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Aquatic and shoreline vegetation of Lake Nubia, Sudan

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The paper reports on the flora along the banks of Lake Nubia and the long-term changes that have taken place since the formation of the Aswan High Dam (AHD) Lake about 40 years ago. Both aquatic and shoreline vegetation were studied in 15 transects located across the lake, from Debeira (337.5 km south of the Aswan High Dam), to the Dal Cataract (500 km south of AHD). Water temperature, pH, dissolved oxygen, total dissolved solids, electric conductivity and turbidity were measured in the field. Water and hydrosoil samples were collected and analysed for phosphates, nitrates, sulphates, carbonates, bicarbonates, calcium, magnesium, and silicates. The shoreline was classified into four moisture segments depending on the period of inundation, namely: wet (frequently inundated and recently exposed); moist (periodically inundated); semi-dry (rarely inundated); and dry (never inundated). Plants characterising each segment have been identified. Factors affecting the distribution of aquatic macrophytes in Lake Nubia were analysed using canonical correspondence analysis. Temporal and spatial variations of the shoreline vegetation were revealed.

Key words: aquatic, macrophytes, vegetation, High Dam Lake, Lake Nubia, shoreline habitat, water level, Sudan

Introduction

The construction of the Aswan High Dam in Upper Egypt created one of the largest man-made lakes in Africa, extending 500 km south of the Dam. It extends from the Dam itself in the north to the cataract at Dal in the Sudan in the south (Fig. 1). The major portion of the Lake lies in Egypt, where it is known as Lake Nasser, and continues into Lake Nubia on the Sudanese side (20° 27' – 22° 00' N latitude and longitudes 30° 35' – 31° 14' E).

Although many botanical studies were carried out on Lake Nasser (e.g. BOULOS 1966, MURPHY et al. 1990, SPRINGUEL et al. 1991, ALI et al. 1995, ALI 2000), the literature contains very few floristic records on Lake Nubia. Before the construction of the Lake only, AHTI et al. (1973) reported the botanical finds made during the Finnish Biological Expedi-

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tion to Nubia in 1962 and PETTET et al. (1964) carried out a bioclimatic flora and fauna survey of Wadi Halfa area in the same year.

The present paper aims to study the flora of Lake Nubia, to detect the vegetation temporal variation that may have occurred after the construction of the Dam and formation of the Lake about 40 years ago, and to determine the main factors that govern plant distribution in the southern reaches.

Geology

The area studied is situated in the contact zone of two extensive geological formations. North of the 2nd Cataract, the Nile Valley and its surroundings belong to the Mesozoic Nubia Sandstone formation. The valley south of the 2nd Cataract and most of the Nubian Desert, including the Red Sea Hills, form a part of the ancient Basement Complex (the Nubian-Arabian Shield) (e.g. BARBOUR 1961). The alluvial silt or clay terraces form a narrow strip along the lake shore, varying from a few metres to about 2 km in width.

Climate

According to the Bioclimatic Map of the Mediterranean Zone (1963), the study area is a true desert climate. The rainfall of this area is not only scanty, but also extremely irregular and variable (KASSAS 1955).

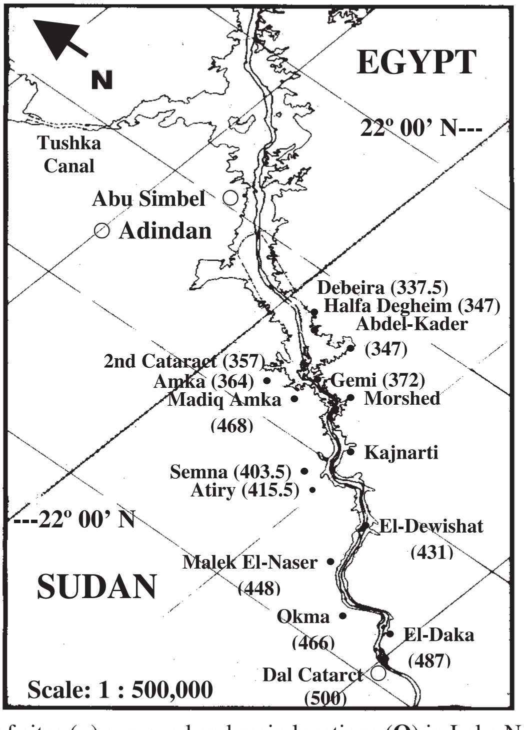


Fig. 1. Location map of sites (●) surveyed and main locations (**O**) in Lake Nubia. The latitude 22° 00 N is the border line between Egypt and Sudan

Water Level

Another feature, which is in fact climatic and is peculiar to the Nile Valley, is the annual flooding of this great river; throughout the year there is a steady flow of water in the Nile, even when it traverses the rainless country of the Libyan and Nubian Deserts, where the loss of water is very high. This steady flow comes from the tropical rainy districts of Uganda and Tanzania through the White Nile. However, in July to November the water level of the Lake rises several meters, owing to an increase in the flow from the Blue Nile and Atbara Rivers, which comes from the summer rainfall areas of the Ethiopian Plateau (HURST 1952, BARBOUR 1961).

The water level in the reservoir reaches its maximum in November and December each year, and then decreases gradually till the second half of July (dry period; Fig. 2). When the floodwater reaches the Reservoir, the water level starts to rise again. Recently, in November 1999, the water level reached its highest so far (181.60 m above mean sea level (MSL) (Fig. 2).

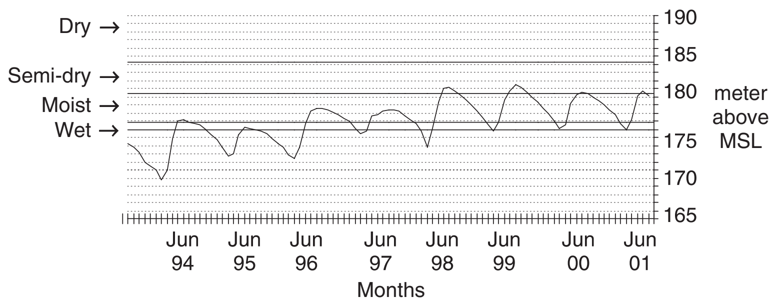


Fig. 2. Changes in Lake Nubia water level in the period from 1994 to 2001 in relation to moisture zones recognised (wet, moist, semi-dry, and dry).

Sedimentation

Deposition in Lake Nubia differs from that of the Egyptian part of the lake. The areas of most intense deposition were at Gomi and Amka at the Second Cataract, in Lake Nubia. Until 1975, layers of 17 and 20 m, respectively, were formed, compared to only 2 m at Adindan and 1 m at Abu-Simbel within Lake Nasser (ABOUL-HAGGAG 1977). At the entrance of Lake Nubia, the Nile velocity and its related transporting power decrease and the river begins to drop its suspended load as sediment. Therefore, the Nile is building up a new delta at the southern part of Lake Nubia by the sedimentation of the relatively heavier and coarser parts of the material in suspension while the finer fractions settle down further north in the Egyptian part of the reservoir. The areas of most intense deposition (20 m) were at Amka (ABOUL-HAGGAG 1977) and at El-Dewishat (HDA 1982); 360 km and 431 km S. of the Aswan High Dam, respectively.

Materials and Methods

In total, 15 sites (24 transects) were located along the Lake, from Debeira at the Sudanese-Egyptian border (337.5 km S. of the Aswan High Dam), to the Dal Cataract at the southern end of the Lake (500 km S. of the Aswan High Dam).

Aquatic habitat

Along each sample transect, submerged macrophytes were sampled using a grapnel screwed to a metal pole from 1 m depth-zone intervals to the limit of plant colonisation. The average dry weight standing crop was calculated for each species per site. In total 16 water physico-chemical variables (pH, electric conductivity, turbidity, dissolved oxygen, sulphates, nitrates, nitrites, ammonia, total phosphates, available phosphates, chlorides, calcium, magnesium, carbonates, bicarbonates and silicon dioxide) were measured using standard methods (APHA 1985).

Shoreline habitat

At each site two transects were situated, one on the east bank and another on the west bank (when it was accessible). Using data on water level fluctuations during the past few years and by base levelling using a Theodolite, four moisture gradient zones were recognised: ***1) Wet Zone*** (frequently inundated and recently exposed zone): the main part of the zone exposed for a short period (1–2 months), too freshly exposed and too wet to support any vegetation (175.9–176.9 m above MSL); ***2) Moist Zone*** (periodically inundated zone): most of the zone exposed for a longer period (3–4 months) than the wet zone (176.9–180.3 m above MSL); ***3) Semi-dry Zone*** (rarely inundated): the lower edge of the zone was inundated twice in 1998 and 1999 for short periods, but since then it has been exposed (180.30–184.80 m above MSL); and ***4) Dry Zone*** (never inundated): < 184.80 m above MSL.

Average cover abundance percentages for 58 species were obtained on 86 stands (each comprising five randomly located 1 m^2 quadrats).

The environmental factors here are variables represented by dummy classes. The texture of the soil surface type (with five classes) was dealt with by multiple regression (MONTGOMERY and PECK 1982: chapter 6), by defining five dummy environmental variables: 'silt', 'loam', 'sandy loam', 'sand' and 'gravely sand'. The thickness of the sediments comprises two dummy variables: 'thin' (< 0.5 m) and 'thick' (> 0.5 m). Elevation and period of inundation are represented by four dummy variables of the above described moisture zones: 'wet', 'moist', 'semi-dry' and 'dry'. For example, the variable 'silt' takes the value 1 when the soil texture is silt and the value 0 otherwise.

Data analysis

All the shoreline habitat and aquatic habitat data were drawn up in the form of matrices of plant species (cover percentage for shoreline plants or dry weight standing crop g sample^{-1} (DWSC) for submerged plants x samples, and environmental variables x samples. Canonical Correspondence Analysis (CCA) ordination for the two matrices was carried out using CANOCO for Windows Version 4.0 (TER BRAAK and SMILAUER 1998).

Results

Aquatic habitat

Only six submerged macrophytes (*Potamogeton crispus*, *Potamogeton pectinatus*, *Myriophyllum spicatum*, *Najas horrida*, *Vallisneria spiralis* and *Zannichellia palustris*) were recorded in the northern sector of the Lake (in the six sites, from Debeira to the Second Cataract). No other euhydrophytes were recorded south of this point. All of these six species were recorded in Debeira West. Two species were recorded in Debeira East: *Potamogeton crispus* and *Myriophyllum spicatum*. In Halfa Degheim West, four species: *Potamogeton crispus*, *Myriophyllum spicatum*, *Najas horrida* and *Vallisneria spiralis,* were listed. Halfa Degheim East, Abdel-Kader East and Second Cataract West have only one species each: *Myriophyllum spicatum*, *Vallisneria spiralis* and *Najas horrida*, respectively.

From the CCA diagram (Fig. 3), water turbidity, silicon dioxide, total phosphates, and electric conductivity were the most important water variables relative to growth and distribution of the recorded aquatic plants, while nitrate and nitrite were less important.

In spite of the limited presence and number of the submerged macrophytes recorded, they are quite different in their nutrient needs and habitat selection. The CCA diagram (Fig. 3) indicates that *Potamogeton crispus* grows best in aquatic habitats that have high water dissolved oxygen, Ca and pH value (alkaline). *Najas horrida* was able to stand high water turbidity, and thrive with high total and available phosphates and silicon dioxide. *Vallisneria spiralis* grows well in water characterised by high transparency and high bicarbonate, ammonia and chloride concentrations, but low phosphate and carbonate concentrations.

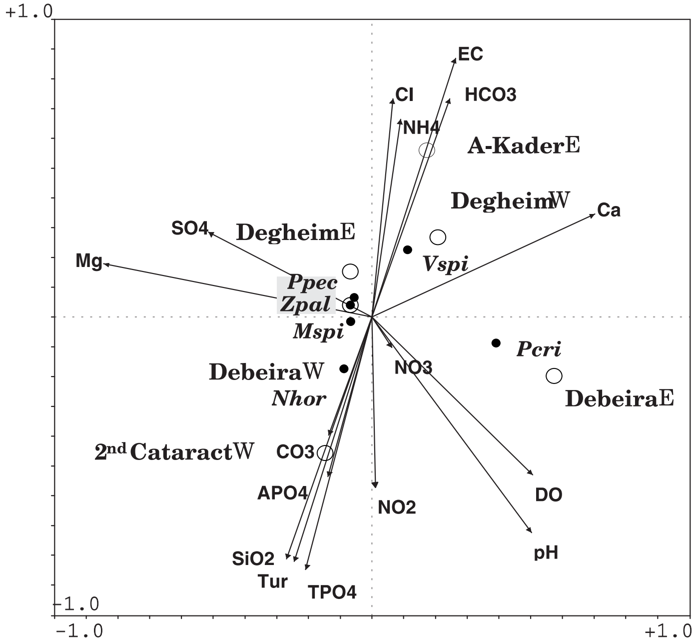
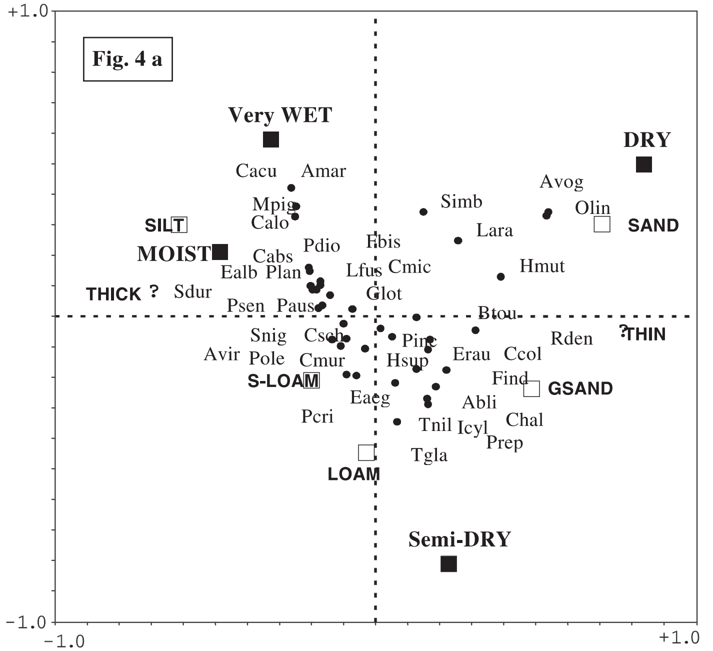
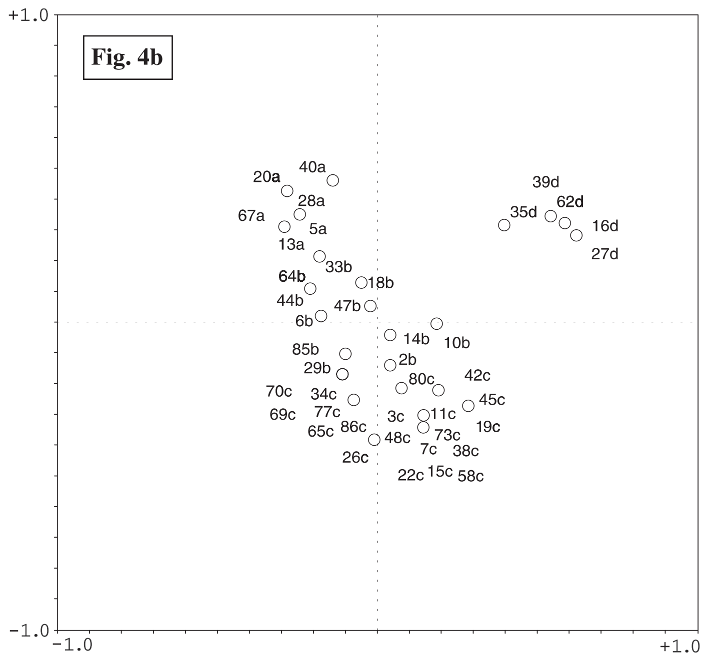


Fig. 3. CCA ordination diagram illustrates the distribution of six submerged species (●) ***Mspi*** = *Myriophyllum spicatum*, ***Vspi*** = *Vallisneria spiralis*, ***Pcri*** = *Potamogeton crispus*, ***Ppec*** = *Potamogeton pectinatus*, ***Zpal*** = *Zannichellia palustris* and ***Nhor*** = *Najas horrida*; from six sampling sites (O) at the northern section of Lake Nubia in relation to 16 water parameters (arrows): pH = water pH, EC = electric conductivity, Tur = turbidity, DO = dissolved oxygen, SO_4 = sulphates, NO_3 = nitrates, NO_2 = nitrites, NH_4 = ammonia, TPO_4 = total phosphates, APO_4 = available phosphates, Cl = chlorides, Ca = calcium, Mg = magnesium, CO_3 = carbonates, HCO_3 = bicarbonates and SiO_2 = silicon dioxide.

Other species (*Potamogeton pectinatus*, *Myriophyllum spicatum* and *Zannichellia palustris*) occur at the origin of the CCA ordination diagram (Fig. 3), showing that they grow in habitats of moderate values of all the water parameters measured.





Shoreline habitat

The ordination diagram resulting from the shoreline vegetation CCA was too crowded, and hence species and nominal environmental variables were displayed in Fig. 4a and sites were displayed separately in Fig. 4b.

Species recorded only once (usually as individuals) were excluded from the analysis. These are *Acacia nilotica*, *Polygonum plebejum, Aerva javanica, Cocculus pendulus, Desmostachya bipinnata, Calotropis procera, Ceruana pratensis, Coronopus niloticus, Gnaphalium luteo-album, Haplophyllum tuberculatum, Polypogon monspeliensis, Senecio vulgaris, Solanum incanum, Herniaria hirsuta, Hypericum triquetrifolium, Ludwigia erecta, Phoenix dactylifera,* and *Hyphaene thebaica.* In El-Dakka (487 km S of the Aswan High Dam), where limited agriculture is practised, date palm (*Phoenix dactylifera*) grooves with a few individuals of doum palm (*Hyphaene thebaica*) were noticed.

Sampling sites were numbered and each labelled according to their elevation zone. Label 'a' was given to those collected in the wet zone (between levels 175.9 and 176.9 m above MSL), label 'b' was given to those collected in the moist zone (between levels 176.9–180.3 m above MSL), label 'c' to those collected in the semi-dry zone (between levels 180.3–184.8 m above MSL), and label 'd' to those collected in the dry zone (more than 184.80 m MSL).

In the CCA diagram (Fig. 4a), the wet and the moist zones appear close to each other while sites labelled 'a' and 'b' were grouped together at the top-left corner of the diagram (Fig. 4b). The two zones are characterised by thick silt sediment that can hold water for longer periods. Species such as *Cyperus alopecuroides*, *Cyperus michelianus*, *Mimosa pigra*, *Ambrosia maritima*, *Crypsis aculeata* characterise the 'wet' zone. Denser vegetation was recorded in the 'moist' zone, which is characterised by *Persicaria lanigera*, *Persicaria senegalensis*, *Coccinia absyssinca*, *Phragmites australis*, and *Eclipta alba*.

The 'semi-dry' zone is situated at the lower-middle of the CCA diagram (Fig. 4a, b). Some sites of this zone are characterised by loamy deposits where an abundance of

Fig. 4. ⟵ CCA ordination triplot of shoreline vegetation (●) in relation to the nominal environmental classes (located in the diagram at the centroids of the samples belonging to that class) (Fig. 4a) recorded in 86 sites (Fig. 4b). Shoreline species are Tnil = *Tamarix nilotica,* Hmut = *Hyoscyamus muticus,* Plan = *Persicaria lanigera,* Psen = *Persicaria senegalensis,* Chal = *Cardiospermum halicacabum,* Ccol = *Citrullus colocynthis,* Lfus = *Leptochloa fusca,* Paus = *Phragmites australis,* Icyl = *Imperata cylindrica,* Cabs = *Coccinia absyssinca,* Find = *Fagonia indica.* Simb = *Salsola imbricata,* Pcri = *Pulicaria crispa,* Mper = *Mimosa pigra,* Prep = *Panicum repens,* Abli = *Amarnthus blitoides,* Glot = *Glinus lotoides,* Amar = *Ambrosia maritima,* Pdio = *Pluchea dioscoridis,* Pinc = *Pulicaria incisa,* Aliv = *Amaranthus viridis,* Avog = *Astragalus vogelii,* Btou = *Brassica tournefortii,* Cmur = *Chenopodium murale,* Cacu = *Crypsis aculeata,* Csch = *Crypsis schoenoides,* Calo = *Cyperus alopecuroides,* Cmic = *Cyperus michelianus,* Erau = *Echium rauwolfii,* Ealb = *Eclipta alba,* Eaeg = *Eragrostis aegyptiaca,* Fbis = *Fimbristylis bisumbellata,* Hsup = *Heliotropium supinum,* Lara = *Lotus arabicus,* Olin = *Oligomeris linifolia,* Pole = *Portulaca oleracea,* Rden = *Rumex dentatus,* Saeg = *Senesio aegyptius,* Snig = *Solanum nigrum,* Sdur = *Sorghum dura,* Tgla = *Trigonella glabra*. Nominal environmental classes: moisture zones (■) are 'wet', 'moist', 'semi-dry' and 'dry'; deposits texture type (□) 'silt', 'loam', 'sandy loam', 'sand' and 'gravely sand'; and deposits thickness (≡) 'thin' and 'thick'. Sites (O) numbers ended by the letter 'a' are from the 'wet zone', 'b' from the moist zone, 'c' from the 'semi-dry zone' and 'd' from the 'dry zone'.

Tamarix nilotica, *Imperata cylindrica*, *Panicum repens* and *Trigonella glabra* was observed. Other sites are characterised by thinner deposits of gravelly-sandy texture (on the right hand side of the CCA diagram, Fig. 4a), where *Fagonia indica* and *Citrullus colocynthis* were common. On the left hand side of the CCA diagram, other sites belonging to the same zone were characterised by thicker sandy-loam deposits, where *Eragrostis aegyptiaca*, *Amaranthus viridis*, *Crypsis schoenoides*, and *Portulaca oleracea* were observed. Some of the 'b' sites penetrate to the lower part of the diagram where sites labelled 'c' are located (Fig. 4b).

The 'dry' zone (at the top-right hand corner of the CCA diagram, Fig. 4a) is characterised by shallow sand deposits and by the presence of *Hyoscyamus muticus*, *Salsola imbricata*, *Astragalus vogelii*, *Oligomeris linifolia*. All sites labelled 'd' were clearly separated from the rest of the sites (Fig. 4b).

Discussion

A total of 65 species (of them six submerged macrophytes and two cultivated species) belonging to 25 families were recorded in the Lake Nubia area. This figure is less than the 119 species (of them 30 species are cultivated crops and 13 species are agricultural weeds) reported by AHTI et al. (1973) in the area from Wadi Halfa to Gemi, and is closer to the total 64 recorded by PETTET et al. (1964) in the same area. In the present study 27 species are new records to the area, not reported by previous studies. These species are *Amaranthus blitoides, Astragalus vogelii, Brassica tournefortii, Chenopodium murale, Coccinia absyssinca, Cocculus pendulus, Crypsis aculeata, Cyperus alopecuroides, Eragrostis aegyptiaca, Gnaphalium luteo-album, Heliotropium supinum, Herniaria hirsuta, Hyoscyamus muticus, Hypericum triquetrifolium, Leptochloa fusca, Ludwigia erecta, Oligomeris linifolia, Persicaria lanigera, Persicaria senegalensis, Pluchea dioscoridis, Polygonum plebejum, Polypogon monspeliensis, Pulicaria incisa, Panicum repens, Rumex dentatus, Senecio vulgaris,* and *Trigonella glabra*. These findings indicate the pronounced effect of the lake formation on the flora of the area. Sørenson's similarity index between the two studies of PETTET et al. (1964) and AHTI et al. (1973), was 69%. This may be due to variation in the sampling site locations (e.g. close to cultivated land or towns), although the two studies were in the same area at the same time (in 1962). The present study was less similar to the above two studies (34% and 39%), indicating that the flora of the area has greatly changed after about 40 years of lake formation, as predicted by GHABBOUR (1972). The inundation of almost all farmlands should have reduced the weed species recorded by AHTI et al. (1973).

Sites from the wet and the moist zones are similar in term of their species composition and type and depth of deposits. Therefore, CCA could not sharply distinguish between them on the diagram. However, sites sampled from the dry zone were clearly distinguished from the rest of the sites of other zones, because they contained distinct desert vegetation elements (e.g. *Salsola imbricata*, *Astragalus vogelii*, *Oligomeris linifolia*) as well as sand deposits that were not recorded in any of the other zones. On the other hand, some sites from the moist zone were quite similar to other sites from the semi-dry zone. These sites are intermediate transitional sites between the two zones.

The study revealed that the semi-dry zone can be subdivided into three sub-zones, according to the deposit type as well as the species that distinguish them: (a) a sub-zone with thin gravely-sand deposits, where *Fagonia indica, Citrullus colocynthis, Rumex dentatus,* and *Echium rauwolfii* were abundant, mainly in sites from the northern sector; (b) a sub-zone with loam deposits, characterised by *Tamarix nilotica*, *Amaranthus blitoides*, *Panicum repens*, *Imperata cylindrica*, and *Trigonella glabra,* mainly in sites from the middle sector; and (c) a sub-zone with sandy-loam deposits dominated by annuals and/or short living perennials, e.g. *Amaranthus viridis*, *Portulaca oleracea*, *Pulicaria crispa*, *Crypsis schoenoides*, and *Eragrostis aegyptiaca*, mainly in sites from the southern sector.

Looking at the strategies of the plants present at each of the four recognised moisture zones, some plant traits can be used directly to associate them with Grime's plant strategy theory (GRIME et al. 1986, MURPHY 1990, MURPHY et al. 1990). Species recorded in the wet and the moist zones are mainly disturbance-tolerant with little stress evidence (disturbance traits: e.g. annuals and a few short-living perennials, growing rapidly, flowering early, producing large vegetative propagules and/or with vigorous seed production). Most of the species in the 'semi-dry' zone are competitive-stress-tolerant (stress traits: e.g. perennials, deeply rooted; competitive traits: e.g. high biomass, high water requirement). Species that characterise the 'dry' zone are stress-tolerant (stress traits: e.g. xerophytic, rigid waxy leaves or very small-sized leaf, perennials, deeply rooted).

Water level fluctuation is considered by many authors the most important factor that controls the distribution of shoreline (SPRINGUEL et al. 1990, 1991) and aquatic vegetation (e.g. RØRSLETT 1989, ALI et al. 1995). SPRINGUEL et al. (1991) found that elevation and period of inundation divided the Lake Nasser shore into four moisture zones. On the other hand, FRIEDEL et al. (1993), found that texture of deposits, as stated in studying vegetation changes in arid Australian landscapes, is also an important factor. The present study revealed that these same factors also play together an important role in governing the distribution of the shoreline vegetation. In the Lake Nubia aquatic ecosystem, it seems likely that stress is produced by high turbidity due the sedimentation process that takes place in Amka and El-Dewishat, 364 km and 431 km south of the Aswan High Dam, respectively (HDA 1982). In addition, total phosphates and electric conductivity were the most important water variables that influenced the growth and the distribution of the recorded aquatic plants, while nitrate and nitrite were less important. These findings agree with those reported by BEST (1979) and ALI et al. (1995). The submerged aquatic plants recorded here are stress-disturbance tolerant (MURPHY 1990, ALI et al. 1999).

The present paper recommends a long-term study to follow up the development of the vegetation populations and the role of sediment transportation in this process. In addition, monitoring of vegetation communities with a high degree of ecological preservation is needed for the sake of future comparisons as a reference frame.

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