Permanent swamp vegetation of the Upper Nile

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Abstract

This paper describes vegetation in the nothern Sudd area of the Sudan. A visit by boat was made in April 1978 along the White Nile from Malakal to Lake No; to the inflow regions of the Bahr el Jebel, the Bahr el Zeraf and to the Bahr el Ghazal. Only the vegetation along the fringe of the rivers was observed as plants were tall and dense and it was not possible to penetrate into the inner swamps.

The outer edge of the vegetation was fringed by extensive mats of free-floating *Eichhornia crassipes* which was easily dislodged and formed floating islands to be carried downstream. The main rivers, excluding the Bahr el Ghazal, were too deep and turbid to support beds of submerged species but plants such as *Ceratophyllum demersum* could be found amongst floating plants.

Vossia cuspidata usually produced a broad zone to the landward of *Eichhornia*. It dominated the shallow water with a floating raft of stems growing out from the shore over the water surface. Massive stands of *Cyperus papyrus* and/or *Phragmites karka*, over 5 metres tall, dominated the vegetation behind and sometimes excluded the *Vossia* zone. The papyrus could form dense, floating rafts of rhizomes at the water's edge, but *Phragmites* always remained firmly rooted to the bottom. Floating papyrus and *Vossia* would become detached from the main beds and drifted downstream with *Eichhornia*.

Creepers were common amongst papyrus but less common amongst *Phragmites* where the vegetation was generally more dense. Large stands of *Typha domingensis* were observed behind the fringe vegetation.

The vegetation of the Bahr el Ghazal, in marked contrast to the rest, was stunted, and reasons for this are suggested. Species diversity was greater and the less turbid waters allowed considerable development of floating-leaved and submerged species.

Estimates of fresh weights and heights of dominant vegetation types were attained but methods were very laborious and alternative ways have been suggested. The fresh weight of *Eichhornia* from a one metre square quadrat in the White Nile was around 70 kg. The shoots of *Phragmites* weighed 18.5 kg and *Cyperus papyrus*, 11.0 kg m^{-2}.

Introduction

Early records of Sudd vegetation arise from passage through navigable channels of the Nile from Malakal to Bor, Mongalla or Juba. The gradient of land between Malakal and Mongalla is shallow and in places is only about 1 cm per kilometre (E.N.P., 1954; Table 1). Downstream from Mongalla the water spills laterally into lakes, side channels and swamps; some flows back into the main river but much is lost by evapo-transpiration. In places the side channels form distinct river systems such as that of the Atem, on the east of the Bahr el Jebel, north of Bor. The Bahr el Zeraf, which

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probably has its headwaters in the swamps of this area also, flows north parallel to the Bahr el Jebel, and is joined to it artificially by the Zeraf cuts. Only the southern cut is still open and water from the Bahr el Jebel flows through it into the Bahr el Zeraf (Fig. 1). The Bahr el Zeraf meanders to the east of the Bahr el Jebel before joining the White Nile. The Bahr el Jebel joins the Bahr el Ghazal where the latter flows out of Lake No, the combined rivers forming the White Nile. The Bahr el Ghazal drains the swamps to the south-west of Lake No. Zeraf Island, the triangle of '*terra firma*' which is bounded by the Bahr el Zeraf, the Bahr el Jebel and the White Nile varies in terrestrial area depending upon water levels; recently it has been almost entirely inundated. The whole area is susceptible to swamp development and in 1954 the permanent swamp was estimated to occupy some 8 300 km^2. As a result of the heavy rains in East Africa during 1961–1962, water flow along the Bahr el Jebel from the Victoria Nile and Albert Nile has increased and water levels have risen substantially to extend the area of swamp to nearer 16 000 km^2 (Lock, pers. comm.).

South of Bor the river flows in a distinct broad swamp trough with well-defined raised banks and within this, the river branches and meanders. North of Bor there are no defined banks and ramifications of the river pass through the swamp creating deep channels. Islands of floating vegetation drift down these to form the notorious floating Sudd which hinder navigation and trap boats. Demarcation between the swamp edge and the floating islands is frequently obscure and accumulation of floating vegetation may cause the main flow of the river to be diverted. At its outer limits the swamp grades into extensive areas of seasonally flooded grassland or *Toich* which provides valuable grazing land.

With the possibility of cutting a canal, the Jonglei Canal, to bypass the Sudd and divert some of the water more directly northwards (the Equatorial Nile Project, E.N.P.) various surveys have been undertaken which provide the bases of most of our present knowledge (E.N.P. Jonglei Investigation Team, 1954; Euroconsult, 1976, 1977; UNEP/FAO Technical Report, 1977). The Jonglei Investigation Team (E.N.P., Vol. 1, pp. 140–142; 150–166), and Sutcliffe (1974), a participant of the team, provide a good general account of the Sudd and especially the vegetation of the Upper Nile between Juba and Bor. An excellent study and comprehensive report by Migahid (1948) is the only real attempt to describe the vegetation of the central swamps, and Rzoska (1974; 1976) outlines the limnology and gives some account of the vegetation of the northern swamps (in the region of the current work). The swamps of East Africa and the headwaters of the Nile have been studied much more fully and provide good introductions to swamp vegetation (e.g. Carter 1955; Thompson 1976; Gaudet 1977). The canal is now being cut and over the last few years, renewed activity is rapidly expanding our knowledge of the swamp vegetation, but the difficulties of working in the Sudd still means that much is to be achieved.

I joined Dr Moghrabi and his survey team at the Hydrobiological Research Unit, the University of Sudan, in a pilot project in 1978 and examined stands of vegetation within the northern region of the Sudd. My gratitude is extended to Dr. Moghrabi, to the Unit and boat teams, and to my colleague Professor Green, without whose assistance the information could not have been gathered.

Methods

In April 1978 a journey by boat was made westwards along the White Nile from Malakal to the Lake No area. The vegetation bordering the river was noted and stops were made to study sites of special interest. It was not possible to penetrate the swamp on foot for more than a few metres and only fringe vegetation could be described in any detail. At some of the sites, short transects were laid at right angles to the river and total vegetation within 1 m^2 quadrats was recorded.

Specimens of all species were collected, pressed, dried and labelled, and a complete set were deposited in the Herbarium, the University of Khartoum. A set was also deposited in the Herbarium of the Royal Botanic Gardens, Kew, England, and a third was deposited at the Waterplant Herbarium, Westfield College, University of London. A list of species is given in Appendix I.

Attempts ware made to estimate the fresh weights m^{-2} of some dominant species by placing quadrats randomly within a uniform patch of vegetation. In stands of *Eichhornia*, all plants within a quadrat were removed: each plant was allowed to drip for approximately one minute; was weighed on a spring balance to obtain a fresh weight value, and the length of the longest root and tallest leaf was measured. In the case of *Cyperus papyrus*, culms were cut just above the rhizome. Measurements were made of the circumference of each culm at the base, and the height of the culm was measured to just below the head. The maximum diameter of each head, and the total fresh weight of culms was noted. In a stand of *Phragmites* shoots were cut from the rhizomes; the height, and diameter of the base of each shoot was measured, and the total fresh weight of shoot in the quadrat was recorded.

Description of vegetation

The areas under investigation include: the White Nile between Tonga and Lake No; the Bahr el Ghazal and Bahr el Jebel in the Lake No area; and the Bahr el Zeraf as it enters the White Nile (Fig. 1).

Around the Tonga area the Nile river was clearly demarcated and vegetation zones of free-floating and emergent plants were distinguishable. The river was broad and the open water was too deep and turbid to support submerged vegetation, but its steady flow carried a continuous supply of the free floating plant, *Eichhornia crassipes*, downstream. The river margins were bordered by the emergent grass, *Vossia cuspidata* (Fig. 2a). An outer zone of *Vossia*, 8–10 m wide, spread from the shore into the water and rhizomes anchored the plants in the substrate to a water depth of about one metre. Shoots and floating rhizomes from the plants spread over the water surface to form a raft of vegetation 1–2 m high, and covered water up to 4.5 m deep. *Eichhor-*

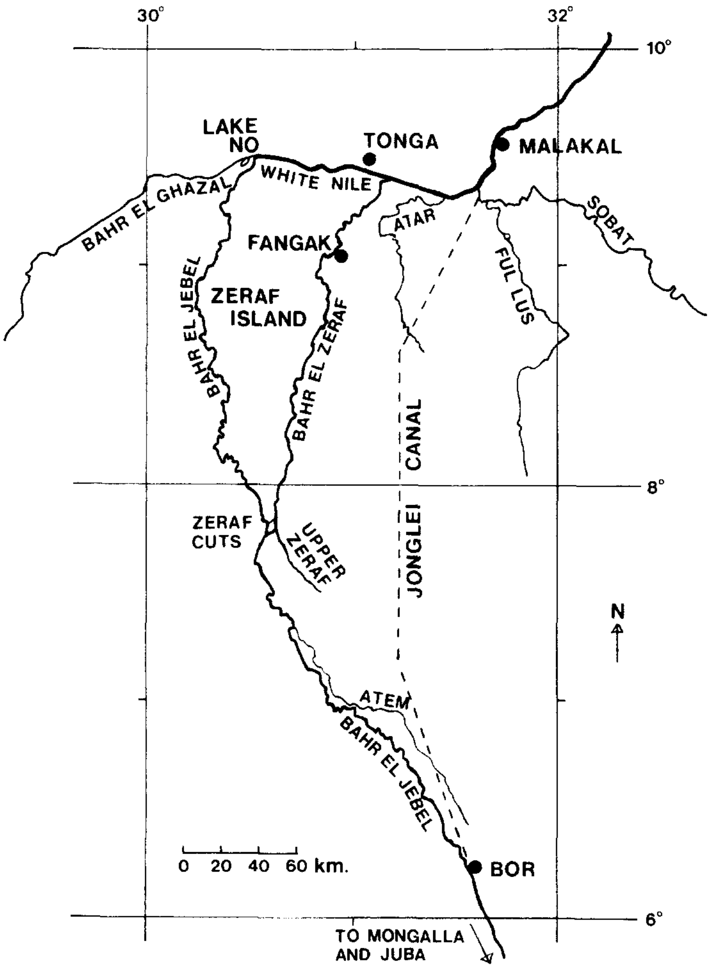

Fig. 1. Map showing the Upper Nile region of the Sudan.

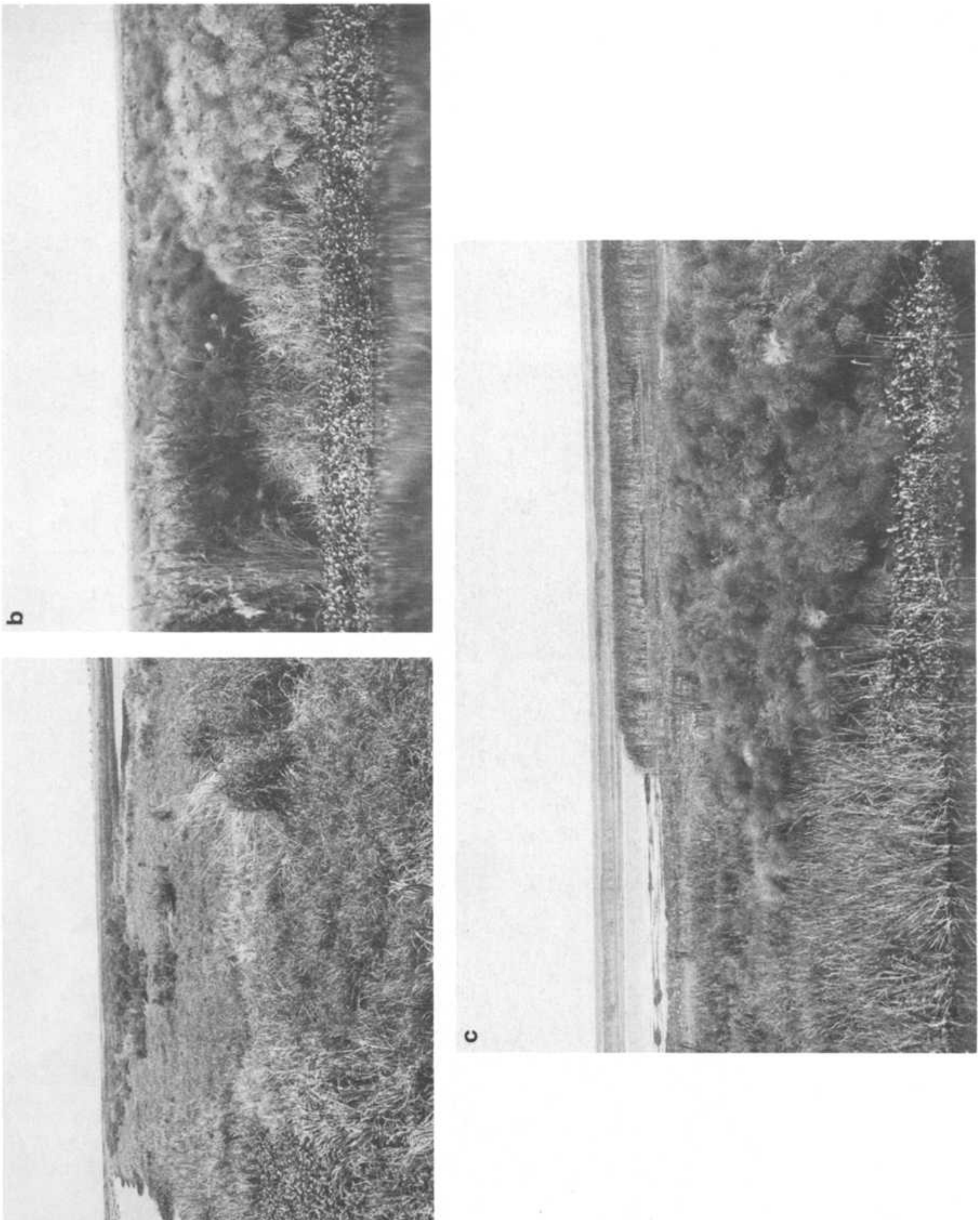

Fig. 2. Photographs showing the different types of vegetation seen in the Sudd. (2a) The White Nile near Tonga showing *Vossia*-dominated vegetation with indentations of *Eichhornia*. Occasional outcrops of *Phragmites karka* can be seen amongst the *Vossia*. (2b) The White Nile towards Lake No. *Phragmites* and *Cyperus papyrus* dominate the vegetation whilst *Vossia* and *Eichhornia* are restricted to the outer fringes. (2c) The mouth of the Bahr el Ghazal at Lake No. *Vossia* and *Eichhornia* can be seen in the foreground with poorly-developed papyrus. Behind the papyrus a pool of water-lilies *(Nymphaea lotus)* are established and, in the background, *Typha domingensis* stretches back as far as the eye can see. (2d) A dense stand of *Phragmites karka*, over 5 metres tall, along the white Nile. (2e) A dense stand of *Cyperus papyrus* in the Bahr el Jebel, south of Lake No. Note the creepers entangling the culms. (2f) A birds-eye-view of a newly described emergent plant, *Suddia sagittifolia*, belonging to the family, Poaceae, discovered amongst the payrus of the White Nile.

nia crassipes grew amongst the *Vossia* and created regular indentations several metres broad, of dense, floating vegetation. In places the *Eichhornia* formed a distinct zone, 2–3 m wide, outside the *Vossia*. The largest *Eichhornia* occurred in the middle of the indentations and had a biomass of 70 kg m^{-2} fresh weight (Table 1), but plants diminished in size towards the water's edge. Those on the edge were insecure and tended to get washed away.

Amongst the fringe vegetation, where some protection from the flowing river was afforded, small clusters of *Lemna gibba, Spirodela polyrrhiza,* and *Azolla nilotica* floated on the water surface and, very rarely, a *Pistia stratiotes* plant was found. Some *Ceratophyllum demersum* grew amongst the roots of *Eichhornia* and strands of the creeping sedge, *Cyperus mundtii* (= *Pycreus mundtii*) spread amongst the floating *Vossia*.

The water level was low and behind the outer fringe of *Vossia* the swamp raft was suspended on pillars of mud 60 cm above the water. Beyond, the *Vossia* formed a broad expanse of coarse grassland. This had been recently burnt and young shoots up to 70 cm tall were sprouting from the rhizomes. Small islands of *Phragmites karka* and *Cyperus papyrus* were trapped in the *Vossia* but no other species could be seen. In the drier areas affected by habitation attempts had been made to clear the *Vossia* and an invasion of short grass had occurred. Set back from the river, lagoons of flowering waterlilies, *Nymphaea lotus,* could be seen.

This pattern of vegetation, dominated by *Vossia* with pockets of *Eichhornia,* recurred for many kilometres as one progressed upriver but towards Lake No the *Vossia* became increasingly displaced by *Cyperus papyrus* or *Phragmites karka.* These being much taller, tended to enclose the river so the vegetation beyond could not be observed. One gained the impression that papyrus predominated but *Phragmites* made large inroads into the papyrus beds. The *Vossia* was now confined to small clumps at the edge of the swamp and a narrow band of *Eichhornia,* not more then 2 m wide, fringed the outer vegetation (Fig. 2b). The *Cyperus papyrus* formed a uniform canopy of vegetation about 4 m tall and at the edge of the swamp the culms leaned outwards over the water. Stands of papyrus were not examined closely here but few species other than the creeper, *Ipomoea cairica,* were apparent. The *Phragmites* tended to be taller than the papyrus: rhizomes formed a closely knitted raft rooting in the soft mud at the water surface and a mass of shoots, up to 5.5 m tall, excluded species other than *Ipomoea cairica* (Fig. 2d). The density of shoots was high (86 shoots m^{-2}) and their fresh weight at the fringe was estimated to be 18 kg m^{-2} (Table 1).

At Lake No the river opened out into a broad, shallow expanse of water with shallow-sloping shorelines. *Eichhornia* was much more in evidence and in places, the shore could only be approached through a zone over 40 m wide. A study at the south shore showed that within the more stable floating mats of *Eichhornia, Vossia* plants were becoming established. Larger areas of *Vossia* occurred inside the *Eichhornia* zone in about 1 metre of water but *Cyperus papyrus* and *Phragmites* dominated the swamp behind. Papyrus rhizomes spread out from the swamp to form a floating raft over water 1–2 metres deep but the *Phragmites* remained firmly rooted to the bottom.

In shallow, open water (1–2 metres), submerged beds of *Najas pectinata* were recorded and amongst the floating vegetation, *Ceratophyllum demersum; Lemna gibba; Spirodela polyrrhiza* and occasional *Pistia* were found. Tangled with the roots of *Eichhornia* the small, delicate *Utricularia, U. gibba* ssp. *exoleta* abounded whilst the creeping sedges, *Cyperus mundtii* and *Fimbristylis subaphylla,* and an aquatic grass, *Echinochloa sp.* grew in the floating mat of papyrus rhizomes. *Nymphaea lotus* occurred in shallow pools within the swamp.

The Bahr el Ghazal, flowing into Lake No from the west, was a smaller river and carried less silt. The vegetation was not so tall and lush and large stands of *Typha domingensis* were observed to stretch back as far as the eye could see (Fig. 2c). At the river's edge species diversity increased. Submerged beds of *Potamogeton pectinatus; P. bunyonyiensis, P. schweinfurthii* and *Najas pectinata,* were all common. *Trapa natans* and *Nymphaea lotus* grew in shallow water, 0.5–1.0 m in depth, where *Eichhornia* had not encroached but the latter predominated the fringe vegetation. *Ceratophyllum demersum,* Lemnaceae, and *Utricularia gibba* again occurred with the *Eichhornia* whilst flowers of the larger *Utricularia, U. inflexa,* emerged between plants. Strands of the submerged, carnivorous species, *Aldrovanda vesiculosa* (Droseraceae), were collected from the roots of *Eichhornia,* and *Limnophila indica* was washed up in the fringe emergents. Smaller cyperaceous plants including *C. mundtii* and *Scirpus cubensis*, and the grass *Echinochloa sp.*, grew in the inner *Eichhornia* zone, and an occasional plant of *Ludwigia leptocarpa* was observed. The fringe vegetation was dominated by *Vossia* but it was shorter than previously observed – not greater than 1.5 m tall – although still producing a distinct zone behind the *Eichhornia*. Amongst the *Vossia*, fronds of a fern emerged. *Phragmites* was less common, and patches of papyrus alternated with *Typha* in the fringe zone before the extensive stands of *Typha* behind.

Westward to approximately 30° 0′E the pattern of vegetation remained similar with the fringe being dominated by *Vossia*, with occasional stands of *Cyperus papyrus* and, rarely, *Phragmites*. The *Eichhornia* zone had become much reduced being replaced in the sheltered inlets and open water by a floating-leaved plant zone dominated by *Nymphaea lotus* and *Trapa natans*. *Nymphaea caerulea* and *Ottelia ulvifolia* made their first appearances and beds of submerged plants were widespread. Behind the *Vossia*, stands of *Typha* and a mixture of Cyperaceae, including *Scirpus cubensis*, prevailed. The *Scirpus* increased markedly up river. The most noticeable change in the vegetation, however, was the paucity of growth compared with down river. The *Vossia* was only 1.3 m high and the papyrus plants were spindly and rarely over 2 metres. *Phragmites* was reduced to thin stems, 2–3 m tall and the *Eichhornia* plants were badly stunted with a fresh weight value of 32 kg m^{-2}, and leaves no more than 40 cm tall (Table 1.).

In marked contrast to the vegetation of the Bahr el Ghazal, that of the Bahr el Jebel was very tall and it was not possible to see beyond the swamp edge. At 1 km south of Lake No a vegetation study was attempted. The swamp there was dominated by *Cyperus papyrus* to the exclusion of other tall emergent species (Fig. 2e). The rhizomatous raft, which was at least 1–2 m thick was supported on soft mud and the swamp water lay between the surface rhizomes. The familiar outer fringe of *Vossia* was absent and *Eichhornia* existed only as occasional plants. The river was too deep to support any submerged vegetation but *Lemna gibba* and *Azolla nilotica* occurred in pools amongst the papyrus rhizomes.

Patches of *Polygonum pulchrum* grew 1–2 m tall on the papyrus raft at the outer edge of the swamp whilst *Commelina benghalensis*(?) spread over the swamp floor.

The papyrus culms were up to 4 m tall and supported a head often in excess of 1 m diameter. Total fresh weight of culms plus heads cut from a square metre weighed 11 kg (Table 1) but the stands were more 'open' than the *Phragmites* stands of the White Nile (only 18–20 culms m^{-2} compared with >80 stems of *Phragmites*). Inside the swamp the large heads of papyrus propped each other up but towards the edge the weights of the heads caused the culms to bend and lean. This provided a sufficiently open canopy for a variety of creepers and climbers to grow and indeed, the twining of these around the papyrus made the cropping of individual culms particularly tedious. Species included: *Melanthera scandens* ssp. *madagascariensis* (the yellow flowered composite); *Cayratia ibuensis (= Cissus ibuensis); Ipomoea rubens (=I. riparia)*, and *Luffa cylindrica* (with its bath sponges hanging down!).

The vegetation of the Bahr el Zeraf along the last few kilometres before it joins the White Nile has similarities with that of the White Nile beyond Tonga. Five kilometres from the mouth the river was relatively narrow (40–60 m wide) and fast flowing and carried many floating islands of *Eichhornia* downstream. Occasionally, some *Vossia* had become dislodged with the *Eichhornia*. The river had a distinct bank which confined the aquatic vegetation to a narrow zone (7–10 m) of *Vossia* mixed with *Eichhornia*. The emergent shoots of *Vossia* were fairly short (1.0–1.5 m) but floating shoots spread from the bank over the water to a depth of nearly 4 metres. Robust *Eichhornia* plants, with leaves up to 90 cm tall, grew in the floating raft. Submerged plants were absent and no other species was recorded. *Echinochloa* sp. grew to the landward of the *Vossia* and good pastureland, managed from many small villages along the bank, spreads back from the river.

A highlight of the journey was the finding of an undescribed swamp species. The plant was first observed on the north shore of the White Nile west of Tonga amongst papyrus, growing to a height of 2.5 m (Fig. 2f). Occasional plants were also seen in small patches along the Bahr el Ghazal where the bright green leaves contrasted with other emergents. The plant is rhizomatous with roots at each node. From three to five, long (± 1.5 m), terete, fibrous petioles, up to 7 mm in diameter, emerge from the rhizome within a protective sheath, and each supports a linear-lanceolate leaf. The leaf blade is about 1 m long, 12 cm broad, and has a distinct midrib running into an acute tip. The leaf has parallel venation and a striking feature is found at the leaf base where the leaf lamina extends back, beyond the joint with the petiole, and returns to produce a sagittate base. No flowers were found but recently flowering spikes have been collected from the south of the swamps by Dr Lock and others. This confirms that the plant is a member of the Poaceae. It has now been described and named *Suddia sagittifolia* Renv.

Quantitative analysis

Table 1 provides some quantitative data on vegetation.

The fresh weight per unit area of *Eichhornia* in the White Nile was about twice that of the Bahr el Ghazal and the plants were much larger. Even those plants from the Bahr el Ghazal deliberately selected for their greater size were not as heavy as the average *Eichhornia* plant from the White Nile. The longest leaf (petiole + blade) on each plant was measured to obtain an estimate of the average height of the plants and it can be seen that the *Eichhornia* of the White Nile were approximately three times as tall as those of the Bahr el Ghazal. It was not uncommon to record individual plants of up to a metre tall and 1.9 kg fresh weight in the White Nile but these dimensions were never reached in the Bahr el Ghazal. The same cannot be said for the roots of the plants. Although root length was much more variable than shoot length the roots of plants from the Bahr el Ghazal were always longer. The longest roots were mainly (59%) in the range 60–80 cm. 18% of plants had roots greater than 80 cm long and of these, several were greater than one metre. In direct contrast, nearly half (49%) the plants of the White Nile had roots in the range of 40–60 cm and 29% were below 40 cm long: none were over 70 cm long. Whilst the roots of those plants growing in the White Nile were invariably shorter than the shoots (root:shoot ratio = 0.5) the opposite was true for plants from the Bahr el Gazal

Table 1. Quantitative data from stands of vegetation within the Sudd.

Site	No. of plants (m^{-2})	Mean length of tallest shoot (cm)	Mean length of longest root (cm)	Mean fresh weight of plant (g)	Total fresh weight of plants per m^2 (kg)
EICHHORNIA CRASSIPES					
White Nile					
Tonga area	63	89 ± 10	46 ± 15	1119 ± 550	70.5
9°28′N; 30°58′E					
Bahr el Ghazal	73	32 ± 5	67 ± 18	438 ± 34	32.0
9°30′N; 30°22′E	(10*)	73 ± 5	106 ± 11	965 ± 175	-
	No. of shoots (m^{-2})	Mean height of plant (m)	Mean diam. of stem base (mm)	Mean fresh weight of shoot (g)	Total fresh weight of shoots (kg)
PHRAGMITES KARKA					
White Nile					
East of Lake No	86	3.1 ± 1.2	14.8 ± 6	215	18.5
9°31′N; 30°31′E					
	No. of culms (m^{-2})	Mean height of culm (excl. head) (m)	Mean circumfr. culm base (mm)	Mean fresh weight of culm (inc. head) (g)	Total fresh weight of culms (kg)
CYPERUS PAPYRUS					
Bar el Jebel					
South of Lake No	18	2.9 ± 1.1	989 ± 144	611	11.0
9°28′N; 30°26′E					

* Ten large plants selected from surrounding area.

(root:shoot ratio = 2.1). Even the largest plants selected from the Bahr el Ghazal did not have a root: shoot ratio of less than one.

The results of a study of a 1 m^2 quadrat of *Cyperus papyrus* from the Bahr el Jebel and a quadrat of *Phragmites karka* from the White Nile are also given in Table 1.

Discussion

The difficulties associated with small survey teams working within the Sudd vegetation prohibit all but the most simple observations and the limitations of this survey are obvious. However, a few sites were studied in some detail and it is hoped that the information gained will be of value.

In most of the areas visited a zonation of vegetation could be distinguished. In deeper water a free-floating fringe of *Eichhornia* was usually trapped by a raft of floating stems of *Vossia* attached in the shallow water to the substratum. To the landward of *Vossia* the conspicuously large emergents *Cyperus papyrus* and/or *Phragmites karka* dominated. The papyrus could extend out into the water on a floating raft but both emergents tended to form a mat of rhizomes on the mud. *Typha domingensis* may extend 'inland' and Migahid (1948) considered it to be an unfailing landmark of higher ground within the swamp. Figure 3 represents a compiled

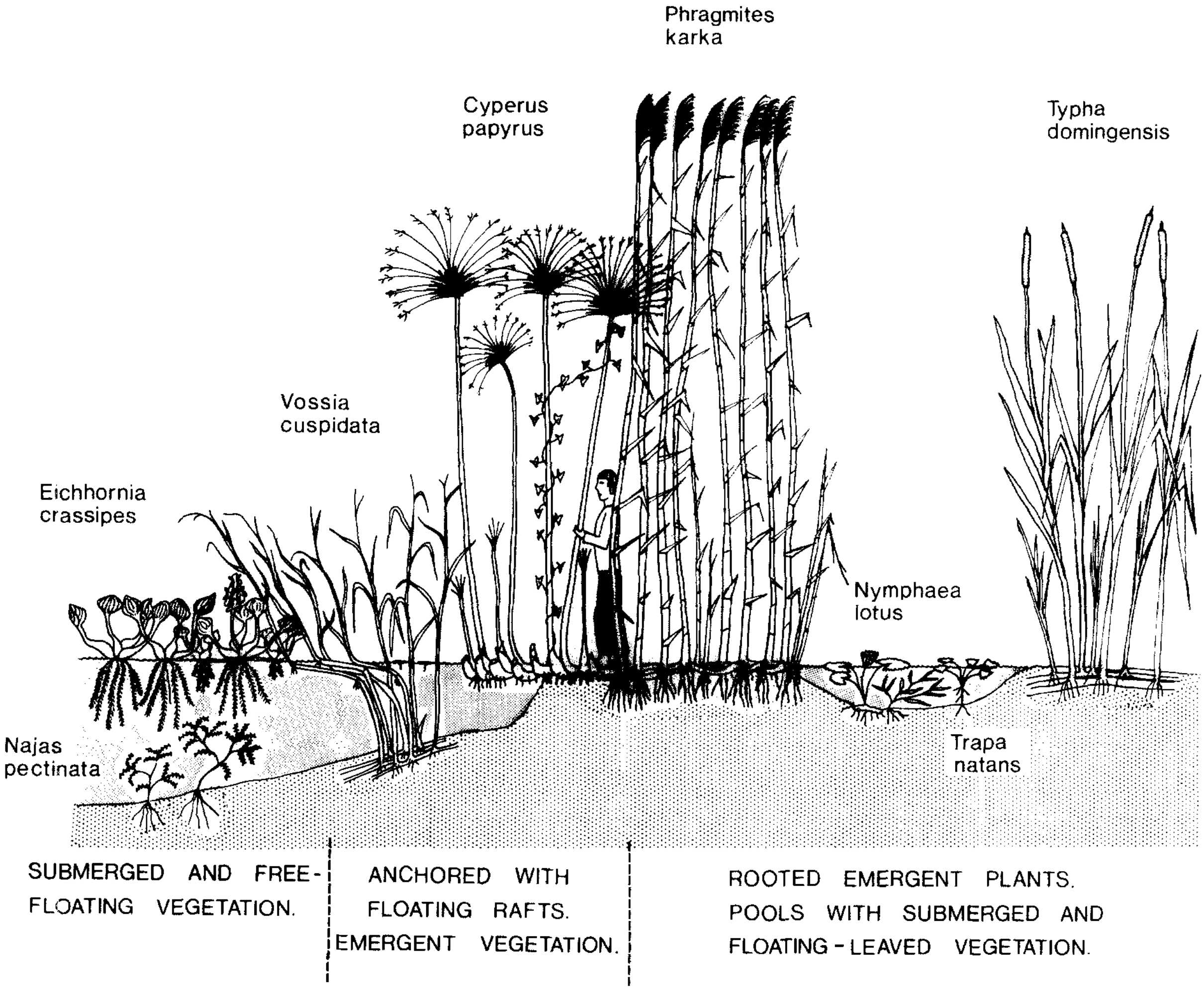

Fig. 3. Theoretical compiled transect of vegetation at the fringe of a swamp in the northern Sudd. The person is drawn to give an indication of vertical scale. The horizontal scale is flexible and arbitary and may represent kilometres.

theoretical transect through fringe vegetation showing the zonation and growth form of dominant species.

The factors which may determine the dominant species of large emergents in the Sudd were not investigated and suggestions only can be made. The growth habit of *Vossia* and its ability to form flexible, floating stems is an excellent adaptation for coping with changes in water level. Vossia is also a component of the seasonally flooded land and can tolerate drying out. However, it would appear unable to compete with the larger emergents *(Phragmites; Typha* and papyrus) and where these flourish it is restricted to their outer fringes. The competition between *Phragmites karka* and *Cyperus papyrus* may relate in part to water level preferences. Certainly, Migahid (1948) felt that *Phragmites* was more capable of enduring terrestrial conditions than papyrus and, in the southern swamps between Juba and Bor, Sutcliffe (1974) found that the transition between *Phragmites*-dominated and papyrus-dominated swamps was correlated with increasing water level: but this is unlikely to be the only controlling factor. Papyrus forms a floating raft of rhizomes and also attaches itself to the mud and thus, it has a degree of adaptation to changes in the water level.

However, although *Phragmites* is firmly anchored to the substratum (hence its lack of occurrence in floating islands), it also has a reasonable tolerance to submergence: in Lake Bunyonyi, S. W. Uganda, I recorded *Phragmites australis* rooted to the bottom in depths of water up to 4.2 m (Denny, 1973). Perhaps nutrient supply also affects distribution, papyrus being more tolerant of oligotrophic conditions.

It was rarely possible to see beyond the fringe vegetation as it was so tall. This has lead to the belief that '... the Sudd vegetation is dominated by papyrus' (UNDP/FAO Technical report 1977), but in areas such as the Lake No and Bahr el Ghazal region where fringe vegetation is shorter, very extensive stands of *Typha domingensis* could be identified. The E.N.P. (1954, p. 142) reported pure stands of *Typha* within the Sudd but considered it not to be a major constituent of the vegetation, but recent aerial surveys suggest that it is widespread (J. M. Lock, pers. comm.).

Eichhornia crassipes is a South American species introduced into Africa around the turn of the century and first reported from the Sudan in 1957 (Gay, 1958). It is now a serious pest and occupies those niches in the Sudd previously colonised by *Pistia stratiotes* (see E.N.P., 1954; Rzoska, 1974) and was the dominant vegetation being carried down river towards Malakal. (Larger floating islands, which had broken away from the swamp edge, had a central 'core' of *Vossia* and/or papyrus and their associated species, and an outer 'skirt' of *Eichhornia.*) *Pistia* can still be found in dense beds in small, isolated backwaters (and it was noted drifting down the river at Malakal) but it is clearly under intense pressure from *Eichhornia.*

The main rivers – the White Nile, the Bahr el Jebel and the Bahr el Zeraf – were quite fast flowing with high silt burdens and beds of submerged plants were absent from the open water. However, plants such as *Ceratophyllum demersum* and *Utricularia spp.* normally could be found in association with floating vegetation at the swamp edge. The quieter waters of the Bahr el Ghazal and the sheltered areas of Lake No. on the other hand, supported broad beds of submerged vegetation especially *Najas pectinata* and *Potamogeton schweinfurthii,* whilst zones of floating-leaved plants *(Nymphaea lotus* and *Trapa natans*) occurred in the shallow water. Pools within the swamps and bodies of water away from the main rivers often had clear water supporting extensive development of submerged and floating-leaved plants (Figs. 2c and 3) – as long as free-floating plants did not cover the surface.

Compared with other regions, the vegetation of the Bahr el Ghazal is remarkable and has been commented upon in the E.N.P. report (1954, p. 142). The report suggested that the stunted growth of plants may be due to the sluggish flow of the river providing a poor supply of oxygen to the plant roots, but Bishai's data (1962) does not indicate this. The Bahr el Ghazal tends to have a lower conductivity and pH, and Rzoska (1974) draws attention to the unusually high diversity of Desmids reported by Gronblad *et al.* (1958). Desmids are typical of oligotrophic waters and the stunted vegetation is more likely to be related to nutrient deficiencies. It is significant that the carnivorous plants *Aldrovanda visiculosa* and *Utricularia spp.* were found amongst the roots of *Eichhornia.* Carnivorous plants are found in oligotrophic conditions and supplement their nitrogen supply by digestion of animal tissues (in this case zooplankton). This points to a shortage of nitrogen in the water although Talling (1957) and Bishai (1962) report detectable amounts. The high root:shoot ratios of the *Eichhornia* plants support this. It is well known that nitrogen deficiency in laboratory cultures of floating plants such as *Lemna* and *Salvinia* is expressed by an increase in the root:shoot ratio (see, for example, Luond, 1980). The *Eichhornia* plants of the White Nile were large and healthy and had root:shoot ratios of about 0.5. Those of the Bahr el Ghazal were stunted and had a ratio of around 2. The difference in the ratio was the result of decreased shoot length *and* increased root length of plants from the Bahr el Ghazal. Was this due to nitrogen deficiency?

Finally, the quantitative data must be considered. The reader will have noticed the lack of replication within a site and the lack of comparative samples from different sites. Further, samples were only collected from the fringe vegetation and no information is provided from within the swamp. Figures 2d, 2e and 3 go some way towards an explanation: the vegetation is tall and dense and movement through it is slow. In addition, the clearing and measurement of fresh weights from even a very small area is laborious. To clear a 1 m^2 quadrat of *Phragmites* shoots to provide the data in Table 1 took the team, working steadily, just over 8 manhours. Replication was out of the question! However, by adapting a technique used by Thompson *et al.* (1979) for papyrus, the stems of *Phragmites* can supply sufficient information for an alternative method of standing crop estimation, *viz:*

If a plot is made of stem basal diameter against height a positive correlation is obtained with a correlation coefficient of $r = 0.58$, significant at the 0.1% level. Therefore, the regression of plant heights, y, on diameter of stem bases, x, ($b = 0.1123 \pm 0.0173$) allows height to be calculated on the basis of $y = 0.1123x + 1.46$ (Fig. 4). Thus, by the simple quick measurement of stem bases *in situ*, the height of the vegetation can be estimated. As height of shoot and fresh weight is also correlated the standing crop can be estimated simply by measuring the basal diameters of all the shoots in a quadrat. In this particular quadrat each mm diameter of stem base was equivalent to 14.67 g fresh weight and thus, a plant with a stem basal diameter of 10 mm would weigh about 147 g and have a height of around 2.58 m.

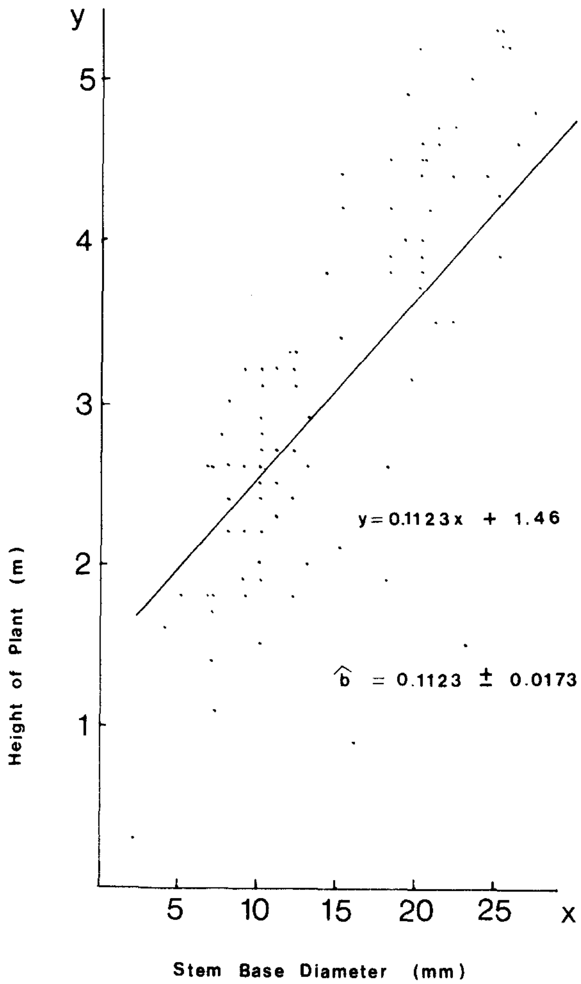

Fig. 4. Plot of diameters of stem bases against heights of shoots of *Phragmites karka* collected from a one metre square quadrat of vegetation in the White Nile. There is a high correlation so measurements of stem bases alone can be used to estimate height.

There is no reason to assume that the relationship between stem base, height and fresh weight is the same at different localities and regular checking is essential but, once the correlations are obtained for a particular, uniform area, standing crop estimates are possible. Thompson *et al.* (1979) obtained similar high positive correlations between culm basal diameter (or circumference), height and dry weight of *Cyperus papyrus*, but there is no comparable data for *Typha*.

Appendix I. Flora of the northern Sudd.

	PTERIDOPHYTES
AZOLLACEAE	*Azolla nilotica* Mett.
	MONOCOTYLEDONS
ARACEAE	*Pistia statiotes L.*
COMMELINACEAE	*Commelina benghalensis L. (?)*
CYPERACEAE	*Cyperus mundtii* (Nees) Kunth
	Cyperus papyrus L.
	Fimbristylis subaphylla Boeck.
	Scirpus cubensis Poepp & Endl.
HYDROCHARITACEAE	*Ottelia ulvifolia* (Planch.) Walp.
LEMNACEAE	*Lemna gibba L.*
	Spirodela polyrrhiza (L.) Schleid.
NAJADACEAE	*Najas pectinata* (Parl.) Magnus
POACEAE	*Echinochloa sp.*
	Phragmites karka (Retz.) Steud.
	Vossia cuspidata (Roxb.) Griff.
	Species nova
PONTEDERIACEAE	*Eichhornia crassipes* (Mart.) Solms-Laub
POTAMOGETONAECAE	*Potamogeton bunyonyiensis* (Denny & Lye)
	Potamogeton pectinatus L.
	Potamogeton schweinfurthii A. Benn.
TYPHACEAE	*Typha domingensis* Pers.
	DICOTYLENDONS
ASTERACEAE	*Melanthera scandens* ssp. *madagascariensis* Schumach & Thonn.
CERATOPHYLLACEAE	*Ceratophyllum demersum* L.
CONVOLVULACEAE	*Ipomoea cairica* (L.) Sweet, Hort.
	Ipomoea rubens Choisy
CUBURBITACEAE	*Luffa cylindrica* M. Roem
DROSERACEAE	*Aldrovanda vesiculosa* L.
LENTIBULARIACEAE	*Utricularia gibba* L. ssp. *exoleta* (R. Br.) P. Taylor
	Utricularia inflexa Forssk.
NYMPHAEACEAE	*Nymphaea lotus L.*
	Nymphaea caerulea Sav.
ONAGRACEAE	*Ludwigia leptocarpa* Nutt.
POLYGONACEAE	*Polygonum pulchrum* Blume
SCROPHULARIACEAE	*Limnophila indica* (L.) Druce
TRAPACEAE	*Trapa natans* L. var. *bispinosa* (Roxb.)
VITACEAE	*Cayratia ibuensis* (Hook. f.) Suesseng.

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