamarix mannifera* was present at the periphery of the oasis. The outer most margin of the oasis was characterized by small palm groups of *Phoenix dactylifera*, which grew in shallow hollows in the sandy plain.

Few individuals of *Cornulaca monacantha* reached the outer belt of the groundwater-dependent vegetation and a groundwater contact of this normally accidental vegetaseemed possible.

For comparison with the above mentioned groundwater-dependent vegetation, some investigations were carried out on flora and vegetation of an **artificial oasis** north of the above mentioned oasis of Bahrein. The vegetation, which had been established after groundwater drilling in 1971 by the General Petroleum Company of Egypt, is located in a shallow depression on coarse sandy soils and was supplied continuously by flowing artesian well water. The vegetated area was 1.2 km to 0.2 km with a north-south extension and a discharge pipe at its northeastern edge.

Dominant components of the vegetation were *Phragmites australis*, which covered the whole centre of the oasis and *Tamarix mannifera* at the outer margin, forming a high belt of shrubs with tree-like character. Several young tamarisk plants and seedlings were found. Considerably less individuals were found of the tamarisk *Tamarix passerinoides* which occurred sporadically in the innermost parts of the shrub belt.

A few plants of *Typha domingensis ssp. australis* were distributed only in the immediate area of fresh water runnels.

The transition zone between *Phragmites* and *Tamarix* near sporadically flooded hollows with a distinct salt crust, supported *Juncus rigidus* and *Cyperus laevigatus* in a mosaic pattern of distribution. On the sandy border of the shallow hollows, *Imperata cylindrica* grew with a slight density.

On the outer margin some patches of ephemeral vegetation were distributed once more in slight hollows. The establishment of this vegetation had probably taken place after rainfall on slightly moistened soils in deeper layers, produced by the artificial spring. The presence of *Francoeuria crispa, Cotula cinera* and *Seteria viridis* indicated a low salt content in the soil.

4 DISCUSSION

The ring-shaped vegetation formations in NW-Egypt resulting from different habitat gradients has been described in detail for accidental playa vegetation (KEHL et al. 1984) but also as a consequence of gradients in salinity and depth of groundwater (KASSAS 1971, 493, ABU-ZIADA 1980, 286–297). These authors have given detailed reports on vegetation of small lakes and salt marshes of Egyptian oases, esp. regarding the concentric zonation of halophytic community types. Although this type of vegetation of the large oases of Kharga and Dakhla has been strongly influenced by man and his agriculture over a long period of time, the communities of dry salt marshes constitute more than 80% of the natural vegetation of these oases (ABU-ZIADA 1980, 292) and show essential similarities to the investigated oases presented in this paper.

A floristic and structural comparison of the analyzed oases of Egypt and Sudan shows a remarkable coincidence in the sequence of species and their zonational pattern (tab.2) . The groundwater-dependent perennial vegetation can be classified as salt-tolerable to hydrohalophytic, as the swamp and shore vegetation with *Phragmites, Juncus* and *Cyperus* which occurs on gleyic solonchak mainly covered by a thick salt crust. However, as STOCKER (1927/28) already stated for the Wadi Natrun in northern Egypt, the salt saturation of the groundwater in slightly deeper soil layers of *Juncus* -stands may be only 0.9% at 30 cm below the surface. In addition to the salt accumulation as a result of continuous evaporation of groundwater, the plants themselves enrich the soil surface with a considerable amount of salt in their immediate vicinity. As a reaction on the presence of excess salt in the soil environment, some plants, e.g. *Juncus rigidus* and *Tamarix spp.*, are able to drop off parts with high salt content (CHAPMAN 1975, 9) or to control high salt contents in the root medium with secretion. BERRY (1970 inTHOMPSON 1974, 134) has reported that the salt concentration of the secreted fluid produced by the leaf glands of *Tamarix* is 50-fold higher than the root medium.

The described sequences of population from the wettest area in the centre of the oases with extremely high salt contents on the soil surfaces to the drier surrounding landscapes with increasing depth to groundwater lead to the question of the possible establishment and distribution of the species.

As RODEWALD-RODESCU (1974) already pointed out, *Phragmites australis* has a wide ecological range and has been found to be a very important component in the vegetation of all surveyed oases, except in Bir Tarfawi. In the oasis of Nukheila, the reed reaches far into the shallow water of the lake, and is established in a sediment with a relatively low salt content compared with the open water (personal communication, PACHUR 1986).

With regard to a generative reproduction of *Phragmites australis*, excessive salt saturation decreases the germination (RODEWALD-RODESCU 1974, 85). Germination experiments under field conditions with seeds from the reed stands of "Tall Grasses" near Bir Safsaf appr. 35 km SE of Bir Tarfawi seem to confirm these assumptions (SCHLICHT & SCHNEIDER, unpublished data). Since no young plants have been found in the oases under investigation, it must be assumed that *Phragmites austalis* reproduces itself vegetatively by rhizomes, wich are able to surmount large distances by creeping under the surface.

A germination of the date palm *Phoenix dactylifera* is possible in the same habitat, where *Juncus rigidus* has its highest density (cf. DANIN, 1983, 120, regarding the distribution of the date palm on the Sinai). Beside a possible germination of the date palm under superficial moist conditions produced by a high water table, *Juncus rigidus* is, apart from a primarily vegetative reproduction, also able to establish seeds under these conditions. An important preconditions is, however, a slightly saline water content of the germination locality (DANIN 1983, 122). The same can be assumed for *Cyperus laevigatus*. STOCKER (1928) suggests that germination can take place between salt crusts which have been broken by animals.

However, for *Juncus* and *Cyperus* as well as for *Phragmites* it can be assumed that generative reproduction seldom takes place, due to extremely unfavourable germination conditions. The reproduction and distribution of these plants nearly always takes place in the vegetative way by rhizomes creeping with numerous stems in moist sandy and salty soils. In addition to possible germination conditions mentioned by STOCKER, sufficient precipitation would lead to a decrease of salt concentrations in the upper soil layers.

For the species outside of the highly groundwater-moistened soils, an establishment and generative reproduction can exclusively take place after sufficient rainfall has led to thorough moistening of the soil layers. The reproduction of already established plants is only possible during periods of non-precipitation in the vegetative way. *Imperata, Desmostachya, Sporobolus* and *Alhagi* possess the ability to secure their establishment through a network of stolons and rhizomes for a long period of time.

The two "Halfa-Grasses" *Imperata cylindrica* and *Desmostachya bipinnata* (FLORA OF EGYPT 1973) can be considered as facultative halophytes (ZOHARY 1973), since both mainly occur on sandy soils with a slight salt content, but also in salty marshes covered by sand. Where *Imperata* sporadically contacts gleyic solonchak with *Juncus* or *Cyperus*, the plants are highly necrotic with low cover values. The restriction of the *Imperata*-population on higher levels is causes by the incapability of this species to reach the capillary fringe of the groundwater with its roots—in order to exist, it requires water, which is fairly close to the surface (RIKLI 1943, 321/323). The growth zone of *Imperata* in the oasis of Nukheila extends over approx. 1.5 m to 3 m above lake level and has its highest density at 2 m above lake level.

Desmostachya bipinnata, which covers nearly the same growth zone as *Imperata*, has thick creeping rhizomes with a deep and extensive root system. Although this grass reaches slightly higher levels above groundwater in the oases of Nukheila and Selima (tab.2), their differences in distribution on the surveyed transects are only minimal. The observation of DANIN (1983, 49) that *Desmostachya* in the Arava Valley occurs together with the salt shrub *Nitraria retusa* on salt marsh edges with sandy soils (cf. BORNKAMM & KEHL 1985) or on formerly cultivated lands in oases (FLORA OF EGYPT 1973) confirm the observations, that this species is not strongly bound to groundwater very near to the surface. However, its salt resistance is relatively high, since it often forms an association with the above mentioned *Nitraria retusa* or *Zygophyllum album* (ZOHARY 1973, 224).

The *Sporobolus*-stands, wich reach far into the *Juncus rigidus* zone at Bir Tarfawi (cp. schematic cross section in fig.2) are more abundant in the periphery of the Sudanese oases (tab.2). The ring-shaped polycorms with a diameter of up to 20 m observed at Bir Tarfawi, are not present in the other oases investigated. The highly salt-resisting stiff perennial grass is strongly bound to sandy places, especially where the sand is firm and salty, but occurs also in dune areas as a valuable sand binder (BATANOUNY 1981, 197). *Sporobolus* obviously marks the transition zone of sandy orthic solonchaks to moister orthic solonchaks with salt crusts. In the oasis of Bir Tarfawi this species is distributed between 1 m to 5 m and in the oases of Nukheila and Selima between 3 m to 7 m above the lowest points of the oases depressions, but occurs occasionally on soils with a high salt content, if sufficient sand supply is available for sand accumulation around the tussocks (e.g. Bir Tarfawi in fig.2).

In the oases of Bir Tarwafi and Nuweimisa, *Alhagi mannifera* occupies the groundwater-remote sandy orthic solonchaks. In Bir Tarwafi the growth zone reaches higher levels than *Sporobolus* and into the main distribution area of the *Tamarix*-hillocks. The extremely salt-tolerant and deep rooting *Alhagi mannifera* can reach a depth as great as 20 m (KASSAS 1955, 57) and is well distributed on deep alluvial soils. Its absence as a mainly irano-turanian floral element (FLORA PALAESTINA 1972, 112) in the Sudanese oases has to be seen in its natural distribution boundary in SE-Egypt (FRANKENBERG & KLAUS 1980).

The remarkable deep rooting capability of *Alhagi mannifera* is restricted to its natural distribution area with less extreme climatic conditions, since in Bir Tarfawi this species occupies a drier belt of 1 m to 6 m above ground-water level and in Nuweisima up to 10 m above the salt marsh.

Tamarix mannifera grows as a shrub in the inner part of the oases (e.g. Bir Tarwafi and Selima) in shallower hillocks but on the outer margin with enormous phytogenetic hills.

Apart from Bir Tarfawi, the oases of Nukheila and Selima have shown very old *Tamarix*-hillocks. In Bir Tarfawi, two smaller dark green and extremely dense *Tamarix mannifera*-stands without sand accumulations have been found in a shallow isolated depression.

Tamarix has an extensive deep rooting system like *Acacia*. During the construction of the Suez-Canal, roots of *Tamarix* were found in a depth of 30 m below the surface. In addition the lateral root system reaches a distance of approx. 50 m from the plant itself (KAUSCH 1959, 8, 30).

BAUM (1978, 13) assumes that the reproduction of *Tamarix* by seed germination is restricted and bound to special conditions. However, high temperature and a favourable water supply with fairly fresh water, as in the artificial oasis north of Bahrein or at the Lake Nasser shore near Sarra West (personal observations in April 1986), allow *Tamarix* a successful establishment by seed germination in a relatively short period. Without open-water conditions and under extreme aridity, vegetative reproduction is most important. The side roots are capable of producing adventitious buds when the plant is buried by shifting dunes (BAUM 1978, 3). Extensive complexes of *Tamarix*-hillocks in the oasis of Bir Tarfawi may represent large polycorms with an enormous age.

Radio-carbon studies for age determination by PACHUR(1974, 34) on dead *Tamarix*-hillocks with a height of 7 m in the central Sahara (Serir Tibesti) have pointed to a growth period of approx. 700 years. The detritus-age of leaves and branches of the top of the investigated hillock was 1625 ± 145 B.P. Furthermore, according to these determinations, it can be assumed that the life cycle of these plants could have been even longer due to the erosion of the hillock between 1625 ± 145 B.P. and the time of the investigations.

After the *Tamarix*-plants have been established as a result of strong rainfall events, the growth culmination and the potential age of the plants depend on their ability to reach the capillary fringe of the groundwater (compare fig.3). Otherwise the plants are dependent on sufficient rainfall, which occasionally accumulates in the sediments. Although these plants can resist drought for as long as 20 to 30 years (EL-HADIDI 1980, 350), they are rainwater-dependent and must consequently be named accidental vegetation (cp. tab.1). The groundwater-dependent vegetation has essentially more stable growth conditions and a disturbance of already established plants is possible only by variations in the groundwater level or by extreme changes in the surface conditions.

With KAUSCH (1959) it can be assumed, that *Tamarix* just as *Acacia* is able to withstand variations in the soil moisture conditions only if they have developed an extensive deep root system. Germination and establishment of both genera at the groundwater remote areas can only take place after very sporadic and sufficient rainfall events. Although both genera, as the other elements of the oases, occur on relatively salty soils as for example orthic solonchaks, the germination takes place only under conditions of reduced salinity, just as it is known from obligate halophytes (CHAPMAN 1975).

5 CONCLUSIONS

As described in this paper, the permanent vegetation of the oases is at present clearly bound to surface-near groundwater and owes its establishment primarily to preceding episodic rainfall events. Vegetation in the outer margins in contrast to the inner areas needs a larger amount of rainfall as an absolute precondition for germination and development. Most of oases species are endowed with very effective vegetative reproduction systems of rhizomes, stolons or roots with adventition buds in order to survive.

The zonation of the vegetation and the similar distribution of the same genera of the investigated oases give a good idea of the site factors, distributed between the deepest point and the outer parts. Besides the physical features of the soils, the groundwater-nearness and the salinity of the soils are the most important factors

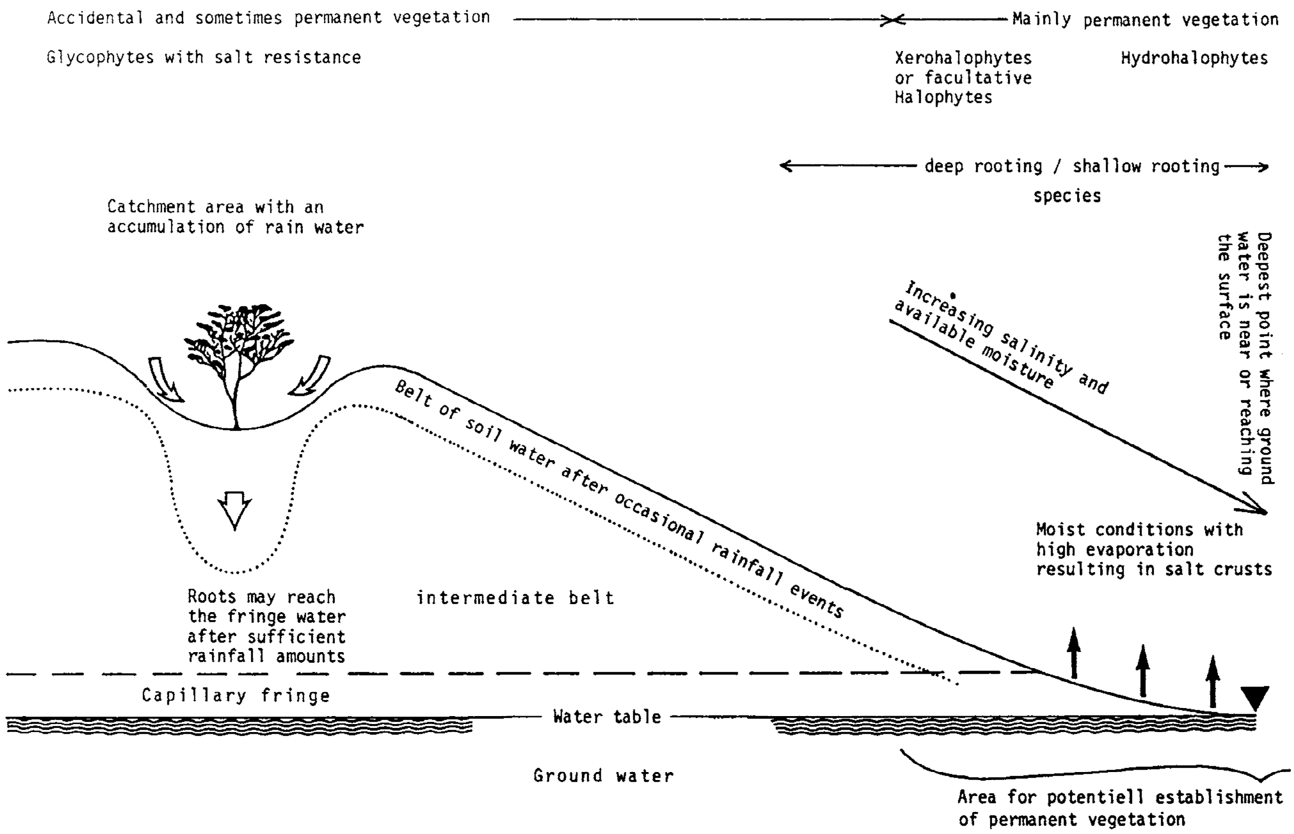


Figure 3: *Schematic cross-section of habitat conditions for plant establishment in oases.*

for plant growth. In extreme arid conditions the prompt germination capability after sufficient rainfall and the rapid development of an extensive deep rooting system are essential. High salt content of the surfce layer, even of wet soils, permit germination only under conditions of reduced salinity caused by a considerable dilution of the soil solution.

The decreasing salinity of the soils toward the periphery of the oases goes along with increasing depth-to-groundwater (fig.3) . At the outer margin only quick germinating species with deeply penetrating roots with slight salt resistance are able to reach the capillary fringe of the groundwater. A possible stable establishment or generative reproduction of halophytic plants on sites near the groundwater level is more likely to succeed than on higher levels for facultative halophytes.

Although perennial desert plants normally have the capability of fast germination and are able to reach moister soils in deeper layers with an extensive root system, the distance between the soil water caused by unfrequent rainfall events and the capillary fringe of the groundwater is the main obstacle to achieve permanent establishment. Investigations of KAUSCH (1959) lead to the assumption that a locally and temporarily sufficient water supply in the upper soil layers, allow plants to surmount the intermediate belt between soil water and fringe water. Thickness of the dry horizon is certainly the determining factor in this case.

The high duration of life time and the disappearance of young individuals of

Tamarix and *Acacia* species in the oases of Bir Tarfawi, Selima and Nukheila, indicate the scarcity of favourable rainfall.

Structure and dynamic of the floristic composition of the vegetation over a certain period of time result in a characteristic stable population diversity. A slight decrease of the groundwater table would affect the vegetation of the oases dramatically. Firstly, the decrease would cause the hydrohalophyte components, which are restricted to favourable moisture conditions, to disappear. Subsequently, after this phase of desiccation, the less deep-rooting species would lose their growth conditions. Finally plants with more extensive root systems, as for example *Tamarix* and *Acacia*, would be the last to succumb.

Dead or isolated enormous *Tamarix*-hillocks in playas or morphologic depressions could show the evidence of a moister climatic phase in the latter stages of the Holocene period, as GABRIEL (1986) supposed. The reconstruction of paleohistoric lakes and their surrounding vegetation, not taking into account the groundwater table (KRÖPELIN 1985, 82, 162), shows broad similarities in floristical composition of the investigated oases, although the glycophytic components are more prevalent (NEUMANN 1986, 12).

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