# Dynamics of vegetation development on drained peat soils of the Hula Valley, Israel

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## SUMMARY

Lake Hula and its neighbouring peatland in the upper Galilee, Israel were drained during the 1950s. For about 40 years after drainage most of the area was under continuous intensive cultivation with rain-fed winter crops and irrigated summer crops. In 1994 an area of about 110 ha of mainly peat soil was re-flooded and 350 ha surrounding it were partly taken out of intensive agricultural use. The surrounding area was still cultivated under rain-fed conditions in the cool winter season, but left fallow during the hot, dry summer. The summer vegetation was mowed periodically to promote the development of a continuous sward cover for recreation and control of wind erosion. The goal of this research was to study the relationship between dynamic changes in the soil and water conditions and the composition and species distribution of the spontaneous summer vegetation. During four consecutive years the vegetation dynamics were characterised by increasing dominance of *Cynodon dactylon* and *Sorghum halepense*. *Cyperus rotundus*, which was common under irrigated cultivation, partly disappeared under the new non-irrigated regime. The density and growth rate of the vegetation mainly reflected differences in the water table depth, which varied between 0.5 m and 3 m. Three years after re-flooding, soil salinity was high in areas where the water table was higher than 0.5 m and in dry patches where almost no cover of vegetation was found. In these sites the concentration of mineral nitrogen (N-$NO_3$ and/or N-$NH_4$) was especially high. A continuous vegetation cover developed on the peat soil in areas where the depth of the water table was between 1 m and 2 m. Mowing the vegetation periodically in summer suppressed the growth of tall, weedy species and promoted the dominance of *Cynodon dactylon* creating a dense, productive sward.

**KEY WORDS**: *Cynodon dactylon*, management, peatland restoration, soil moisture, soil nitrates**.**

## INTRODUCTION

The Hula valley is situated in the upper Jordan catchment near the northernmost extremity of the Syro-African rift valley. Before 1950, the valley consisted of a lake and peatland which together covered 4,000–6,000 ha, depending on the annual precipitation. Before drainage the main swampy area was dominated by a virtually impenetrable stand of *Cyperus papyrus* L. (Washbourn & Jones 1936, Oppenheimer 1938, Jones 1940), growing mainly on peat and peat-derived soils (Zohary & Orshansky 1947). The swamp was intersected by channels and pools that carried water into the lake from three tributaries of the River Jordan.

During the 1950s the lake and the swamp were drained to create cultivable land (Dimentman *et al.* 1992). An area of about 400 ha that was later partly re-flooded was declared a nature reserve (Paz 1975). Since 1958, most of the drained land has been used for growing winter cereals (mainly wheat), cotton, sorghum and lucerne (alfalfa). The natural vegetation of the areas cultivated after the 1950s drainage operation was not monitored. Monitoring of native vegetation continued only in the flooded area within the nature reserve (Paz 1975).

Subsequently, some areas of organic soil, composed mostly of peat, proved difficult to manage because of high levels of mineralised N, subsidence of the peat, and underground fires that could be extinguished only with great difficulty. Finally, economic and ecological considerations made it necessary to forego irrigated cultivation and to change the land use of the core of this area to a more extensively managed agro-ecological system. Additional goals of this project were to control wind erosion from the dry peat soils and to protect the water of the Kinneret (Sea of Galilee) from potential pollution by excess minerals derived from the decomposing peat and carried to the lake by the River Jordan. Similar wetland creation and restoration projects are frequently carried out in the USA with motivations including habitat replacement, water-quality enhancement and flood minimisation (Mitsch & Gosselink 1993, Mitsch *et al.* 1998).

The new Hula project, which was initiated in 1993, involved re-flooding an area of about 110 ha in the centre of the original swamp to create a shallow lake known as ‘Agmon’. A network of


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drainage channels (ditches) was constructed in the 350 ha surrounding the newly formed lake in order to control the water table level so as to prevent underground fires and wind erosion. This network facilitated the regulation of the water table in most of the area to a depth of between 0.5 and 2.0 m, but ranging from close to zero in low-altitude areas to deeper than 3 m in areas of higher altitude. After completion of the partial re-flooding, the 350 ha surrounding Lake Agmon were partly cultivated and sown with winter cereals, usually in November. The crops were harvested in April–May. After the harvest, natural vegetation that developed during the summer season was cut periodically (2–4 times), with no other cultivation practices following until the next year. Development and management plans for the area of the new Hula project incorporated provisions for recreation facilities and nature restoration, particularly the creation of resting and nesting sites for avifauna including accommodation for the impressive annual mass bird migrations between Europe and Africa, together with pasture for grazing animals (Shacham 1994). Continuous vegetation cover is required to achieve these goals.

The aims of the present research were: to study the dynamics of the vegetation in the terrestrial area surrounding Lake Agmon and the relationship between vegetation composition and various water and soil characteristics after the re-flooding; and to determine the relative importance of these characteristics in the context of deriving management practices to maintain a dense herbaceous vegetation structure.

## METHODS

### Study site

The study was conducted on the 350 ha of dry land surrounding the re-flooded area of the Hula Valley in Upper Galilee, Israel (35º 43' E, 33º 03' N, altitude 60 m a.s.l., average annual rainfall 517 mm). The soil is peat-derived, rich in organic matter (100–350 g $kg^{-1}$), with nitrate content varying between 100 and 2000 mg $kg^{-1}$ (Avnimelech 1971). Except for small areas with very high water table (< 50 cm depth), most of the area is cultivated each winter and sown with cereal crops. According to the land management system the natural vegetation is mowed 2–4 times over the course of the summer in order to promote the growth of an herbaceous sward.

### Vegetation survey

During each year of the study (1994–1997), vegetation that developed after the first harvest was surveyed, with the sampling season ending just before sowing of the next season's crop. The vegetation was monitored in 90 quadrats of dimensions 10×10 m, which were placed systematically at 100 m intervals along 14 permanent transects that covered the entire 350 ha of the dry land area**.** Seven vegetation surveys were conducted between 1994 and 1997. The first survey took place in the early autumn of 1994 (September), just after the re-flooding was completed and before the area was first cultivated. Surveys were subsequently conducted in midsummer (July) and in early autumn (September) (i.e. twice a year) in 1995 and 1996, and in early autumn (September) in 1997, using the Braun-Blanquet (1964) phytosociological relevé method. Vegetation composition and total and relative cover of species in each of the quadrats were recorded on all survey dates. The botanical nomenclature follows Feinbrun-Dothan & Danin (1991).

### Soil sampling

In summer (August) 1997, after identifying the major vegetation units, soil was sampled at two depths (0–30 and 50–60 cm). Five sample cores were taken at each vegetation unit and the following variables were determined: depth of water table, soil moisture content, soil physical and pedological structure, pH, electrical conductivity (EC), organic matter content, Ca, N-$NO_3$ and N-$NH_4$. For each variable in each plant community a mean and standard deviation were calculated.

### Vegetation and soil analysis

Changes in the total cover of vegetation and of the most common species were analysed over consecutive sampling seasons. Two multivariate methods—classification and ordination—were used to identify and describe the vegetation units. Data based on absolute cover of species present in the sampled area were classified by Two Way Indicator Species Analaysis (TWINSPAN in DECORANA) (Hill 1979a, 1979b). Twenty-six sample groups (classes) were identified by TWINSPAN classification and then treated as combined samples in a second TWINSPAN classification. In order to understand the relationship between the vegetation units and species composition, the same modified data set was analysed by indirect ordination. Since we could not assume linearity, we used Detrended Correspondence Analysis (DCA) (Gauch 1995), which is known to be more robust and gives better results in longer gradients (gradient length of Axis 1 = 3.4). We used the DCA procedure from the CANOCO Program Version 3.12. In addition, correlations between depth of water table, soil moisture and conductivity (EC) were determined. The relationship between vegetation units and soil moisture content sampled in August 1997 was tested using the GLM procedure (SAS 2002).


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## RESULTS

### Species richness

In the terrestrial area surrounding Lake Agmon, 99 species were recorded between 1994 and 1997. Only eleven were common (Table 1), with a frequency of occurrence higher than 10 % (Figure 1, Table 2). Species richness was low; most 10×10 m quadrats contained no more than nine species and the maximum number was 14 (Figure 1).

Table 1. Changes in vegetation cover (%) of the most common plant species in the land around the re-flooded area of the drained Hula swamp over the period 1994 to 1997; the values given are Mean and (S.D.).

| Species | October 1994 | October 1995 | October 1996 | October 1997 |
|---|---|---|---|---|
| *Cynodon dactylon* | 17.8 (26.7) | 28.9 (32.0) | 37.3 (36.1) | 48.3 (37.8) |
| *Sorghum halepense* | 6.3 (14.5) | 11.6 (19.7) | 12.8 (22.2) | 8.8 (17.2) |
| *Phragmites australis* | 2.2 (11.1) | 4.6 (17.4) | 6.3 (20.6) | 4.0 (16.1) |
| *Conyza bonariensis* | 0.3 (1.3) | 0.9 (3.1) | 1.5 (6.6) | 1.7 (5.4) |
| *Polygonum arenastrum* | 6.6 (15.0) | 6.9 (18.0) | 5.3 (15.3) | 1.7 (6.0) |
| *Cyperus rotundus* | 3.7 (12.0) | 1.1 (3.0) | 0.5 (1.8) | 0.3 (0.8) |
| *Amaranthus blitiodes* | 2.4 (10.5) | 0.5 (2.2) | 0.1 (0.5) | 0.2 (0.8) |
| *Chenopodium album* | 2.0 (8.9) | 1.4 (5.9) | 0.1 (0.8) | 0.1 (0.6) |
| *Amaranthus palmeri* | 0.45 (1.5) | 0.4 (1.7) | 0. 01 | 0.01 (0.05) |
| *Solanum negrum* | 0.1 (0.3) | 0.2 (1.1) | 0.1 (0.6) | 0.1 (0.3) |
| *Cuscuta campestris* | 0.4 (1.5) | 0.1 (0.4) | 0.1 (0.5) | 0.01 (0.02) |

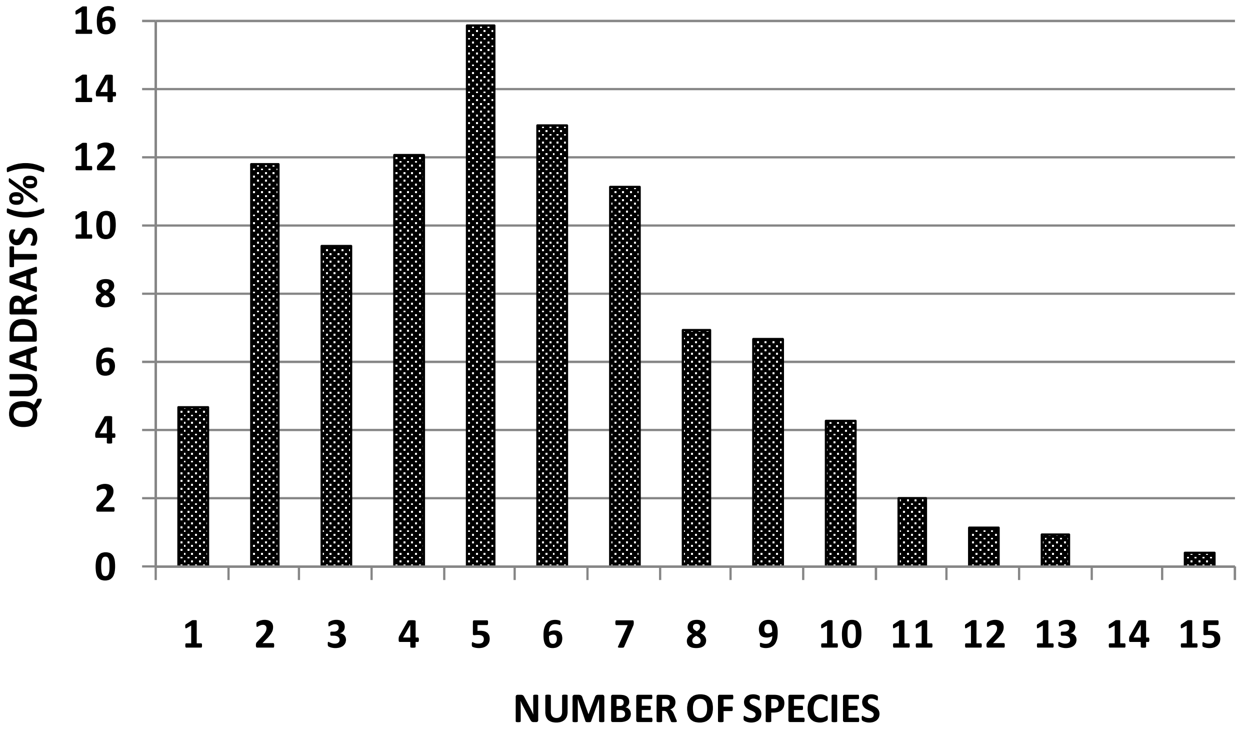


Figure 1. Average species richness of summer vegetation in the terrestrial areas around Lake Agmon for all surveys conducted between 1994 and 1996.


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Table 2. List of main species recorded in the areas around Lake Agmon and their frequency of occurrence (%). Abbreviations (letter codes) and number codes apply to Figure 4.

| Letter or number code | Species | Frequency (%) |
|---|---|---|
| Cyn dac | *Cynodon dactylon* | 78.6 |
| Sor hal | *Sorghum halepense* | 52.6 |
| Cyp rot | *Cyperus rotundus* | 36.9 |
| Pol are | *Polygonum arenastrum* | 46.1 |
| Che alb | *Chenopodium album* | 26.7 |
| Ama bli | *Amaranthus blitoides* | 31.7 |
| Phr aus | *Phragmites australis* | 20.7 |
| Con bon | *Conyza bonariensis* | 25.8 |
| Ama pal | *Amaranthus palmeri* | 18.6 |
| Sol nig | *Solanum nigrum* | 25.9 |
| Cus cam | *Cuscuta campestris* | 11.9 |
| 12 | *Datura stramonium* | 1.1 |
| 13 | *Lactuca serriola* | 4.0 |
| 14 | *Polygonum lapathifolium* | 0.7 |
| 15 | *Chenopodium ambrosioides* | 6.9 |
| 16 | *Kickxia sieberi* | 5.8 |
| 17 | *Amaranthus rudis* | 6.1 |
| 18 | *Epilibium hirsutum* | 0.9 |
| 19 | *Sinapis arvensis* | 1.8 |
| 20 | *Rumex dentatus* | 4.0 |
| 21 | *Bromus madritensis* | 1.1 |
| 22 | *Cynanchum acutum* | 1.6 |
| 23 | *Tamarix sp.* | 1.8 |
| 24 | *Lythrum salicaria* | 0.4 |
| 25 | *Typha domingensis* | 0.2 |
| 26 | *Echinochola crus-galli* | 3.4 |
| 27 | *Helminthotheca echioides* | 1.6 |
| 28 | *Chrozophora tinctoria* | 0.7 |
| 29 | *Pulicaria arabica* | 0.2 |
| 30 | *Plantago Lanceolata* | 0.4 |
| 31 | *Verbena officinalis* | 0.7 |
| 32 | *Paspalum dilatatum* | 0.4 |
| 33 | *Anchusa sp.* | 0.2 |
| 34 | *Lavatera cretica* | 2.2 |
| 35 | *Eleusine indica* | 0.2 |
| 36 | *Plantago major* | 0.2 |
| 37 | *Inula viscosa* | 0.4 |
| 38 | *Portulaca oleracea* | 0.4 |
| 39 | *Alternanthera sessilis* | 0.2 |
| 40 | *Lycopus europaeus* | 0.2 |
| 41 | *Pulicaria dysenterica* | 0.4 |
| 42 | *Pluchea dioscoridis* | 0.2 |
| 43 | *Aster subulatus* | 0.4 |
| 44 | *Polypogon monspeliensis* | 1.8 |
| 45 | *Pluchea sicula* | 0.4 |
| 46 | *Onopordum cynarocephalum* | 0.2 |
| 47 | *Conyza albida* | 0.4 |
| 48 | *Lythrum junceum* | 0.2 |
| 49 | *Hordeum glaucum* | 0.2 |
| 50 | *Phalaris brachystachys* | 0.2 |
| 51 | *Carthamus tenuis* | 0.2 |
| 52 | *Phytolacca americana* | 0.2 |


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**Plant composition and vegetation cover**

During the four sequential summers after re-flooding, the total natural vegetation cover of the area surrounding Lake Agmon increased significantly ($P<0.001$) from 42 % to 64 % (Figure 2). Immediately after the cultivation of irrigated summer crops ceased, the most abundant plants that developed between the winter crop harvest and re-sowing the next autumn were ruderals and weeds. *Cynodon dactylon* covered 18 % of the area in the first year after re-flooding and increased steadily to 48 % three years later (Table 1). *Sorghum halepense* and *Phragmites australis* also increased initially, but their cover declined in favour of *C. dactylon* in the fourth year. These three species spread mostly onto bare ground and to a lesser extent into areas occupied by ruderal species; mainly *Polygonum arenastrum*, *Cyperus rotundus*, *Amaranthus blitiodes* and *Chenopodium album*. The cover of ruderal species generally decreased precipitously except for that of *Conyza bonariensis*, which increased, and *Solanum nigrum*, which remained more or less constant.

The remaining 88 species occupied various habitats. Indigenous swamp species (*Lythrum salicaria* L., *Epilobium hirsutum* L., *Cyperus papyrus* L., *Cyperus alopecuroides* Rottb., *Typha domingensis* (Pers.) Steudel, *Polygonum lapathifolium* L., *Polygonum salicifolium* Willd., *Polygonum lanigerum* R.Br. and *Salix acmophylla* Boiss.) appeared on ditch banks and non-arable areas of burnt peat with high water table. These habitats, which were initially dominated by *Phragmites australis*, were rapidly invaded by *Tamarix* species.

**Vegetation units**

The primary classification by TWINSPAN (Hill 1979a, 1979b) of the 450 vegetation relevés (90 quadrats sampled five times from 1994 to 1996) produced 26 groups which were later grouped by a secondary TWINSPAN classification into five main vegetation units (Table 3) with eigenvalues between 0.426 and 0.507. The differentiation of vegetation types was not obvious because the most common species tended to appear in all habitats, so that the TWINSPAN classification mainly reflects the different proportions of the dominant species. The validity of these units was confirmed by Detrended Correspondence Analysis (DCA) (Gauch 1995; Figure 3). The ordination and list of the main species are shown in Figure 4 and Table 2.

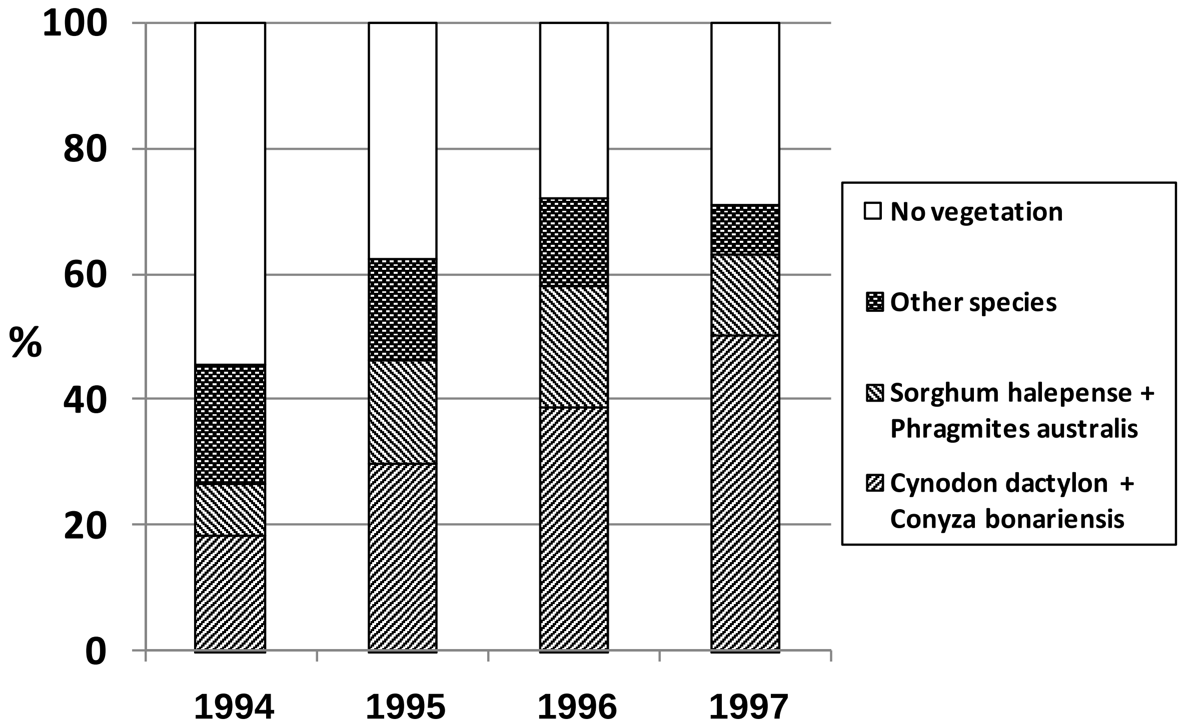


Figure 2. Changes in the overall average cover of natural terrestrial vegetation sampled at the end of summer in the areas around Lake Agmon during the three seasons after re-flooding. The species are divided into: 1. Increasers (*Cynodon dactylon* and *Conyza bonariensis*); 2. Transient increasers (*Sorghum halepense* and *Phragmites australis*); and 3. All other species.


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Table 3. Terrestrial vegetation units around Lake Agmon as identified using TWINSPAN based on five surveys conducted between October 1994 and October 1996.

| Characteristic species for vegetation units | Accompanying species | Frequency (%) | Average number of species |
|---|---|---|---|
| 1. *Phragmites australis* | | 8.7 | |
| a) without *Cynodon dactylon* | *Amaranthus rudis*<br>*Datura innoxia* | 1.0 | 3.8 |
| b) with *Cynodon dactylon* | | 2.2 | 2.0 |
| c) with *Cynodon dactylon* | *Typha domingensis*<br>*Lythrum salicaria*<br>*Tamarix sp.*<br>*Salix acmophylla* | 5.5 | 2.5 |
| 2. *Cyperus rotundus* | *Cynodon dactylon*<br>*Sorghum halepense*<br>*Amaranthus blithoides*<br>*Chenopodium album*<br>*Amaranthus palmeri* | 11.3 | 3.5 |
| 3. *Cynodon dactylon* and *Sorghum halepense* | *Conyza bonariensis*<br>*Polygonum arenastrum*<br>*Phragmites australis*<br>*Amaranthus rudis*<br>*Chenopodium album*<br>*Chenopodium ambrosioides*<br>*Amaranthus blithoides* | 61.6 | 4.9 |
| 4. *Polygonum arenastrum* | *Amaranthus blithoides*<br>*Cynodon dactylon*<br>*Chenopodium album*<br>*Sorghum halepense*<br>*Conyza bonariensis*<br>*Cyperus rotundus* | 16.9 | 5.7 |
| 5. *Cynodon dactylon*, *Polygonum arenastrum* and *Cuscuta campestris* | *Amaranthus blithoides* | 1.5 | 10.0 |


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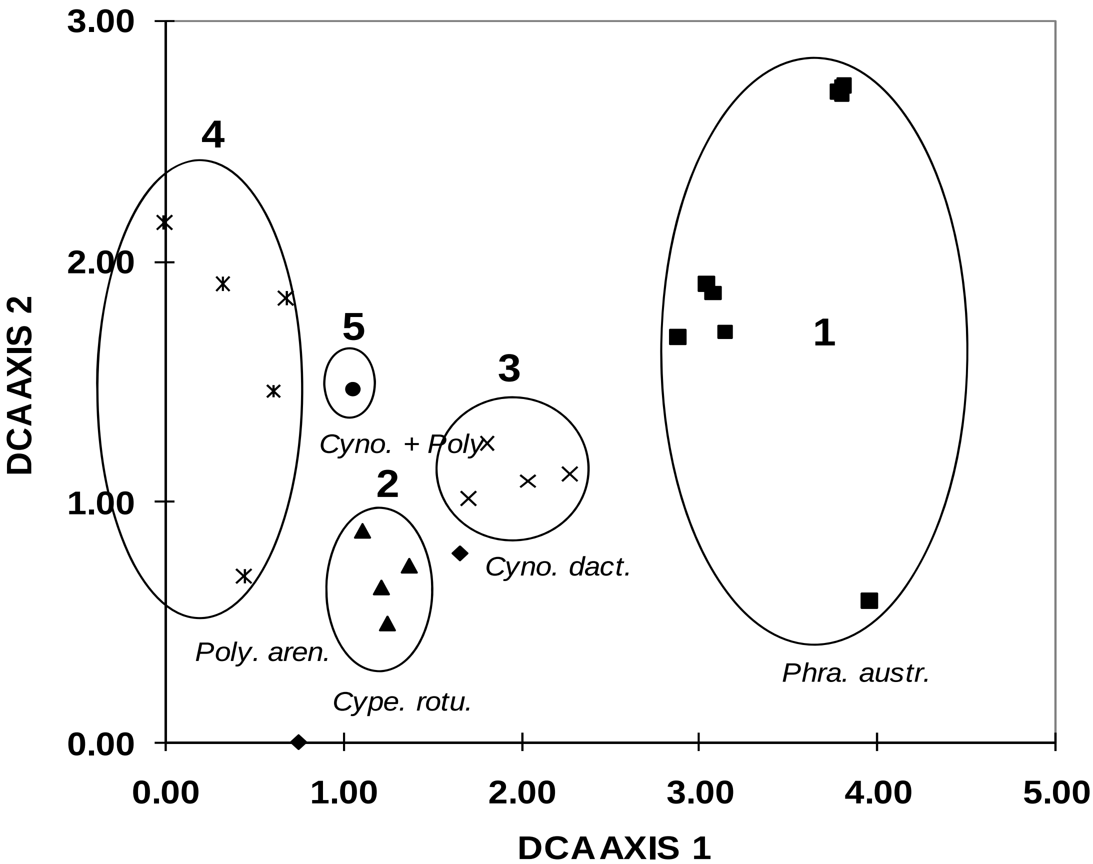


Figure 3. Detrended Correspondence Analysis ordination of vegetation units according to 450 vegetation relevés (90 quadrats sampled five times from 1994 to 1996) from the terrestrial areas around Lake Agmon (1: *Phragmites australis* with and without *Cynodon dactylon*; 2: *Cyperus rotundus*; 3: *Cynodon dactylon* and *Sorghum halepense*; 4: *Polygonum arenastrum*; 5: *Cynodon dactylon, Polygonum arenastrum* and *Cuscuta campestris*).

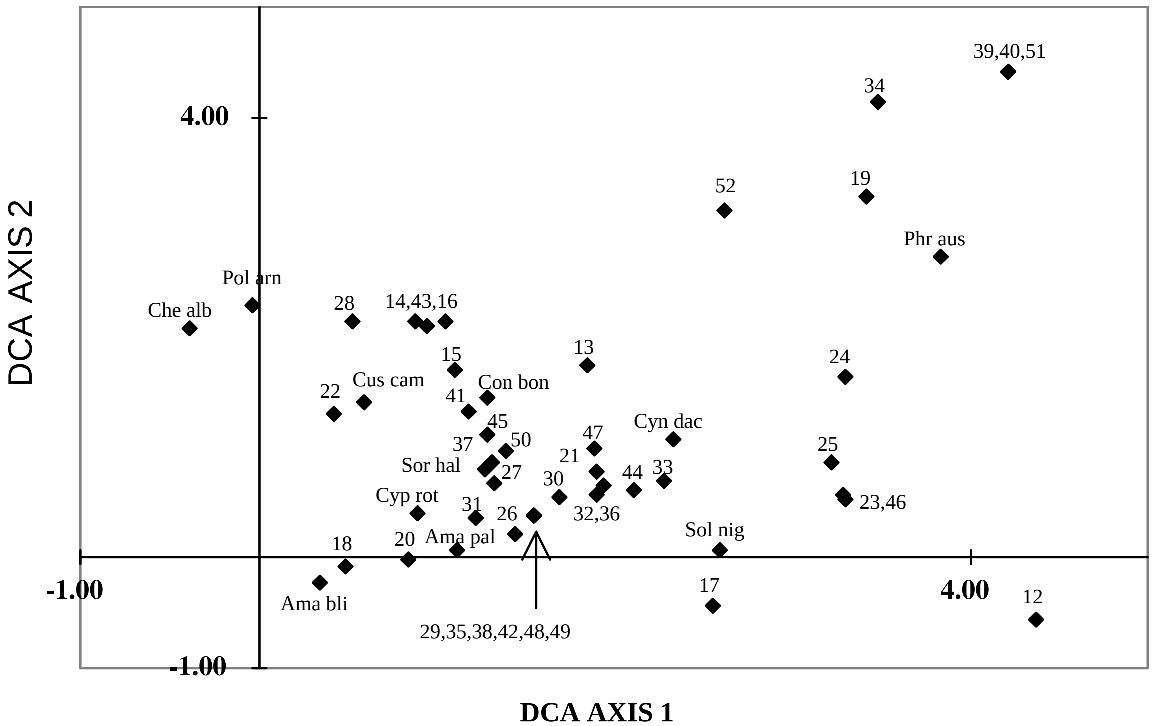


Figure 4. Detrended Correspondence Analysis ordination of species from the terrestrial areas around Lake Agmon. The data, codes and species list are given in Table 2.


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**Soil characteristics and vegetation distribution**

Soil moisture content sampled in August 1997 was related to the different vegetation units ($P<0.03$). As expected, soil moisture was also correlated with the depth of the water table ($R^2$= 0.43 and 0.35, $P<0.0001$ and $P=0.001$) (Figure 5).

The organic matter content of the peat-derived soil was between 0.1 g $g^{-1}$ and 0.25 g $g^{-1}$, and the texture of the mineral components of the soil was 62 % sand, 25 % silt and 13 % clay. The moisture level at saturation per unit of dry soil in the upper 0–30 cm layer was high (1.05–1.15 g $g^{-1}$), and even higher in the deeper 50–60 cm layer (1.15–1.30 g $g^{-1}$) (Table 4). No significant differences in these soil properties were found between the vegetation units (Tables 5 and 6). Ca concentration and pH level were relatively low in the *Phragmites australis* unit. In the drier habitats $N\text{-}NO_3$ concentration was relatively high, as was the soil electrical conductivity (EC) in the deeper layer. $N\text{-}NH_4$ concentration was very high in the dry ‘unit’ with no vegetation and the wet *Phragmites australis* unit. As the depth of ground water level increased, soil moisture in the 1–30 cm and 50–60 cm layers decreased (Figures 5a and 5c). No correlation was found between soil EC in the upper 30 cm layer and change in ground water level (Figure 5b). However, soil EC in the 50–60 cm layer increased as ground water level dropped (Figure 5c).

Two major gradients are represented by the first two DCA axes (Figures 3 and 4). The positioning of the communities suggests that the first axis is correlated with the depth of groundwater. *Phragmites australis* and the vegetation unit it dominates is at the “wet” end and *Polygonum arenastrum* and its vegetation unit is at the “dry” end. Three vegetation types, characterised by a combination of *Cynodon dactylon* with *Sorghum halepense*, *Polygonum arenastrum and Cuscuta campestris* or *Cyperus rotundus*, were related to intermediate moisture levels. These three vegetation types were ordered along the second DCA axis, which appears to reflect cultivation intensity; *Cyperus rotundus* being dominant on the intensively cultivated land and *Cynodon dactylon* on the less intensively cultivated land. The sixth ‘vegetation unit’ shown in Tables 4–6 includes areas with vegetation cover of less than 5 %.

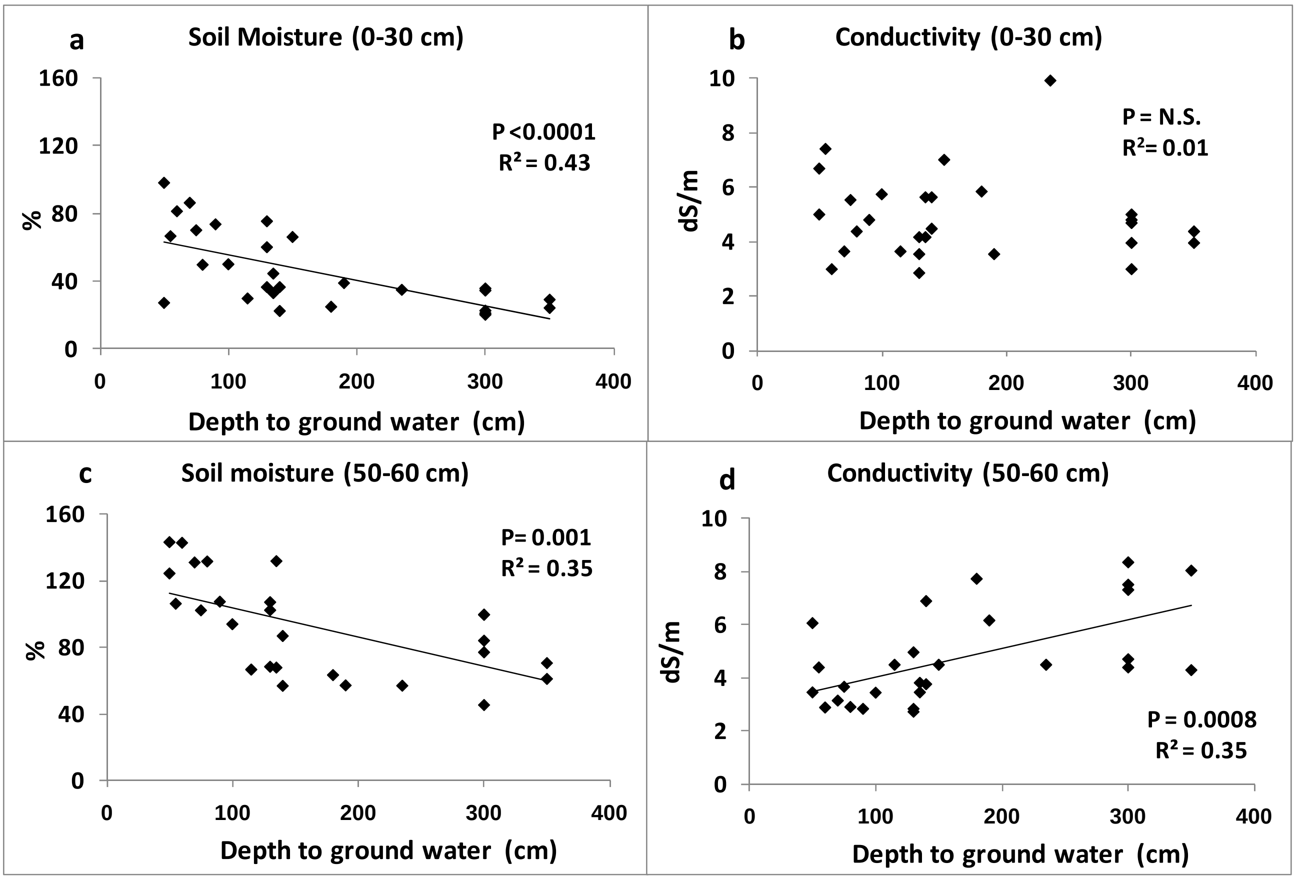


Figure 5. Correlation between depth of water table and soil moisture and conductivity (EC) for the 0–30 cm and 50–60 cm soil layers.


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Table 4. Depth of water table and gravimetric soil moisture (Average ± S.D.) in the 0–30 cm and 50–60 cm soil layers, sampled in the different vegetation units around Lake Agmon in August 1997.

| Vegetation unit * | Depth to water table (cm) | Soil moisture (0–30 cm) ($g\ g^{-1}$ ± S.D) | Soil moisture (50–60 cm) ($g\ g^{-1}$ ± S.D) |
|---|---|---|---|
| 1 | 70 ± 33 | 0.67± 0.27 | 1.30± 0.14** |
| 2 | 122 ± 19 | 0.47± 0.14 | 0.88± 0.18 |
| 3 | 111 ± 33 | 0.62± 0.15 | 1.01± 0.27 |
| 4 | 207 ± 109 | 0.30± 0.57 | 0.73± 0.11 |
| 5 | 240 ± 85 | 0.29± 0.68 | 0.82 ± 0.26 |
| No vegetation | 265 ± 50 | 0.27± 0.87 | 0.67± 0.21 |

* 1: *Phragmites australis* with *Cynodon* dactylon; 2: *Cyperus rotundus*; 3: *Cynodon dactylon* and *Sorghum halepense*; 4: *Polygonum arenastrum;* 5. *Cynodon dactylon*, *Polygonum arenastrum* and *Cuscuta campestris*. ** Organic soils with water content higher than dry matter content.

Table 5. Soil properties of the upper 30 cm layer sampled in August 1997 in each vegetation unit around Lake Agmon (Average ± S.D.). Vegetation units as in Table 4.

| Vegetation unit | pH | Conductivity $dS\ m^{-1}$ | Ca ($mg\ g^{-1}$) | $N\text{-}NO_3$ ($mg\ kg^{-1}$) | $N\text{-}NH_4$ ($mg\ kg^{-1}$) |
|---|---|---|---|---|---|
| 1 | 4.3 ± 0.6 | 5.2 ± 1.7 | 3 ± 1 | 171 ± 180 | 338 ± 424 |
| 2 | 6.9 ± 0.1 | 4.3 ± 1.4 | 199 ± 120 | 255 ± 113 | 48 ± 6 |
| 3 | 6.8 ± 0.4 | 5.3 ± 1.0 | 203 ± 144 | 89 ± 115 | 70 ± 22 |
| 4 | 6.8 ± .03 | 4.2 ± 0.5 | 201 ± 169 | 149 ± 91 | 47 ± 6 |
| 5 | 6.6 ± 0.2 | 5.3 ± 0.8 | 288 ± 316 | 210 ± 277 | 37 ± 2 |
| No vegetation | 6.2 ± 0.9 | 5.1 ± 2.8 | 108 ± 104 | 351 ± 489 | 96 ± 101 |

Table 6. Soil properties of the 50–60 cm layer sampled in August 1997 in each vegetation unit around Lake Agmon (Average ± S.D.). Vegetation units as in Table 4.

| Vegetation unit | pH | Conductivity $dS\ m^{-1}$ | Ca ($mg\ g^{-1}$) | $N\text{-}NO_3$ ($mg\ kg^{-1}$) | $N\text{-}NH_4$ ($mg\ kg^{-1}$) |
|---|---|---|---|---|---|
| 1 | 4.6 ± 0.8 | 3.9 ± 1.2 | 10 ± 19 | 40 ± 16 | 738 ± 815 |
| 2 | 7.0 ± 0.3 | 3.2 ± 0.4 | 447 ± 308 | 47 ± 28 | 44 ± 31 |
| 3 | 6.7 ± 1.0 | 3.4 ± 0.7 | 453 ± 282 | 21 ± 31 | 62 ± 45 |
| 4 | 6.3 ± 0.7 | 5.1 ± 1.0 | 337 ± 338 | 289 ± 152 | 51 ± 19 |
| 5 | 6.2 ± 0.3 | 6.1 ± 2.4 | 103 ± 128 | 398 ± 485 | 68 ± 11 |
| No vegetation | 5.5 ± 1.7 | 6.8 ± 1.5 | 209 ± 254 | 412 ± 344 | 877 ± 1152 |


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## DISCUSSION

The aim of the Hula restoration project was to maintain a high cover of vegetation during summer in the drier land surrounding Lake Agmon, most of which was cultivated during winter. Accordingly, the specific aim of this study was to discover the dynamics of the spontaneous summer vegetation. The summer vegetation was dominated by *Cynodon dactylon* and *Sorghum halepense*; while the cover of *Cyperus rotundus*, *Polygonum arenastrum* and *Amaranthus blitiodes* decreased over the period 1994 to 1997. The decline in *Cyperus rotundus* was probably a consequence of the cessation of intensive agriculture. The cover of *Phragmites australis* increased during the first two years but then stabilised in areas with very high water table and along old ditches that were constructed during drainage of the valley and later filled with soil.

Generally, the vegetation cover increased during the four years of the study. This was probably related to the slow rise of the water table until it stabilised in 1995 and 1996 (Tsipris 1997). Small-scale differences in water table depth affected vegetation cover and composition. In the wettest zones, where the water table depth was only 50 cm and no cultivation was possible, the soil moisture was very high, and dense stands of *Phragmites australis* accompanied by *Cynodon dactylon*, *Tamarix* sp., *Salix acmophylla* and other indigenous swamp species became established (Table 2). *Cynodon dactylon*, *Sorghum halepense* and *Cyperus rotundus* were common in areas with water table depths between 0.75 and 1.5 m and with high soil moisture content in the upper 30 cm layer. Where the water table depth was greater than 2 m, the upper soil layer was relatively dry and the vegetation was mainly characterised by *Polygonum arenastrum*. Where it was deeper than 2.5 m the upper soil layer was much drier and 95% of the land remained bare during the summer. Soil water content in the upper layer had a direct effect on root oxygen in plants, and an indirect effect in eliminating mechanical cultivation as a result of the high soil moisture. Thus, in addition to the major soil moisture gradient, the appearance of species was related on a smaller scale to the management of the vegetation. Mowing during the summer favoured *Cynodon dactylon*, and eliminated taller plants like *Chenopodium album* and *Amaranthus palmeri*.

Three years after initiation of the project, the natural vegetation of the dry land surrounding the lake became increasingly stable. The importance of *Cynodon dactylon*, which dominates this area, is due partly to its high quality as pasture, but mainly to its ability to utilise nitrogen and maintain relatively low concentrations of $N\text{-}NO_3$ and $N\text{-}NH_4$ in the soil. The high nitrate concentration found in most other plant species harvested in the terrestrial areas surrounding Lake Agmon is the main reason for their low quality as herbivore feed. Reduced accumulation of nitrates under perennial crops compared with uncultivated soil was also found by Levanon *et al*. (1987). Extremely high values of $N\text{-}NH_4$ were found where the water table was shallow (less than 0.5 m) with high soil moisture. It seems that further nitrification did not occur under very wet soil conditions. Extremely high values of $N\text{-}NO_3$ were found mainly on the dry land with almost no cover of vegetation.

## CONCLUSIONS

In order to maintain vegetation cover on the rich organic peat-derived soil in the area around the new Lake Agmon, the depth of the water table should be kept in the range 0.8–2 m. This encourages the development of herbaceous vegetation, mainly *Cynodon dactylon*, during the summer months, and helps to sustain low concentrations of mineral nitrogen in the soil. In addition, it appears necessary to mow (and/or graze) the area to control undesirable species and to increase the dominance of *Cynodon dactylon*. In areas where natural vegetation does not develop it is necessary to irrigate during summer in order to enhance vegetation growth.

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