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9. ABSTRACT

Included in this report are twelve articles dealing with the water resources of the Upper Nile, agricultural and aquatic environments of the Sudan, and problems of controlling the spread of water hyacinth, which is interfering with navigation, irrigation, fishing, and supplies of drinking water. For the Sudan the Nile is the main source of irrigation water for agriculture, hydro-power potential, fish supply, riverain grazing, and water transport. Present irrigated areas of 4.6 million acres are supplied by a hierarchical system of supply canals. The estimated surface area of fresh water in the Sudan is about 10 million acres. This is equal to the area of irrigable land to be developed. New dams and water channels are increasing the surface area of water, and means must be found of preventing the spread of water hyacinth and other aquatic weeds in the present and new waterways. The water hyacinth now infests vast areas. It reproduces so rapidly that efforts to control it have been ineffective. Many means have been considered for utilizing the plant in order to recoup costs incurred in efforts to kill it. Much research must be conducted to establish the most effective new means of control, and cost-effective uses of the plant as animal protein. Some of those possibilities are discussed in the articles in this document.

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AQUATIC WEEDS IN THE SUDAN

WITH SPECIAL REFERENCE TO WATER HYACINTH

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NATIONAL COUNCIL FOR RESEARCH
AGRICULTURAL RESEARCH COUNCIL

Khartoum Sudan November, 1975

AQUATIC WEEDS IN THE SUDAN
WITH SPECIAL REFERENCE TO
WATERHYACINTH

Background for the problem in the Sudan

Prepared for

THE WORKSHOP ON AQUATIC WEED
MANAGEMENT AND UTILISATION

Organised by

THE NATIONAL COUNCIL FOR RESEARCH, SUDAN

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CONTENTS

INTRODUCTION

"Water is the best of all things," said the Greek poet Pindar. Rivers, dams and canals are the lifelines of many nations and the threads from which their subsistence and development are woven.

Of the great rivers of the World, the Nile has, without question, admirably, played the most significant part in the early history and development of mankind.

For the Sudan the Nile constitutes the main source of irrigated agriculture, hydro-power potential, fish supply, riverain grazing potential and navigation. At present irrigated areas represent some 4.6 million acres of land. Almost in all of these the system of irrigation consists of a hierarchical system of supply canals. The estimated surface area of fresh water in the Sudan is about 10 million acres which is equal to the area of irrigable land to be developed.

The development of irrigated agriculture is a function of the availability of water. New lakes (dams) and water channels are continuously being formed to provide this water. This increases the surface area of water spread and creates an extensive aquatic habitat with its special environmental consequences.

The treatise presented here deals with the aquatic environment of the Nile, its tributaries and the irrigation canals, specially as far as aquatic weeds are concerned with special reference to waterhyacinth (*Eichhornia crassipes* Marts. Solms) in the Sudan.

Weeds, defined as higher plants which are a nuisance, interfer with one or another of man's activities. Biologically weeds are among the most highly successful plants. Hence, their control has still remained one of the most arduous and expensive tasks.

The waterhyacinth -- one of the most successful aquatic weeds -- has found in the White Nile and its tributaries a most favourable enviroment for spread. The vastness of the infested area, the fantastic productivity and reproductivity of the weed, the deceptive temporal and spatial distributions of floating mats and the expense incurred, have turned, all the efforts to combat this weed species, into a mere lip-stick service.

Many people have considered methods of utilizing waterhyacinth in someway in order to recoup some of the losses involved in trying to kill it. Experiments have been carried out and ideas advocated to turn this plant from 'a curse into a crop' and optimism have described the plant as 'a menace that could be turned to a blessing'.

However, whether a 'curse' or a crop, research and exchange of ideas and experiences are still needed to help in the removal of the curse or the husbandry of the crop.

This treatise represents part of our contribution to the problem. It is written for the general reader, the administrator, the student, and the fresh research worker who is looking for a guide.

I wish to acknowledge the help and enthusiasm of all the writers and to specially thank Dr. M.E. Beshir for editing the first and last contributions in this treatise and Dr. M. Tag El Seed for his patient and careful reading of the manuscript during the typing process.

M. Obeid
Editor

THE WATER RESOURCES OF THE NILE FOR AGRICULTURAL DEVELOPMENT IN SUDAN

BY

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INTRODUCTION

The land area of the Sudan of 2496138 km^2 may be divided in terms of the amount of rainfall and associated vegetation types into the following propotions:-

a) 29% desert stretching over 6 degrees of latitude north of the 17th parallel with an annual rainfall of less than 75 mm.

b) 20% semidesert north of latitude 15 with an annual rainfall of 75-300 mm.

c) 27% savanna lying between latitudes 9 and 15. The total annual rainfall varies between 300-800 mm.

d) 10% of Tropical Forest, Savanna and Flood plants lying to the South of latitude 9 and having rainfall of 800-1200 mm.

e) 14% of Tropical Forest in the High Plateau of the Southern Region with an annual rainfall of up to 1400 mm.

The above distribution of rainfall, despite its low value, is furthermore very highly seasonal in character. The Sudan is, therefore, dependent on its rivers for perennial irrigation for reliable agricultural production. Resort for a source of perennial irrigation is, therefore, made to the Nile systems in the Sudan and since some of its rivers are torrential and run part of the year only, resort is also made to regulate river flows by the construction of dams.

RESOURCES OF THE NILE

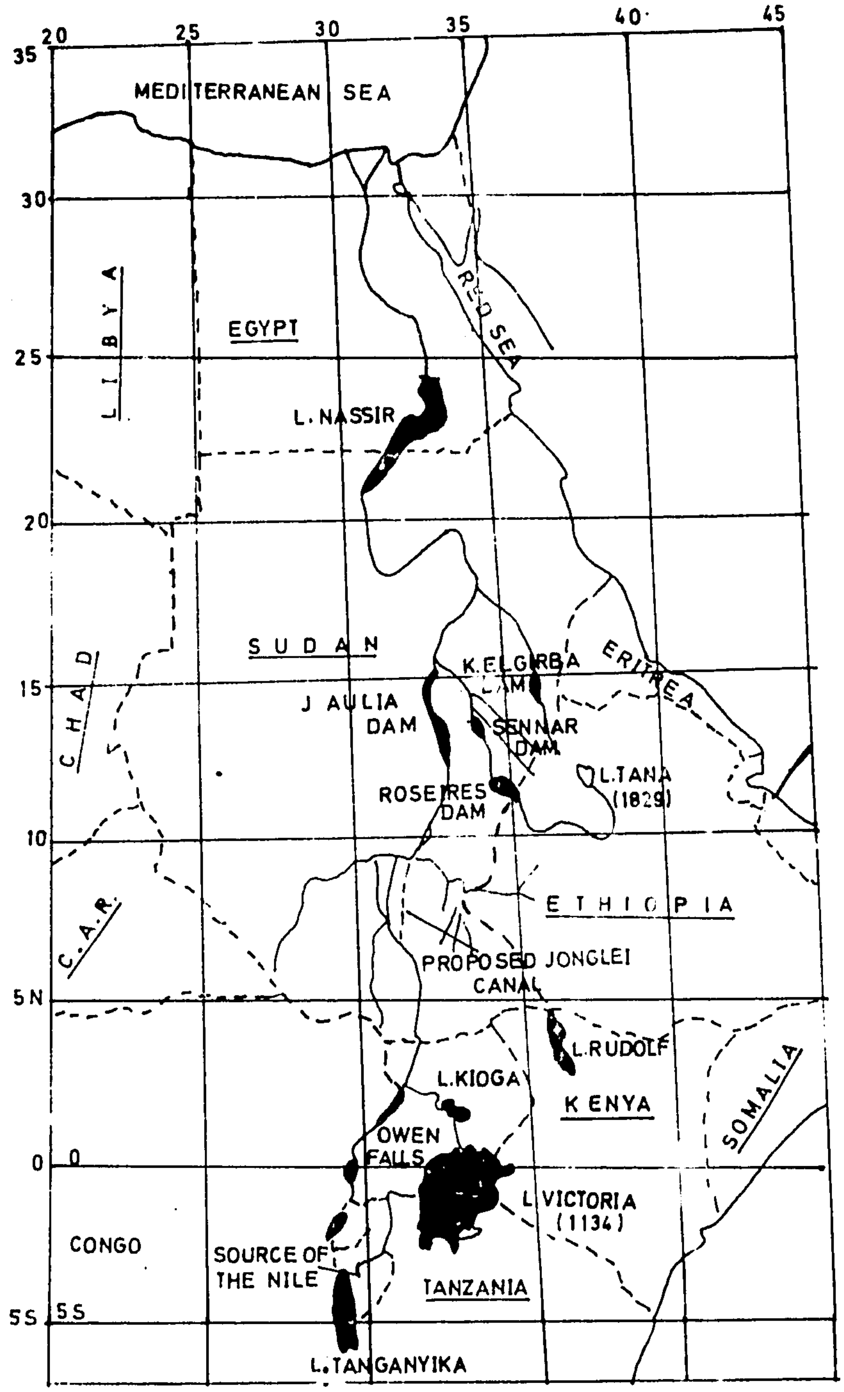
The River Nile and its tributaries constitute the only source in the country for irrigated crop production,hydro-power potential, fish supply, grazing and navigation.

Irrigated agriculture has so far contributed the bulk of the country's wealth and this role will continue to be dominant for a long time to come. The main irrigable lands lie in the vicinity of the Nile and its tributaries, and are concentrated on the 400 mm rainfall belt of the Savanna woodlands bordering the river. Of the estimated 10 million acres of irrigable land, only about 46% is thus far developed comprising the Gezira Scheme, Managil Extension, Khasm El Girba Scheme and the Pump Schemes on the Blue and White Niles.

The hydro-power potential is to be found on Bahr El Jebel from Nimule to Juba with a potential of 1000 megawatts and on the main Nile north of Khartoum with a potential of 800 megawatts. This is in addition to smaller potentials on the other tributaries. Of this potential only 7.5% is presently developed.

The other water resources of the Nile system include :-

1) 1860 km of year-round navigation between Khartoum and Juba, 1000 km on main Nile north of Khartoum to old Halfa, and seasonal navigation on 330 km along the Sobat river.
2) 1.5 million acres of summer grazing in the Southern Region created by the fluctuations of river flows.
3) An annual fish crop of some 100,000 tons.



NILE VALLEY

MAP 1

HYDROLOGY OF THE NILE

The river Nile is the longest river in the World with a length of 6695 km. Its average flow is estimated at 84 milliards which constitute 6% of the total rainfall on its basin. The flow of the Nile has a marked seasonal and annual fluctuation. More than 80% of the annual flow occurs between August and October. The remaining 20% is discharged during the nine months of the year. The annual variation is very great as it varies between 42 milliards recorded in the season of 1913/1914 and a highest maximum of 155 milliards recorded in 1878/1879.*

In the average year, however, the percent contribution to the total flow of the Nile of its major tributaries is as follows :-

Blue Nile	59
Sobat	14
Bahr El Jebel	14
River Atbara	13

Since the Blue Nile, Sobat and River Atbara originate in the Ethiopian plateau, 86% of the flow comes from that plateau and only 14% comes from the Equatorial Lakes and Bahr El Ghazal Basin. The low contribution of these basins is due

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* This description of the hydrology of the Nile system is based on the work of H.E. Hurst, The Nile Basin, Government Press, Cairo 1952 and H.E. Hurst and P. Philips, The Nile Basin Vol. 5, 1938. Records of discharges, areas cropped and water consumptions are abstracted from the records of the Ministry of Irrigation and Hydro-electric power.

primarily to the great losses of water in the Sudd (Swamp) area where an estimated 45 milliards is lost through evaporation and transpiration.

The main tributaries of the Nile are described briefly below :-

The White Nile

The main source of the White Nile is the Equatorial Lakes of East Africa. The river is known first as the Albert Nile which leaves Lake Albert at its northern end and flows through flat plain to Nimule on the Sudan southern frontier. From Nimule the river flows northwards and is known as Bahr El Jebel for 930 km up to its junction with Bahr El Ghazal at Lake No.

After leaving its rocky gorge at Rejaf just north of Juba. Bahr El Jebel enters its Flood Plain inundating it when the levels are high, and forming fringe swamps and marshes which widen and increase gradually until they form the central swamp, or sudd, north of Bor. Here the main course of the river divides into several channels, and forces its way though the thick _Cyperus papyrus_ L. growing on the swamps over an area of some 8,000 km^2. After reaching Lake No. the river turns sharply eastwards until it joins the river Sobat comming from the Ethiopian frontier. Then, as the White Nile, it flows north forming narrow swamps on either bank to a width not exceeding 2 km until it joins the Blue Nile at Khartoum 1940 km from Nimule.

The flows of Bahr El Jebel vary seasonally and annually. The average annual flow is about 29 milliards m^3 with a maximum and minimum of 65 and 15 milliard m^3 respectively. After passing through the swamps, the river emerges with an annual average flow of only 15 milliards. Half the Bahr El Jebel waters together with the contribution of Bahr El Ghazal are lost in the

Sudd swamps.

Bahr El Ghazal which flows in a north eastern direction drains the south west part of the country and the Nile-Congo water divide. Out of a total normal annual inflow of 12 milliards, only 0.6 milliards reach the White Nile through Bahr El Ghazal.

The Sobat river is formed by the junction of two branches: the Baro which rises in Ethiopia and the Pibor which drains part of the eastern plain of the Sudan. It joins Bahr El Jebel forming the White Nile to which it contributes 13.3 milliards.

The total mean annual yield of the White Nile at Malakal is 28.6 milliards made up of the following components measured between 1905-1965,

Bahr El Jebel	14.7
Bahr El Ghazal	0.6
Sobat	13.3

The regime of the White Nile can therefore be summed as follows. It leaves Lake Albert with practically constant discharge due to the balancing effect of the Lake, then enters the Sudan where it is slightly affected by the torrential streams that run part of the year. Then it enters the Swamps, loses half its water and leaves again with a constant annual flow.

The Blue Nile

The Blue Nile originates in Lake Tana and flows through the Ethiopian plateau in a very deep channel for a distance of 805 km before it reaches the Sudan border. Its catchment - area lies wholly within Ethiopia where all its major tributaries join.

The most important tributaries joining the Blue Nile in the Sudan are the rivers Rahad and Dinder.

The Blue Nile is a torrential river and has very high discharge during the flood but very low flows during low stages. It has a normal maximum flood discharge of 562 million cubic meters per day at the end of August and a normal minimum of 6. The highest recorded discharge was slightly in excess of 1 billion per day whereas the minimum recorded was as low as 6 million cubic meters.

The normal annual discharge is 50.5 milliards out of which 46.6 are brought during the flood season between June to November. The rest is discharged between December and May.

The River Atbara

This river is the last tributary of the Nile and rises in the northern part of the Ethiopian plateau. It has two tributaries, the Atbara and the Setit which unite some 50 miles in the eastern Sudan plain and then run in a westerly direction to join the main Nile.

It is also a seasonal torrent and flows between June to November. It has a peak discharge of 300 million cubic meters/day. Out of a normal annual yield of 12 milliards, 11 are passed in four months.

The River Nile

The main Nile is formed by the confluence of the White and Blue Niles and travels a distance of 3058 km to join the Mediterranean. Its length in the Sudan is 1480 km.

The normal yield of the Nile at Khartoum is 77.3 milliards of which the Blue Nile contributes 52.2 milliards.

PERENNIAL IRRIGATION

The dependence of the Sudan on perennial irrigation for crop production has been indicated earlier. The present utilization of the Sudan share of the Nile waters can be seen in Table (1) which summarises the areas under irrigated crop production together with their annual water consumption.

TABLE 1. Irrigated crop production schemes on the Nile system and their water consumption

Scheme	Area ($X10^3$ feddans)	Annual water consumption ($X10^6$ cubic meter)
Blue Nile		
a) Downstream of Sennar	164	976
b) Gezira and Managil	2052	7598
c) Pump schemes upstream of Sennar	452	1595
d) Rahad Phase 1	300	1139
e) Evaporation losses at Sennar reservoir		669
White Nile		
a) Pump schemes including Asalaya and Melut	620	2840
Main Nile		
a) Pump schemes north of Khartoum	420	1603
River Atbara		
a) Khasm El Girba Scheme	372	1700
b) Evaporation from Girba dam		139
Total	4380	18259

1 Feddan = 1.038 acres

The Sudan share of the Nile Water Agreement is 20-35 milliard cubic metres. Out of this sum 18.239 milliards are already committed to irrigate 4.580 million acres (see Table 1.). The balance of some 2.99 milliards is yet to be allocated.

The Ten Years Plan for the Sudan envisages the development of six new agricultural schemes with a total area of 3.041 million feddans and an estimated water requirement of 9.290 milliards.

It is clear that our present share of the Nile water has to be supplemented so that the above development can be completed. Our first effort to supplement our water requirements is the conservation works in the upper reaches of the Nile basin. The first of these is the Jonglei project which is expected to increase the annual yield of the Nile in its first phase by 4 milliards which are now lost in the Sudd area (see above).

CONSEQUENCES OF DEVELOPMENT

Some consequences of development may be inevitable and in this regard the changes in environment that accompanied the large-scale storage by the Aswan High Dam in Egypt, for example, show the impact of development on the natural environment.

The century storage behind the High Dam has resulted in shifting the tail of the Nile Delta to the south and left the Nile itself now but a system of canals being fed daily by silt-free water from the Dam. This has resulted in the erosion of the river bed and the spread of water weeds including the waterhyacinth.

Some problems may be on the way for us as we use more and more of the Nile water by building or heightening our dams and through the creation of a new environment while attempting the reclamation of the swamps to increase the yield of the Nile.

As far as aquatic weed growth is concerned it can be expected that the creation of large bodies of clear water as reservoirs or canalization systems with slow rate of water flow will be conducive to aquatic weed growth.

In addition it should be expected that any changes in the regime of water flow will induce considerations of the mode of life of human settlements and their socio-economic interests. These are only two examples of a host of problems that can be anticipated.

Therefore the integrated evaluation of development schemes whether for power, navigation, crop production or industry is essential and their possible impact on the natural environment needs to be carefully evaluated.

AQUATIC ENVIRONMENTS IN THE SUDAN WITH SPECIAL REFERENCE TO THE GEZIRA CANALIZATION SYSTEM

BY

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INTRODUCTION

Aquatic plants colonise different and variable water habitats which include standing and flowing, fresh, brackish and saline waters. Their extent of distribution ranges from the cold temperate regions to the tropics. Aquatic plants are either free floating or attached to a substrate and these may be emergent or their leaves floating or entirely submerged. This wide variation in habitat is reflected in their morphological, anatomical and physiological characters and helps to explain their success as weeds (Sculthorpe, 1967).

The foliage of the free floating plants develops as a rosette, comprising aerial or surface-floating leaves, condensed crown-like stem and pendulous submerged roots. In this group of plants it is possible to trace a trend of structural reduction from the rosette habit; the foliage in many plants shows variation in size and form in different habitats.

The floating habit is acquired by the high proportion of air in the lacunate mesophyll foliage in all free-floating rosettes. In other plants the lacunate tissue develops so excessively that bladder-like swellings, known as floats, are formed. The lacunate tissue also serves to keep the foliage rigid and balloon-like in addition to the collective turgor of its living cells.

Some free-floating plants produce numerous lateral stolons which help them to colonise huge masses of water surfaces by this adaptation method for vegetative propagation.

The emergent plants display structural features similarly related to the mechanical and physiological problems of aerial existence. This is achieved by the development and disposition of their collenchyma, sclerenchyma and lignified vascular elements. During the initial growth of the emergent plant organs, they are confronted by the risk of oxygen deficiency in the water. This risk is overcome by developing masses of secondary air-storage tissue, aerenchyma or to sustain anaerobiosis for a limited time.

Plants with floating leaves are adapted to resist tearing and immersing action of wind, waves, and rain by strong, leathery, peltate leaves, circular in shape with an entire margin, water repellent upper surface and long pliable petioles. Strong winds, fast currents, heavy rain and flood waters restrict the distribution of these plants to a narrow ecological niche provided by stationary or very slow-flowing water over a stable silted substrate.

The stems, petioles and leaves of submerged plants contain little or no lignin even in the vascular tissues; sclerenchyma and collenchyma are often absent. This is because of the support given to their submerged organs by the water itself together with the buoyancy endowed by their air-filled lacunate tissues. The lacunae greatly facilitate the respiration of the living tissue by transporting and storing of oxygen. The extremely thin permeable cuticle of submerged organs, and the thinness of leaves and presence of chloroplasts in their epidermis are valuable in solving irradiance and scarcity of oxygen.
The permeability of the thin cuticle and epidermis allows gases dissolved in water to pass in or out through the whole surface of the plant.

AQUATIC PLANTS AS WEEDS

Many aquatic plants readily qualify as weeds. The ability for luxuriant vegetative growth and vigorous spread in addition to the botanical characters outlined above make some aquatic plants perform as insidious weeds. Weeds were defined by Shaw (1956) as those plants growing in undesired locations. They are characterized by being competitive and aggressive (Campbell, 1923) and of "wild" growth (Brenchley, 1920).

As weeds, aquatic plants invade water bodies creating problems that involve, practically, all aspects of water use. For example species of *Phragmites*, *Sagittaria* and *Scirpus* occur as weeds throughout the world. *Phragmites mauritianus* occurs in various parts of Africa, *Sagittaria guayanensis* in Malaysian ricefields and *Scirpus juncoides* in those of Madagascar, Malaysia and the Philippines. Similarly some species of *Typha* occur as weeds in rice cultivations in the Southern U.S.A. and Portugal whilst others form immense colonies in wide lowland rivers such as the Senegal (Wild, 1961). Several species of *Cyperus* are harmful throughout the world in natural waters, irrigation systems and subaquatic crops (Sculthorpe, 1967).

Miscellaneous tropical emergents, such as *Echinochloa colonum*, *E. stagnina*, *Neptunia oleracea*, *Oryza perennis* and *Vossia cuspidata* are likewise important weeds of subaquatic crops and irrigation schemes in West Africa, Madagascar, Sudan, Ceylon, India, Malaysia and the Philippines (Sculthorpe, 1967).

Pistia stratiotes is very troublesome on the upper White Nile of the Sudan where it forms floating obstacles. In Ghana it has covered the new Volta Lake and has resulted in health hazards since *Pistia* serves as a preferred host site for larvae of several species of mosquitoes (Holm, Weldon and Blackburn, 1969).

Salvinia auriculata has spread over wide areas in Central and South America from Cuba to Argentina and is known to occur in the Zaire, the Cameroon River and in some Southeast Asian countries. It first exploded and became a serious problem in Ceylon about 1955 (Williams, 1956) and a similar problem has recently arisen in Lake Kariba in the Zambezi valley (Hattingh, 1961).

AQUATIC HABITATS IN THE SUDAN

The vegetation of the Sudan is classified into five major divisions (see Andrews, 1948; and Harrison and Jackson, 1958). Both classifications recognize a vegetation region referred to as Swamp and Grassland or Flood Region.

This vegetation region comprises an area of 95,000 square miles and extends over much of Upper Nile and parts of Bahr El Ghazal and Equatoria provinces. The region is divided into three subdivisions, High land, Intermediate and Swamp according to the degree of flooding. The High land is so called because it is rarely flooded. The soils of this subdivision are mostly sand and sand loams which support a forest type dominated by _Hyphaene thebaica_ (L.) Mart. with _Borassus aethiopum_ Mart. locally dominant. The Intermediate land, the largest constituent of this region, consists of land flooded during the rainy season but remains dry after the end of the rains. The vegetation that thrives in this area is mainly grassland dominated by _Hyparrhenia rufa_ and _Setaria incrassata_.

Swamp is flooded from the river and other water courses and the duration of the flooding is much longer than on the Intermediate land. The permanent swamp is dominated by _Cyperus papyrus_ L. while in the seasonal swamp _Echinochloa stagnina_ and _E. pyramidalis_ (Lam.) Hitchc. and Chase are generally dominant.

Table 1. gives an inventory of aquatic species (phanerogams) in the Sudan with notes on their habits and geographical locations. It will be noted that the great majority is recorded in the three provinces of the Southern Region. Those recorded in the northern provinces where the climate is considerably

drier originate mostly in localized aquatic or semiaquatic environments.

Table 1. A listing of plant species (phanerogams) living under aquatic or semiaquatic conditions in the Sudan

1- Monocotyledonous Families

1. ALISMATACEAE

Alisma plantago aquatica L. Perennial aquatic herb with tuberous rhizomes. 'Turda' plant. Rahad, Northern Kordofan. Burnatia enneandra M. Mich. Slender aquatic herb, rhizome ovcid. Central and Southern Sudan. Caldesia reniformis (D. Don) Makino. Aquatic herb with very short rhizomes. Equatoria. Limnophyton obtusifolium (L.) Miq. Aquatic herb, rhizome short. Central and Southern Sudan. Lophtocarpus guayanensis (Kunth) Dur. and Schinz. Aquatic herb, small rhizome. Southern Kordofan. Ranalisma humile (Kunth) Hutch. Small marsh herb. Central Sudan on the banks of the White Nile. Wiesneria schweinfurthii Hook f. Slender aquatic herb, Equatoria.

2. APONOGETONACEAE

Aponogeton subconjugatus Schumach. Aquatic herb, Upper Nile Province. Aponogeton vallisnerioides Bak. Aquatic herb, Equatoria.

3. ARACEAE

Pistia stratiotes L. Floating freshwater herb. Central and Southern Sudan, in rivers and pools.

4. BUTOMACEAE

Tenagocharis latifolia (D. Don) Buchen. Annual marsh herb, Central Sudan.

5. CYPERACEAE

Cyperus papyrus L. Glabrous herb, rhizome woody. White Nile and affluents. Cyperus longus var. pallidus Boeck. Glabrous glaucescent herb. Northern and Central Sudan. <u>Cyperus rotundus</u> L. Glabrous herb, widespread. <u>Cyperus alopecuroides</u> Rottb. Large glabrous herb. Central and Southern Sudan.

6. GRAMINEAE

<u>Vossia cuspidata</u> (Roxb.) W. Griff. Perennial herb, culms submerged or floating, rooting from submerged nodes. Central and Southern Sudan. Troublesome weed of the Gezira canals. <u>Echinochloa stagnina</u> (Retz.) Beauv. Perennial herb with creeping and copious rooting rhizome, branching from submerged nodes. Widespread. <u>E. pyramidalis</u> (Lam.) Hitchc. and Chase. Perennial reed-like herb, with long strong rhizome, culms may be floating. Central and Southern Sudan. <u>Panicum meyerianum</u> Nees. Perennial herb, often growing in or near water. Central and Southern Sudan. <u>P. repens</u> L. Perennial herb, long creeping rhizomes. Central and Southern Sudan. An important weed infesting the banks of the Gezira canals. <u>Paspalidium geminatum</u> (Forsk.) Stapf. Perennial herb, with creeping or floating more or less spongy many-noded stolons. Upper Nile Province. <u>Paspalum polystachyum</u> R. Br. Herb, often on the edges of watercourses or in swamps, Equatoria. <u>Phragmites mauritianus</u> Kunth. Perennial herb. One of the commonest species of the "Sudd" region.

7. HYDROCHARITACEAE

<u>Lagarosiphon schweinfurthii</u> Casp. Aquatic herb, Equatoria. <u>L. cordofanus</u> (Hochst.) Casp. Aquatic herb, Blue Nile Province. <u>Nechamandra alternifolia</u> (Roxb.) Thw. Aquatic herb, stems thread-like. White Nile, Kosti. <u>Ottelia alismoides</u> (L.) Pers. Aquatic herb, Central Sudan. <u>O. ulvifolia</u> (Planch.) Walp. Aquatic herb, Central and Southern Sudan. <u>O. brachyphylla</u> (Gurke) Dandy. Aquatic herb, Equatoria. <u>O. scabra</u> Bak. Aquatic herb, Central and Southern Sudan. Common on White Nile. <u>Vallisneria</u>

aethiopica Fenzl. Submerged grass-like plant. Central and Southern Sudan.

8. LENTIBULARIACEAE

Utricularia thonningii Schumach. Submerged aquatic herb, floating close to the surface, stems thread-like. Central and Southern Sudan. U. stellaris L.f. Submerged aquatic herb, floating near the surface; stems thread-like. Central and Southern Sudan. U. exoleta R. Br. floating in water or creeping on mud. Stolons of varying length, Central and Southern Sudan. U. reflexa Oliv. Floating herb, stolons long, branched, slender and glabrous. Equatoria.

9. LEMNACEAE

Lemna polyrhiza L. Floating or submerged herb, reduced to thallus-like fronds. Equatoria. L. perpusilla Torr. Floating or submerged herb, reduced to thallus-like fronds. Equatoria, Central and Southern Sudan. L. aequinoctialis Welw. Central and Southern Sudan. Wolffia hyalina (Del.) Hegelm. Thallus-like frond. Darfur and Kordofan. W. welwitschii Hegelm. Thallus-like-Frond, Equatoria.

10. NAJADACEAE

Najas graminea Del. Aquatic herb, stems long, rooting at the lower nodes. Blue Nile Province, Equatoria. N. Schweinfurthii Magnus. Aquatic herb. Equatoria. N. pectinata (Parl.) Magnus. Aquatic herb, stems with numerous short lateral branches. Central and Southern Sudan. Invaded Gezira canals.

11. POTAMOGETONACEAE

Potamogeton nodosus Poir. Aquatic herb, leaves in mature plants all or mostly floating. Gezira canals. P. schweinfurthii A. Benn. Leaves all or mostly submerged. Southern Sudan. P. perfoliatus L. Leaves all submerged. Blue Nile Province and Gezira Canals. P. octandrus Poir. Plant with or without floating leaves, stems branched, thread-like. Central and Southern Sudan. P. pusillus L. Leaves all submerged, Jebel Marra. Northern Darfur. P. crispus L. Stems thread-like leaves all submerged. Northern and Central Sudan. P. pectinatus L. Stems thread-like, leaves all submerged. Gezira canals.

12. PONTEDERIACEAE

Eichhornia diversifolia (Vahl) Urb. Aquatic herb, submerged and floating leaves. Equatoria. Eichhornia crassipes (Mart.) Solms.Free floating, White Nile and tributaries. Heteranthera callifolia Reichb. ex Kunth. Aquatic herb. Kordofan, Blue Nile Province and Equatoria. Monochoria africana (Solms) N.E.Br. Aquatic herb, Equatoria.

13. TYPHACEAE

Typha angustata Bory and Chaub. Aquatic herb, Blue Nile, White Nile, Kordofan and Gezira Provinces. T. angustifolia L. Marsh herb, Red Sea Province. T. australis schumach. Aquatic herb, Southern Sudan.

2- Dicotyledonous Families

1. AMARANTHACEAE

Alternanthera nodiflora R.Br. Moist places. Central and Southern Sudan. A. sessilis (L.) R.Br. ex Roth. Moist places and stream-beds. Widespread. Centrostachys aquatica (R.Br.) Wall. Marshy places. Central and Southern Sudan.

2. CERATOPHYLLACEAE

Ceratophyllum demersum L. Submerged aquatic herb. Widespread in rivers and irrigation canals.

3. DROSERACEAE

Aldrovanda vesiculosa L. Floating in water , White Nile River. Sudd area.

4. ELATINACEAE

Bergia capensis L. Aquatic herb. Northern and Southern Kordofan Province.

5. HALORAGACEAE

Gunnera perpensa L. Swamp herb. Equatoria. Laurembergia engleri Schindl. Low swamp herb, Equatoria and Bahr El Ghazal.

6. NYMPHAEACEAE

Nymphaea lotus L. Aquatic herb. The Nile river and tributaries south of Khartoum. N. micrantha Guillem. and Perrott. Aquatic herb. The Nile river and tributaries south of Khartoum. N. caerulea savigny. Aquatic herb. The Nile river and tributaries south of Khartoum.

7. PODOSTEMACEAE

Inversodicraea sp. In masses on rocks in streams. Equatoria Imatong Mountains. Spaerothylax sp. On rocks under rapidly flowing water. Equatoria. Tristicha trifaria (Bory) Spreng. Submerged moss-like herb attached to rocks in streams and rivers. Central and Southern Sudan.

8. POLYGONACEAE

Polygonum salcifolium Brouss ex. Willd. Often in marshy places. Central or Southern Sudan. P. limbatum Meisn. In swamps and ditches. Central and Southern Sudan. P. lanigerum R.Br. Aquatic perennial herb, Southern Sudan. P. tomentosum Willd. Aquatic Perennial herb, Central and Southern Sudan. P. senegalense Meisn. In river beds and swamps, Jebel Marra at 6500 ft. P. acuminatum Kunth. In moist places, Darfur and Equatoria.

9. TRAPACEAE

Jussiaea diffusa Forsk. Creeping or floating aquatic herb. Central and Southern Sudan. Trapa bispinosa Roxb. Floating herb, Southern reaches of the White Nile and its tributaries.

GRAVITY FLOW IRRIGATION

The Flood Region constitutes the only natural environment available for aquatic or subaquatic plant life in the Sudan. The other vegetation regions are composed of vegetation types that are supported by the highly seasonal rainfall. This leaves, as the potential for new aquatic environments, the Nile system with its tributaries and the canalization systems of the irrigated agricultural production.

The Gezira canalization system being theoldest and longest is examined here to represent the new and artificial aquatic environments in the Sudan.

The gravity-flow method of irrigation will continue to be the backbone of the irrigated agricultural expansion at least in the forseable future. The advantages of this system, now almost a cherished engineering tradition, lie in its economic feasibility as it is based on engineering hydraulic principles that take maximum advantage of the land contours in any given area. This system of irrigation consists of a hierarchical system of supply canals, i.e. Main canal supplying various Major canals which in turn feed a network of smaller Minor canals. The Minor canals are designed to convey water, through yet smaller and smaller irrigation channels, into the crop land.

The importance of this system of irrigation can be seen in terms of the size of crop rotational areas that have been developed by gravity-flow irrigation.

Scheme	Area ($x10^6$ Feddans)
Gezira Main	1.200
Managil Extension	0.800
Khashm El Girba	0.447
Rahad (Phase 1)	0.300

(One feddan = 1.038 acres)

From the above figures it is clear that the development of new rotational areas means a corresponding increase in the total length of Minor canals that are needed for the direct conveyance of water to crop land. In addition to the absolute increase in canal lengths two other considerations are also important : the national move towards the intensification of cropping and the choice in the new development projects of tight rotations where the traditional agricultural fallow has been discounted as is the case in Khashm El Girba, Suki and more recently, as a result of intensification, the Managil Extension.

The continued increase in the length of irrigation canals as well as the intensified pattern of cropping, implies the creation, within the present system of irrigation and as long as the Minor canal remains the most important element of this repetitive system of irrigation, of a new system of 'continuous' irrigation, and consequently a 'continuous' potential environment for aquatic weed growth in irrigation canals.

Minor Canals

The Gezira Main canal receives water from the Sennar reservoir and conveys it by Major canal take-off to supply Minor distributaries from which field outlets lead irrigation water into the crop land.

Irrigation commences normally towards the end of July and progresses through the cropping season to the beginning of April. After April the majority of the canals are left dry, except for those supplying water necessary for domestic needs.

The operation of the minor canals is such that they receive water for 24 hrs but to store the supply at night, since the field outlets draw water only during the day. During the night the level of water is raised 20-30 cm above the Full Supply Level so that watering commences during the day. The rate of flow during the day is very small , usually in the order of 7 cm per km of canal length but during the period of night-storage this rate falls to near zero. Between 1960 and 1969, the traditional system of 'Night-Storage' has proved to be inflexible to cater for and cope with the increased amounts of water needed for intensified cropping. For the above reason the operation of the night-storage system and the traditional method of watering individual hawashas (units of 5-10 feddans), were gradually replaced by 'continuous-flow watering' technique currently universal in the Gezira (Farbrother, 1974).

Thus the Minor canals, by virtue of their construction to command land for direct application of irrigation water and because of the slow rate of water movement, are in fact, stagnant pools except for the periodical rise in level. Therefore, they provide conditions advantageous to aquatic weed growth.

SOURCE OF INFESTATION

Occurrence of aquatic weeds in the Gezira was first recorded in Hamad El Nil canal in 1929, only four years after the start of irrigation in the Gezira. Since then there has been rapid increase in intensity and extent of infestation of the Gezira Minor canals by water plants.

Because the source of canalization system is the Sennar reservoir, it was not too difficult to trace the source of infestation to the reservoir and ultimately to the Blue Nile.

The Blue Nile is characterized like other rapidly flowing meandering rivers, by the occurrence of mud-flats which remain inundated for some months. The formation of these mud-flats is probably due to the rapidly flowing water during the flood season of the river, by the flowing current impinging on the outside bank which is eroded. The water on the mud-flats is usually stagnant and it is there that Andrews (1945) reported the presence of aquatic weeds and determined the source of infestation of the reservoir and ultimately of the Gezira canalization system.

THE SENNAR RESERVOIR

The Sennar reservoir, 80 km long and 4.25 km wide, is a shallow artificial lake, has been colonized by the water plants that originate on the mud-flats of the Blue Nile river.

The flora consist principally of the following species,

Nymphaea caerulea Savigny.
Ceratophyllum demersum L.
Najas pectinata (Parl.) Magnus.
Ottelia alismoides (L.) Pers.
O. ulvifolia (Planch.) Walp.
Utricularia thonningii Schumach.
U. stellaris L.f.
Pistia stratiotes L.
Chara globularis Thillier.
Nitella batrachosperma Agardh.
Vossia cuspidata (Roxb.) W. Griff.
Echinochloa stagnina (Retz.) Beauv.
Panicum meyerianum Nees.
Juncellus alopecuroides (Rottb.) C.B. Clarke.
Cyperus rotundus L.
Polygonum glabrum Willd.
P. lanigerum R. Br.
Ipomoea reptans Lam.

The distribution of these plants varies, in general, with the depth of water as can be seen in Table 2. which shows the frequency of occurrence of five species with the depth of water determined along the banks of different portions of the reservoir.

Table 2. Frequency of occurrence (%) of the five most common species at various depths

Water depth (cm)	Vossia cuspidata	Ottelia alismoides	Chara globularis	Najas pectinata	Echinochloa stagnina
0- 20	-	-	-	-	-
20- 40	-	10	4	16	-
40- 60	2	18	5	13	-
60- 80	1	12	6	13	-
80-100	4	11	5	10	-
100-120	0	5	2	5	2
120-140	3	4	3	7	1
140-160	2	5	3	8	2
160-180	4	2	4	9	4
180-200	6	-	2	2	2
200-220	5	-	2	3	5
220-240	6	-	-	2	14
240-260	17	-	-	2	10
260-280	14	-	-	-	18
280-300	24	-	-	-	14
300-320	16	-	-	-	2
320-340	6	-	-	-	8
340-360	7	-	-	-	6
360-380	12	-	-	-	-
380-400	10	-	-	-	-

It will be noted that the five species divide themselves into two groups : Those inhabiting shallow water, viz: *Najas pectinata*, *Ottelia alismoides* and *Chara globularis*, and those thriving in deep water, viz: *Vossia cuspidata* and *Echinochloa stagnina*.

AQUATIC WEEDS IN THE MINOR CANALS

Surveys of water plants in the Minor canals have shown the presence of two groups of species, those anchored to the mud and those inhabiting canal banks. The species present include,

1. Anchored to the mud

   Potamogeton perfoliatus L.
   P. nodosus Poir.
   P. crispus L.
   P. pectinatus L.
   Chara globularis Thillier.
   Polygonum glabrum Willd.
   Juncellus alopecuroides (Rottb.) C.B. Clarke.
   Ceratophyllum demersum L.
   Najas pectinata (Parl.) Magnus.
   Nitella batrachosperma Agardh.
   Vallisneria aethiopica Fenzl.
   Zannichellia palustris L. var. *intermedia* Pearsall.
   Typha angustata Bory & Chaub.

2. Inhabiting canal banks

   Panicum meyerianum Nees.
   P. repens L.
   Echinochloa stagnina (Retz.) Beauv.
   Cyperus rotundus L.
   Alternanthera sessilis R. Br.
   Ipomoea reptans Poir.
   Vossia cuspidata (Roxb.) W. Griff.
   Phragmites mauritianus Kunth.

The five common species of the Sennar reservoir (Table 2.) occur, as can be expected, in the Minor canals. It will be noted, however, that some of the species occurring in the reservoir are absent from the canals while others recorded in the canals have not been found in the reservoir. That some species occur in the canals and not in the reservoir might be attributed to the adverse effects of the flow of water, or that the dam might act as a physical barrier in retaining seeds and plants. The general occurrence of species in terms of the depth-frequency follows the general pattern of their occurrence in the reservoir.

The notable exceptions in this regard are the four species of Potamogeton. Not only are they absent from the source of infestation but because they are essentially aquatic plants of temperate climates thriving very well in a subtropical climate. There has been no record of their occurrence in the Sudan except after their identification in the Gezira between 1929-1936. Andrews (1945) has presented some thoughts on the possible route of their introduction, through bird migration, into the Sudan.

P. nodosus has a restricted distribution as it is mainly found towards the northern parts of the Gezira while P. perfoliatus is fairly widely distributed. On the other hand Najas pectinata, Ottelia alismoides and Chara globularis, which prefer the shallower parts of the reservoir, are found scattered throughout the canalization system with a tendency for concentration in the shallower canals and at the southern end of the irrigated area.

Juncellus alopecuroides which is widely present in the reservoir also prefers shallow water in canals. It occurs principally at water edges and at the heads of canals, usually downstream of a regulator where small mounds of mud are formed by the flow of water through the regulator.

Typha angustata is widely present throughout the irrigated areas - its rate of infestation is aided by its ability for spread by rhizomes and seeds.

Of the less important plants are Echinochloa stagnina, Ipomoea reptana which occur mostly in the southern parts of the Gezira.

Pistia stratiotes which is free-floating and occurs abundantly in the Blue Nile has apparently been unable to colonize the Gezira canals. This is probably because it thrives best in shady places, usually among tall grasses and other aquatic plants. The Gezira canals are completely without shade and this explains its non-establishment but might not adequately explain its complete absence.

Life Cycles

Nearly all species grow and produce seed during the time when there is clear water from the reservoir between January to July and after the end of the flood season (July-October) between October to January.

When the more turbid flood water has arrived in July the bulk of vegetative parts of most species tend to die down, probably because the flood water reduces light penetration. Abundant seed germination occurs during this period. Very little vegetative growth occurs but roots and rhizomes are formed in abundance and would wait for the return of the clear water when more active growth would commence.

Potamogeton spp. produce flowers and fruits during the whole period of clear water, and no month seemed more favourable than the others. A much reduced rate of flowering occurs during the flood season. The extent of growth and spread in the canals can be seen in Table 3. which shows the rate of spread of some species into various sections of miniature canals with stagnant water representative of the very slow water velocity in the minor canals, over a period of 14 months which include the flood season.

Table 3. Number of sections of canals invaded by various species after 14 months of growth.

Canal	Species P.P.	O.A.	P.N.	V.C.	N.P.
1	10	1	9	3	7
2	9	-	5	3	10
3	10	-	3	3	10
4	5	-	8	5	10
5	10	-	3	3	10
6	9	-	9	4	9
7	6	-	6	3	7
8	8	-	3	3	10
9	10	-	5	6	10
10	4	-	7	2	10
11	9	-	5	5	8
12	7	-	4	6	10
Total	97	1	67	46	111
Sections grown	120	140	120	140	120

P.P. = Potamogeton perfoliatus, O.A. = Ottelia alismoides, P.N. = Potamogeton nodosus, V.C. = Vossia cuspidata, N.P. = Najas pectinata.

Najas pectinata has shown the greatest spread and this is consistent with the visual observation of its behaviour in the Gezira canals. It is probably the fastest spreader in the canal system. *Potamogeton perfoliatus* has spread over 97 sections and rivals *N. pectinata* in its spreading potential.

METHODS OF CONTROL

Prior to 1960 and during the era of the old Gezira's 8-course rotation, the majority of canals remain dry during the dead season for a period of up to 3-4 months between late March and early July. During this period and despite high summer temperatures the moisture content in the canal beds remains fairly high and apparently the seeds of many species remain viable because of this cool storage. On the other hand, the rhizomes of only few species are able to withstand the efftects of summer drying.

The cyclic pattern of life cycle has indicated that complete eradication may not be feasible since the period of summer drying-out is not long enough to ensure that reinfestation *in situ* will not occur. The abundant seed germination that occurs annually during the flood season when the vegetative parts are not visible, suggests that control measures must also be applied during the flood period. Thus the strategy developed to combat weed infestation is based on the cyclic life history of most species. The strategy employed is designed to retard seed production by weakening vegetative growth during its favourable period.

The system employed relies on mechanical cleaning of infested canals at frequent regular intervals. By cleaning the canals in rotation, seeding during the clear-water period would be prevented and seedling growth during the flood season is removed or at least retarded.

The equipment used consisted of two types of rakes:

(1) A rake with a head 0.5 m long with 15 carved prongs, each about 15 cm long.

(2) A rake with a head 1 m long with 7 prongs, each 20 cm long and the ends of the prongs being joined by a knife blade.

The process of clearance is applied on a rigid rotational schedule. The basis of this rotation system consisted of cleaning each infested canal once every 10-15 days during the clear-water period. This would ensure that no seed formation occurred. During the flood season an interval of 15-20 days is allowed between successive operations since this cleaning is directed to remove and destroy seedlings.

Mechanical method provided satisfactory means for combating the intensity of weed infestation. The success of this method of control was due principally to the availability of cheap labour. Successful weed control programmes were possible through the employment, in the various Gezira administrative subdivisions of the Ministry of Irrigation, of permanent gangs engaged solely for weed clearance, each in a certain section of the subdivision. Each set of labourers usually remained in their particular section and were not transferred elsewhere.

However, with labour becoming expensive and canalization more extensive, the effectiveness and feasibility of this method of control leaves much to be desired.

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THE WATERHYACINTH - EICHHORNIA CRASSIPES (MART.) SOLMS

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TAXONOMY

The earliest descriptions of Eichhornia, which were based upon vegetative characters, are difficult to interpret because of the great vegetative resemblance between Eichhornia crassipes and its close relative Eichhornia azurea (Bock 1968).

Probably the earliest description of either Eichhornia crassipes or E. azurea is that of Sir Patrick Browne published in 1756 and repeated in 1789. He describes a plant which he calls "Pontederia aquatica caulescens, folios, majorbus orbiculatis ...., or" the round leafed water-plantain (Browne 1758). There was nothing in the description which, with absolute certainty, shows it to be one species or the other. He observed this plant in Jamaica "in most of the lagoons and rivers about the Ferry".

The descriptions by swartz in his Prodromus (1788) and in his Flora Indiae Occidentalis (1797), most frequently referred to by subsequent writers refer to Pontederia azurea. According to Bock (1968) these descriptions fit Eichhornia azurea somewhat better than E. crassipes.

However, the first unquestionable description of Eichhornia crassipes was made by Martius in 1833, who called it Pontederia Mart. In 1843 Kunth separated the genus Eichhornia from Pontederia. He named Eichhornia after J.A.F. Eichhorn, who was

Prussian Minister of Education in 1840's. Eichhorn means 'squirrel' in German and is in no way descriptive of these aquatic weeds.

The combination of Eichhornia crassipes (Mart.) Solms was made by Solms - Laubach in 1883.

ORIGIN AND DISTRIBUTION

The first description of Eichhornia crassipes was based upon plants from Brazil (Martius 1824). Since then several workers have said that waterhyacinths originated in Brazil (Schultes and Schultes 1830; Lester-Smith 1926; Penfound and Earle 1948; Backer 1951 and Evans 1963).

However, Hooker (1829) reported on several early collections of E. crassipes which came from Brazil; Demerara River, Guiana; New Granada (Venezuela, Ecuador, Colombia and Panama); Guayaquil, Ecuador; and Buenos Aires, Argentina. Hence, waterhyacinth was, apparently, widespread in South America at that time Viz: 1829. They may have been in Central America at the same time, too, since Panama was part of the New Granada listed in the early collections.

Nevertheless several authors have designated South America as the place of origin of E. crassipes (Bailey 1902; Stadley 1928; Bose 1945; Shibata et al. 1965) with Swartz adding that Puerto Rico is the principal center of dispersal.

However, Britton (1918), Small (1936), Smith and Merchant (1961) and Bock (1968) prefer to call the plant a native of the New world tropics because it seems impossible to designate any small, specific, geographic region as the area of origin of Eichhornia crassipes.

As for its advent in the United States, many authors have written that waterhyacinth was first introduced into the United States in Louisiana. Tabito and Woods (1962) stated that the plant was first naturalized in Louisiana in 1860's. Penfound and Earle (1948) suggested that the waterhyacinth was introduced, probably, at New Orleans before 1884 and Wunderlich (1964) credited the Cotton States Exposition at New Orleans in 1884 with the introduction. However by 1894 waterhyacinth had clogged many streams in Southern Louisiana (Wunderlich 1962). Webber (1897) reported on the tremendous infestations of waterhyacinth in the St. John's River in Northern Florida and Curtiss (1900) discussed the many acres of the St. John's River which were covered with waterhyacinth. Probably the species was introduced into Florida from Louisiana in the 1880's (Britton 1917; Penfound and Earle 1948; and Woods 1962). Harper (1903) found waterhyacinth naturalized near Valdoesta, Georgia. They were collected east of La porte, Texas in 1903 (Shinners 1962) and by 1908 the Sabine river in Texas was blocked above Orange (Anon. 1908). Eichhornia crassipes has been reported, also, in the Mississipi and in Albama and has been naturalized in California since 1904 (Bock 1968).

From the New world the waterhyacinth invaded the tropical and sub-tropical waters of the Old World. Around 1900 introductions of waterhyacinth were reported from many places: Bengal, 1888 or 18889 (Mclean 1922); Australia, 1890 (Parson 1963); Egypt, 1912 (Muschler 1912); Philippines, 1912 (Merrill 1924).

Perhaps, the rapid and fantastic spread during this period was caused by man because the distances of salt water traversed are too great for natural dispersal.

Since 1900 the waterhyacinth has been reported in still more geographic regions. Lester-Smith (1926) reported the invasion by the plant of China, Borneo and Malaya. Waterhyacinth was first reported in Southern Rhodesia in 1937 (Evans 1963) and in Hawai in 1946 (Degener 1946). The Congo River was first invaded in 1952 (Evans 1963); and the plants were recorded in Okinawa (Sonohara et al. 1952) in that same year.

Gay saw the waterhyacinth in the Sudan near Khartoum in 1958 and Heinen and Ahmed (1964) reported that Ethiopia has already been infested from Sudan in the Baro and Gila rivers both within the watershed of the Sobat river. The Republic of Central Africa has been invaded in 1970 (Udo 1974, personal communication).

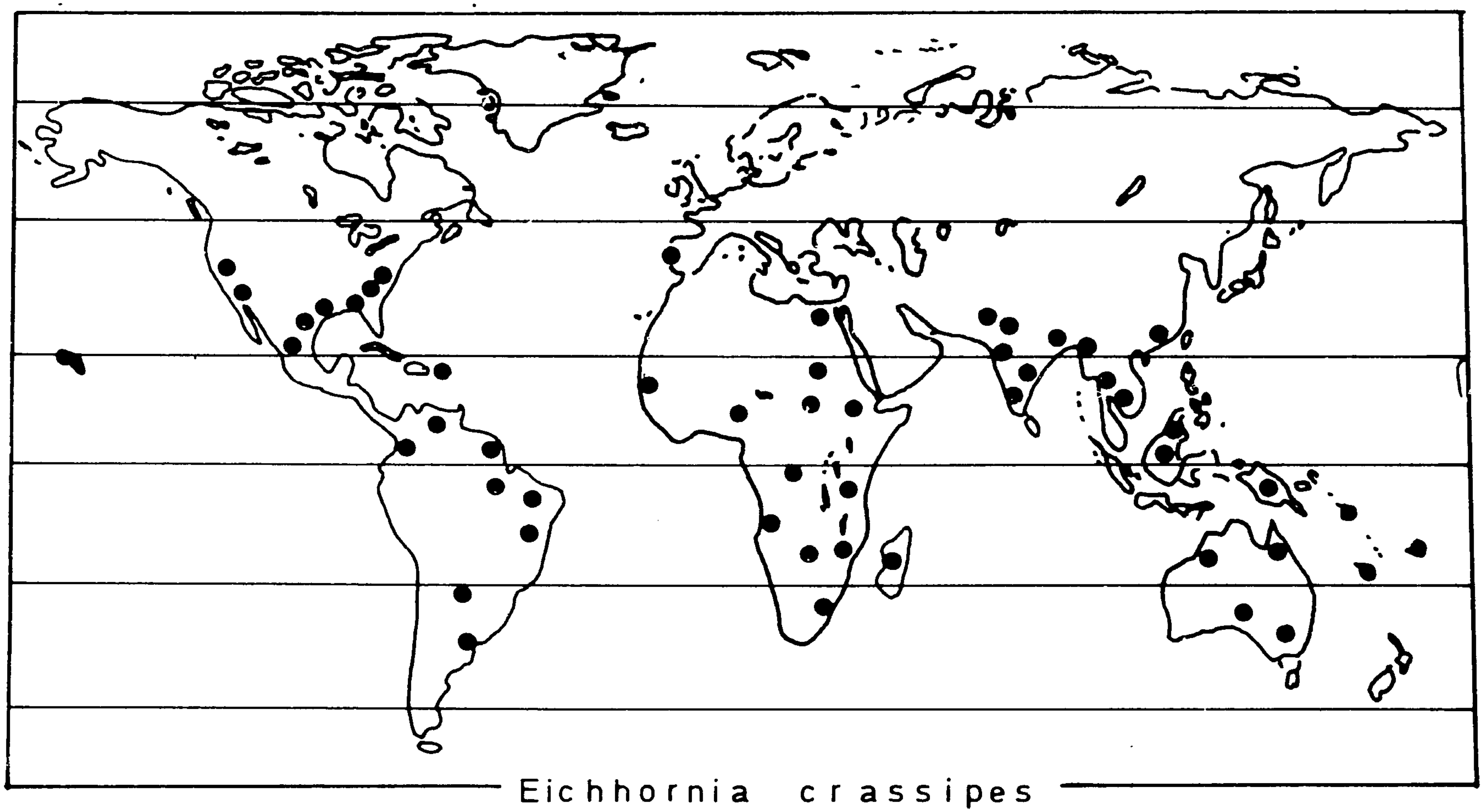
Figure 1 which gives the present distribution of waterhyacinth on the globe shows that this plant species has increased its distribution considerably in the last fifty years.

INFESTATION OF THE SUDANESE NILE SYSTEM

Mr. G.V. Wickrama-Sekara project officer in the Department of Agriculture, Sudan first called the attention of the Sudan Government Officials to the waterhyacinth in January 1958 when he saw the plants being offered for sale in the city of Cairo in Egypt.

Gay (1958 and 1960) reported that <u>Eichhornia crassipes</u> was first seen in the White Nile in March 1958 at a point near Aba Island about 300 km south of Khartoum but was probably present further south between Adok and Bor in the Sudd region, in 1956 or 1957. Wickrama-Sekara, on 20 April, 1958 while on a field trip to the Upper Nile province confirmed the presence of waterhyacinth in the Sudan in a letter stating "......... a considerable stretch of the White Nile is already heavily infested".

As for the origin of infestation, wide inquiries were conducted to reveal when, how and where has the plant made its first appearance. It is almost likely that this plant species appeared in the Nile towards the end of 1955 north of Bor in Bahr el Jebel. The fact that the first occurrence was in the main stream, well inside the Sudan border, warranted Heinen and Ahmed (1964) to suggest that the plant did not come from Uganda, by river. However, the plant seem to have never been



World distribution

MAP 1

reported in Uganda with which the Sudan have direct water connections, but, the Congo River was first invaded in 1952 (Evans 1963). The assumption that birds might have carried the seed from Congo is refused (Heinen and Ahmed 1964) on the grounds that many of the lakes and shallow waters in the Sudd region, where birds usually breed and nest were found clear at the time. The same authors assert that the weed has been brought physically by man.

On the other hand, Bedawi (1972) believes that the only liklihood of origin of infestation of the White Nile would be the heavily infested Congo rivers in the South West borders of the Sudan. Infestation of the Congo rivers particularly the Itembri has been prior to the Sudan. Thus, although the main streams that feed the rivers of the Congo arise in the Congo highlands and flow westwards, nevertheless the probability of of contamination of the streams feeding the Sudan's southern tributaries should not be overlooked. This hypothesis finds support in circumstantial evidence of the existing hydrological conditions during high flood season in the Nile-Congo-Divide, Hurst and Phillips (1938) reported that the Taperi river originating in the south west highlands of the Sudan is connected by swamps to small east-flowing streams of the Nile-Congo-Divide. Hence, Bedawi (1972) concluded that during high flood, Taperi and Gel rivers whose ultimate destination is at shambe can transport waterhyacinth seeds and vegetative propagules into the lower reaches of Bahr el Jebel which joins the sudd swamps as illustrated in Fig. 2.

All of these hypotheses seem to need further verification.

THE PRESENT SITUATION

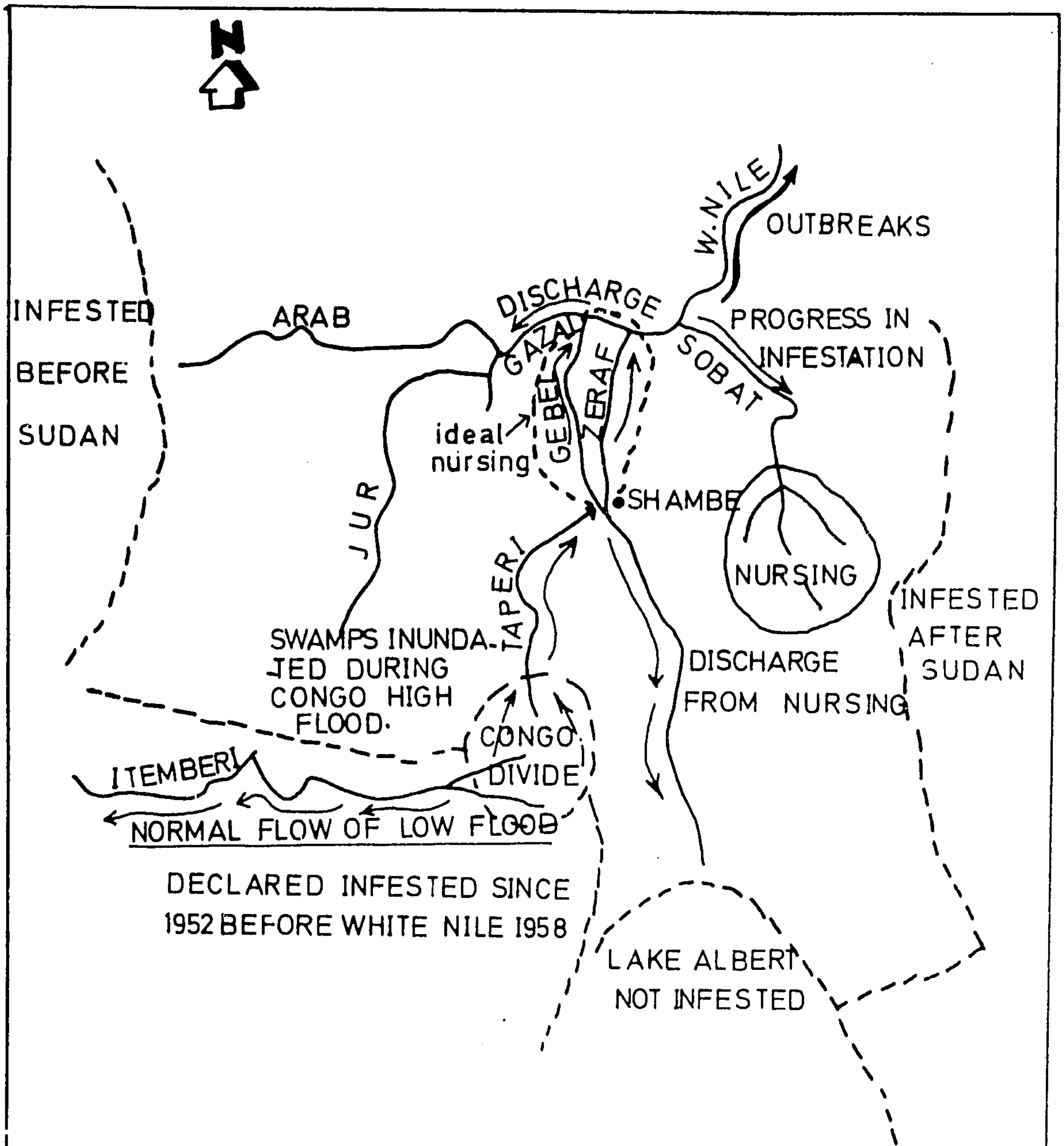
When first reported in 1958, Eichhornia crassipes was occupying the stretch of the river from Shambe, on Bahr El Jebel, to north of Kosti, a distance of about 700 km. By 1962 the plant succeeded in infesting the whole stretch of the White Nile - from Juba to Jebel Aulia Dam; the whole length of the Sobat River from its mouth eastwards up to Baro and Gila Rivers in Ethiopia and southwards up the Pibor River until Akobo; the whole length of Bahr el Zeraf; Lake No and Bahr El Ghazal; and many of the side lakes, <u>khors</u> and tributaries, especially in the Sudd region. The picture today(Fig. 3) is not different from that of the 1960's in spite of the expenditure of about a million Sudanese pounds per year for the control programme (one Sudanese pound = $ 2.5).

In the period April to October vast amounts of waterhyacinth plants drift north towards the Jebel Aulia Dam where they accumulate, completely covering the water surface for a considerable distance to the south. During this period wind and current action continuously compress them into a thick carpet that people may walk on them. After October, and due to the prevalence of the Northerly winds, a totally different picture is encountered. The floating mats are observed in the main course between Jebel Aulia and Malakal. Along the Nile Bank, in khors and in the swampy Sudd Zone-further south, greater aggregations are encountered. Beyond the Sudd region and until Juba, very sparse small marginal aggregations prevail. With the onset of the flood season (June-July), the marginal population starts to show signs of newly extended lateral off-shoots and mats of floating islands of waterhyacinth are seen rapidly moving northwards. By then the gentle rise, in level, of the river starts to feed seasonal side streams and moisten extensive depressions.

Bedawi (1972) recognized three major regions with regards to the magnitude of infestation:

<u>Region</u> <u>I</u>: between Juba and Malakal affords the appropriate nursing conditions and hence signifies the highest congestion of weed.

<u>Region</u> <u>II</u>: between Malakal and Kosti represents the central



MAP 2

UPPER WHITE NILE & TRIBUTARIES

ILLUSTRATION SHOWING THE POSTULATED ORIGIN OF INFESTATION IN THE SUDAN

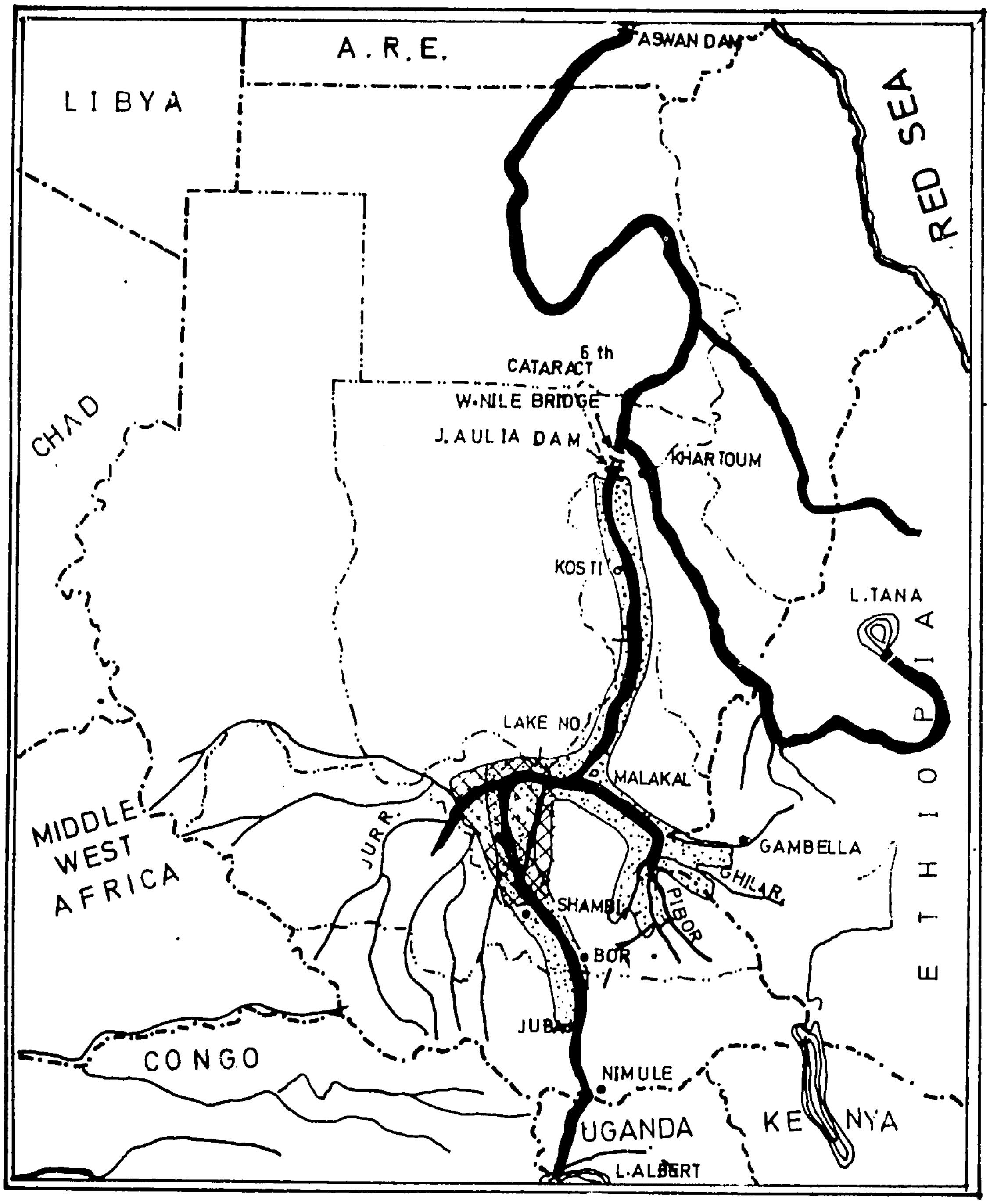
(After Bedawi 1972)

–·→ : INITIAL INFESTATION FROM CONGO NILE DIVIDE

→ : SUBSEQUENT INFESTATION

→ : SEASONAL OUTBREAK (FLOOD)

SUDAN



Scale 1:8,000,000

Hyacinth infested Area

Sudd Rigion

MAP 3

part where discharge of outbreaks is accomodated for a limited period.

Region 111: between Kosti and Jebel Aulia where the habitat incorporates situations destined to receive the ultimate infestation drifts. Jebel Aulia Dam forms a physical barrier against the northwards spread of the weed.

Perhaps it is worth mentioning here that waterhyacinth was not unknown in the Nile prior to 1957; it has been present in the Nile Delta for many years (Muschler 1912 and Tackholm and Dirar 1950) but has never reached the 'plague' proportions exhibited in the Sudan since 1958 and Egypt after 1973. The continuing southward spread of the plant in Egypt after 1972 appears to be a direct consequence of the slowing down of the current of the Nile north of Aswan due to the erection of the High Dam. Waterhyacinth is a common scene on the Nile in Cairo these days and was reported to have reached El Menia town since January, 1973 (Mahir, personal communication).

In the Sudan, E. crassipes varies considerably in its abundance and prolificacy within the Nile system. In the Bahr El Ghazal, the species is less prolific and may even show a stunted and chlorotic appearance, a situation that may be explicable in terms of water characteristics. However, more is needed to identify the specific causative factor(s).

EFFECTS OF WATERHYACINTH INFESTATION

The spread of the waterhyacinth in the Sudanese Nile system have had a number of harmful effects:

Water Loss

The presence of waterhyacinth on the Nile System causes an increase in water loss when compared to a free Nile surface.

Under experimental conditions in the Laboratory the increase in water loss due the presence of waterhyacinth when compared to a free water surface was six-fold in the States (Penfound and Earle 1948), four-to five-fold in Oxford (Little 1967), eight-fold in Indonesia (Spencer 1972) and two-to three-fold in the Sudan (Tag El Seed 1972). Dissogi (1974) working under Sudan conditions obtained values comparable to those of Tag El Seed but asserted the importance of plant size and atmospheric conditions in affecting the amount of water loss-a fact that might explain the diversity of results obtained by the different investigators.

If one takes the modest values of water loss obtained by Dissogi (1974) which are 1.50 $gm/cm^2/$ day for waterhyacinth covered water surface as compared to 0.85 $gm/cm^2/$ day for a free water surface and considering the total of the infested area as 3000 square kilometers as estimated by pirie in 1970 (Koch 1974) then :-

Water loss from a 3000 sq. km free water surface

$= 3000 \times 10^6 \times 10^4 \times 0.85$ gm/day
$= 3 \times 10^7 \times 10^4 \times 85 \times 365$ ml/year
$= 93075 \times 10^{11}$ ml/year
$= 9.3075 \times 10^{15}$ ml/year
$= 9.3075$ milliards M^3/year (1)

Water loss from 3000 sq. km waterhyacinth infested area

$= 3000 \times 10^6 \times 10^4 \times 1.5$ gm/day
$= 3 \times 10^8 \times 10^4 \times 15$ ml/day
$= 45 \times 10^{12} \times 365$ ml/year
$= 16425 \times 10^{12}$ ml/year
$= 16.425 \times 10^{15}$ ml/year
$= 16.425$ milliards M^3/year (2)

Subtracting (1) from (2) yield a total water loss due to the presence of the waterhyacinth that equals 7.12 milliards M^3/year.

This represents one tenth the average of the normal yield of the Nile based on (1912-1965) records as given by Hidyatalla (1975). It, also represents 1.78 times the amount of water expected to be provided as a result of constructing the first phase of the Jonglei Canal. It is more than enough for the irrigation of the 100,000 feddans (one feddan = 1.038 acres) planned for sugarcane cultivation in the area of the White Nile which according to Hidyattlla (1975) shall need 1.235 milliards M^3 of water. It is also 7 times the requirement of the 200,000 feddans envisaged as the area most suitable for agricultural development in the Nile and Northern Provinces--based on a requirement of 5000 cubic meters/feddan for the traditionally practised type of cropping pattern.

Cost of the control programme

Control programmes do cost heavy money. Table 1. gives the expenditure on waterhyacinth control since the beginning of this programme in 1959. The total money spent during these 15 years amounts to 6.829 million pounds ($ equivalent = 19.12 millions).

The rising costs, of the equipment and the herbicide used, during the last four years make one gets much far less from these for the same amount of money. Hence, bilateral and multilateral international aid seems to be very important in this aspect.

Table 1. Hyacinth Control Budget
(thousands of pounds)

Year	Chapter 1 (Personnel)	Chapter 11 (Operation)	Chapter 111 (Equipment)	Total
1959-60	6.0	0.3	-	6.3
1960-61	27.0	103.7	51.6	182.3
1961-62	53.6	235.0	87.0	375.6
1962-63	72.0	325.7	60.0	457.7
1963-64	90.0	363.0	99.0	552.0
1964-65	100.0	430.0	56.0	586.0
1965-66	90.0	427.0	-	517.0
1966-67	100.0	341.0	31.0	472.0
1967-68	138.4	332.0	29.1	499.5
1968-69	140.4	347.8	11.0	499.2
1969-70	141.8	390.5	-	532.3
1970-71	134.8	357.2	40.0	532.0
1971-72	133.5	329.4	53.8	516.7
1972-73	133.5	342.8	53.8	530.1
1973-74	137.3	332.8	100.0	570.1
Grand Total				6,828.8

White Nile pump schemes

Along the White Nile there are more than 176 schemes with a cultivated area exceeding 260 thousand feddans. The advent and spread of the waterhyacinth caused many problems for these agricultural schemes by blocking the suction lines of irrigation pumps and by clogging the canals and other smaller irrigation water channels.

Also, blockage of water distribution for electricity-power plants have been reported in many instances.

Water supply and recreational activities

The presence of the waterhyacinth along the river bank has caused disturbances in the water supply for settlements due to increased drift leading to massive accumulation and decomposition along the banks. Boating, bathing and swimming are no longer possible along many sites in infested areas.

Transportation

The Nile is the main route of transportation between Northern and Southern Sudan. The difficulties that have been experienced by steamers and boats since the advent of the waterhyacinth are well known and have been frequently reported in terms of days of obstruction of navigation.

Beshir (1975) reported on the damage caused to the steamers themselves in their effort to manoeuvre their way between dense mats of waterhyacinth. This incurs :

a- money spent to purchase spare parts,
b- the delay and irregularities of the steamers' trips,
c- delay in the transportation of goods,
d- reduction in the carrying capacity of the steamers, and
e- excess in fuel consumption.

Beshir (1975) mentions that the River Transport Department has estimated a 50 % increase over a total of 250 thousand pounds allocated for boat maintenance; 50 % increase for spare parts purchase over a total of 125 thousand pounds; 10 % increase to meet general repair requirements over a total of 280 thousand pounds; and a 30 % increase over a total of 30 thousand pounds for fuel.The Department is estimated to lose about half a million pounds annually for that reason.

Fishing

Fish is not only an important item in the diet of the riverside dwellers, but with the increase in the prices of meat and its scarcity, sometimes, fish is gaining increasing importance in the diet of the inhabitants of most villages and towns. The locals and fishermen, fish with basket or line from the bank and the presence of the waterhyacinth makes fishing by these methods impossible or very difficult. Many khors and side channels which were formerly of great importance for fishing are now completely chocked up. The Nilotics who normally do some of their fishing by spear from canoes also find their task more difficult as they are pushed out of the shallows into the main stream where the current is stronger. In some areas a restriction of the number of the fish was reported which could be due to waterhyacinth restricting breeding grounds (Davies 1959). Bishai (1961) observed that the presence of the waterhyacinth causes oxygen deficiencies, in many localities along the Nile, khors and lagoons, which render the breeding and nursery areas of fishes unsuitable for life.

Health hazards

Waterhyacinth plants provide a suitable breeding and nursing habitat for mosquitoes which cause an increase in the incidence of malaria. Also, fresh water snails like *Bulinus* and *Biomphelaria* species-which are intermediate hosts for bilharzia-were found attached to the roots of waterhyacinth plants collected from Jebel Aulia area (Dissogi 1974).

The floating and marginal dense mats of waterhyacinths harbour snakes and create suffocation conditions which force crocodiles to get out of the river, thus causing unrest among the inhabitants.

Interaction between waterhyacinth, its environment and other aquatic organisms

Through its shading, surface cover and hinderance to currents, waterhyacinth appears to be generally antagonistic to all other aquatic plant life, and through its creation of oxygen deficiency, to aquatic animals too.

Dearth or complete absence of oxygen beneath floating mats of waterhyacinth was noted by Lynch et al. (1947) in southern United States, and Hickling (1961) in Java. Similarly, Yount (1963) reported the absence of oxygen at only a few centimeters' depth in the isolated pools on surface lime-stone in Florida which are thickly covered with Lemna, Pistia, Salvinia and sometimes Eichhornia.

Floating mats drastically curtail the penetration of light and so inhibit the growth and photosynthesis of phytoplankton. They also shelter the surface from wind, minimising turbulence and retarding reaeration, and hinder thermal water currents, preventing mixing and accelerating stratification.

Effects of 2,4-D

A liquid amine form of 2,4-dichlorophenoxy acetic acid (2,4-D) have been used as the main chemical for the control of the waterhyacinth in the Sudan. Although 2,4-D is one of the safest herbicides concerning its side effects, yet a number of effects have been felt or suspected in the storage and spraying areas:

(i) The intensive repelling odour of 2,4-D is felt in many places where the herbicide and/or its empty containers are stored.

(ii) The decrease of the fish supply from the White Nile in the last few years have been attributed by many to be due to waterhyacinth infestation. However, the amine form which is used in the Nile is known not to be toxic for fish as in the case possibly of an ester-formulation (Koch 1974). Although some, work (Mahdi 1974) have been made on the effect of different concentrations of 2,4-D on the survival of fish yet more work is certainly needed not only on the effects of 2,4-D concentrations on the survival and growth of the different stages in life cycle, of a good number of fish species but in the monitoring and follow up of the 2,4-D content of the water after spraying operations specially if factors like breeding sites of fishes, volumes of water and current speed during the spraying operations and the behaviour and growth of plankton are taken into consideration. Also, Koch (1974) points to questions as to what extent is fish contaminated by the use of 2,4-D ? and where does the herbicide remain after application ? and how does it react (decomposition, effects) ? - all of which still need an answer.

(iii) In and around sprayed areas damage, and anomalies, in growth of trees, bushes and herbs including crops and vegetables are continuously observed and reported. Although, there is a law absolving the Government from liability damage as a result of spray drift yet all precautionary measures are taken to avoid damage to crops and natural vegetation. Nevertheless, Koch (1974) reported that anomalies in the growth of trees, bushes tomatoes and other dicotyledonous plants were, with certainty, extensively observed at distances of of 500-1000 m (bee-line) from the 2,4-D store in the Malakal area.

In Malakal area, it is frequently mentioned that the population which live close to the river complain from stomachache and intestinal troubles - effects that are suspected to be associated with 2,4-D. However remote is the possibility for such an illation, its scientific verification need not be much stressed.

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WATERHYACINTH - THE SUCCESSFUL WEED

BY

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Eichhornia crassipes (Mart.) Solms. is a cosmopolitan, perennial mat-forming aquatic plant species belonging to the *Pontederiaceae*.

Originally a native of the New World tropics, this plant species, has assumed a pan-tropical and sub-tropical distribution. It is also found in some temperate regions such as Central California.

This wide distribution appears to be a manifestation of an excellent colonizing ability. Indeed, *E. crassipes* is considered the most renowned of all aquatic plant species (Sculthorpe 1967).

THE MORPHOLOGY OF THE PLANT

The mature hyacinth plant consists of roots, rhizomes, stolons, leaves, the inflorescence and the fruit clusters.

The foliage develops as a rosette, comprising aerial leaves, a condensed crown-like stem and pendulous submerged roots.

The vegetative stem consists of an axis-with short internodes-which produces at the numerous nodes all the roots, leaves, off-sets and inflorescences of the plant. New off-sets are carried at the distal ends of the stolons which are elongated internodes (Penfound and Earle 1948).

The leaf of the water hyacinth has been the object of much discussion among Botanists (Olive 1894). The leaves, characteristically green with a high glossy sheen, are oval and thick with stomata on both sides. They are arranged in a rosette at the base of which is a short stem that is continued under the water by a rhizome varying in length from about one half to four inches. In fully isolated plants the leaves have a spongy swollen portion called a float (Penfound and Earle 1948) and a pseudo-bulb (Bruhl and Gupta 1927). The float-leaves consist of a membranous ligule, a subfloat, a float, an isthmus (tenuous portion between the float and the blade) and a blade (Penfound and Earle 1948). Arber (1920) believes that the blade is not a true lamina but is merely an extension of the petiole. However, Bock (1968) named this part of the leaf a pseudo-lamina.

The petiole of the leaves is filled with a spongy, porous tissue containing many air spaces. Most of the air space is contributed by the lacunate mesophyll but the extent to which this is developed varies with the prevailing environmental conditions. The whole petiole may be swollen into a bulbous spongy float which has a volume/fresh weight ratio of over 7 cm^3/gm in contrast to about 1.3 cm^3/gm for the other vegetative organs (Penfound and Earle 1948).

The relation of these floats to buoyancy requirements is shown by the fact that in specimens stranded on the mud they do not develop-the petioles or bases of the blades remaining slender and elongated. Yet adaptive though they may be, floats are rarely formed in natural habitats. In established communities most of the foliage is float-less (Sculthorpe 1967).

The branching pattern is sympodial. The youngest leaves are in the centre of the rosette. As the young leaves elongate they rupture the sheathing bracts that surround them.

The roots are fibrous, unbranched and each has a conspicuous root cap. They are purplish when exposed but White when in darkness or when rooted in the soil (Olive 1894). They vary little in diameter but greatly in length (0.3 ft to 3.0 ft) or possibly more (Penfound and Earle 1948). The root system is well developed, composed of clusters of principal adventitious roots closed with rows of laterals (Arnold 1940; and Sculthorpe 1967). The root system represents from 20 to 50 % of the plant biomass depending on the season and habitat conditions (Penfound and Earle 1948; and Westlake 1965).

The inflorescence is elegantly described by Penfound and Earle (1948) as "an attractive lavender spike subtended by two bracts and surmounted on an elongated stalk (peduncle). The individual flower consists of a hypanthium, three sepals, three petals, six stamens, a tricarpellate pistil. The pistil consists of a conical ovary, a long style, and a capitate stigma which is situated about half-way between two groups of anthers. The ovary ripens into a thin walled capsule which is imprisoned in the relatively thick-walled hypanthium".

THE SUCCESS OF WATERHYACINTH

The success of E. crassipes as a weed and a colonizing species is attributed to a number of outstanding traits which can be adumbrated as follows :

1. Environmental tolerance

E. crassipes is known to tolerate a wide range of habitats. Indeed, Bock (1968) has made an elaborate and illuminating reviewing of the literature on the tolerance of this plant species to certain environmental factors :

(i) Temperature

There is enough evidence to show that E. crassipes can tolerate freezing temperatures (Lansdell 1925; Penfound and Earle 1948; Hitchcock et al. 1950; and Bock 1968). Bock (1968) wrote : "The ability to survive temperatures below freezing furnishes an excellent illustration of the wide range of temperatures which this tropical native tolerates".

(ii) Light

"At the old River in Central California the waterhyacinths grow at 60 % full sunlight or better" (Bock 1968). Viscosa (1949) believes that shade checks the growth of the waterhyacinth but Anon. (1957) claimed that light seldom limits the vegetative growth of this plant species.

(iii) pH

E. crassipes can grow in a wide range of pH levels (4-9) provided that its nutrient requirements are satisfied (Parija 1934; Vaas and Sachlan 1949; Obeid 1962; and Tag El Seed 1972).

(iv) Salinity

Bock (1968) wrote : "Water hyacinths can tolerate a wide range of salt concentrations and various inorganic and organic compounds in water .... This tolerance of a variety of organic and inorganic compounds in water undoubtedly contributes to E. crassipes' success as a weed and colonizing species. The plant does well in conditions both oligotrophic (Dymond 1948;) and eutrophic (Backer 1951; Bose 1945 and Yount 1964), as well as in intermediate waters such as those of the Old River".

Penfound and Earle (1948) found that the waterhyacinth can't tolerate more than faintly brackish water-specimens showing epinasty and chlorosis and quickly dying, yet the plant has also been shown to grow freely in estuaries and brackish lugoons and to survive for several days in sea water (cf.C.C.T.A/C.S.A. 1957). Coleman (1957) believes that E. crassipes can tolerate salt water, but cannot establish itself or multiply in brackish water. Indeed, Bock (1968) wrote: "Waterhyacinths exhibit some tolerance to salinity. Some waterhyacinths colonizations may be explained by the plants' floating from one body of fresh water to another across stretches of salt water. Under experimental conditions, waterhyacinths survived for 13 days in 100 % sea water; and they survived for more than 14 days in 50 % sea water".

(v) Winds and currents

Winds and currents are agents of long distance dispersal. Bock (1968) reported that the waterhyacinth can travel in swift currents and can indure considerable buffeting by high winds.

This plant species is adapted for long distance dispersal by means of its sail-like leaves which resist tearing by winds and strong currents. Sculthorpe (1967) stated: "By virtue of the spongy lacunate tissue in all the organs, and sail-like attitude of the leaf-blade, the rosettes are very buoyant and easily swept along by wind even against an appreciable surface current".

(vi) Drought resistance

The advent of the water hyacinth to the Nile and hence to desert and semidesert habitats should trigger research on the drought resistance of this plant species.

Parija (1934) claimed that the waterhyacinth is drought-resistant because the plant was able to grow at 5.7 % of water saturation in the soil. However, he did not mention for how long could this plant endure these relatively dry conditions although he explained their drought-resistance as to be due to an increase in osmotic strength of the plant cells and a decrease of leaf surface. Bock (1968) concluded that the waterhyacinths can withstand considerable drying; but they appear to do best when the relative humidity of the atmosphere, at the level of leaves, is over 30 %.

Under Sudan conditions Tag El Seed (1972) found that the waterhyacinth survived when watered every 4 days whereas plants died when put under a weekly watering regime. The critical water content essential for the survival of the hyacinth plants was found to be about 20 % of the original fresh weight. Penfound and Earle (1948) showed that death occurs when the weight of the plants falls below 15 % of the original fresh weight.

2. Morphological plasticity

The leaves of the waterhyacinth are subject to variation in size and form under different habitats. When floating in shallow, poorly oxygenated water or when stranded in muddy banks, the leaves are small and may only reach a length of about 8 cm with the blades about 3 cm wide and 2 cm long. However, when the plants are not crowded and are living under favourable conditions, the leaves may attain a length of 125 cm, the blades being conspicuously longer than they are wide and may attain about 15 cm x 13 cm (Sculthorpe 1967).

Absence of swelling is associated with plants being anchored in place by rooting or by crowding with other plants (Mclean 1922; Lansdell 1925; La Grade 1930; and Sculthorpe 1967), with high temperatures (La Grade 1930; and Sculthorpe 1967), with shading or light intensities below 5380 Lux (La Grade 1930; Guido et al. 1965; and Sculthorpe 1967). Foliage with well developed floats is correlated with the free-floating habitat (Rao 1920; Bruhl and Gupta 1927; and La Grade 1930). However, Bock (1968) failed to associate the petiolar conditions with shading.

The ability of E. crassipes to change its growth habit (phenotypic) with changing habitats is certainly a good tool of success indicating a wide spectrum of environmental tolerance.

3. Reproductive strategy

E. crassipes can increase vegetatively and sexually. However, the relative importance of vegetative and sexual reproduction in the spread of E. crassipes in different areas is very difficult to assess (C.C.T.A./C.S.A. 1957). There is uncertainty about the role of the seed. According to Backer (1951) fruits are unknown in Malaysia. Adventive plants in Central California appear to be self-incompatible (Baker 1965) but Bock (1968) showed that the water hyacinth, there, is fertile and that self-incompatibility is absent or if present is very weak. Haigh (1936) concluded that the possibility of spread by seed is real and permanent in Ceylon. Sculthorpe (1967) believes that both modes of reproduction are equally important. On the other hand, Pettet (1964) considers that germinating seeds could be a real and important source of infestation in the Nile and not a mere potential one. He envisaged that the control of the infestation through seed germination should be seriously considered. Hitchcock et al. (1950) surmised that the development of seedlings was of negligible significance in the rapid spread of this plant species in Louisiana.

(i) Floral biology

The inflorescence of the waterhyacinth is a spike comprising 2 to 35 or more spirally arranged, zygomorphic flowers. The androecium is composed of 3 short and 3 long stamens. In the Sudan flowers are continuously produced from April to September (Obeid 1962). In the U.S.A. flowering is inagurated April 15th. Maximum anthesis prevails about June the first and a second but lower maximum prevails about September 15th (Penfound and Earle 1948). In nature the inflorescence buds can easily be seen 10 days before opening. The period between the initiation of inflorescence buds and the opening of flowers is about 14 days (Penfound and Earle 1948). Under favourable conditions flowers appear after 26 days in plants produced by vegetative propagation (C.C.T.A./C.S.A. 1957).

(ii) Heterostyly

E. crassipes seems to be potentially tristylic but often two types occur. In Brazil, India, U.S.A., Malaysia and Jamaica almost all the flowers are meso-stylic (Muller 1871; Backer 1951; and Bock 1968) whereas Haigh (1936) found most of the flowers in Ceylon to be long-stylic. Tag El Seed and Obeid (1975) found most of the flowers in the Nile to be meso-stylic with the long-and short-stylic "races" absent or in extreme rarity.

(iii) Factors affecting seed-set

The ovary of the waterhyacinth may lodge up to 500 ovules.

In a recent study Tag El Seed and Obeid (1975) reported the inflorescence of the waterhyacinth to carry 4-26 flowers (the average being 11.6 ± 3.2). The number of fruits that develop per inflorescence varied from 0 to 16 (the average being 1.5 ± 2.3). Tag El Seed and Obeid (1973) found the number of seeds per capsule to vary between 5 and 452 (the average being 99 ± 80.3). The highest number of seeds per capsule reported was by Muller (1883) in Brazil where each of 5 capsules bore over 260 seeds.

The relative positioning of the stamens, the stigma and that of the androgynoecial column seems to make self-pollination difficult in the fully open flower. However, the spiralling and inflexion of the perianth can result in self-pollination (Agharkar and Banerji 1930; Penfound and Earle 1948; and Bock 1968). Indeed, when artificially self-pollinated most of the flowers formed capsules containing seeds (Tag El Seed and Obeid 1975).

Under the Nile conditions of the Sudan the discrepancy that exists between the number of flowers produced and the number of fruits formed appears to be mainly due to the climatic factors. The failure of pollination and/or fertilization could be due to the effects of high temperature and low relative humidity which may lead to the drying up and hence unreceptiveness of the stigma. No visiting insects were seen and wind pollination has not yet been fully investigated (Tag El Seed and Obeid 1975).

(iv) Seed germination

The germination of the seed of E. crassipes has been studied for the last 90 years and in about 8 countries but there is confusion about some of the results. Crocker, as early as (1907), reported that seeds germinated in 7 days when kept constantly in water. Haigh (1936) in Ceylon also germinated seeds 7 days from collection, and found that neither a single drying nor prolonged dry storage are necessary for germination, whereas Muller (1883) believed that desiccation was essential for germination in Brazil. However, Robertson and Thein (1932) in Burma, and Parija (1934) in India concluded that germination was governed by alternate wetting and drying and Hitchcock et al. (1949) reported that dry seeds took about twice as long to germinate when moistened as seeds kept wet from the time of collection. Tag El Seed and Obeid (1973) found the seeds to germinate in a few days (9) or a few weeks from the time of collection. The length of this period appears to be a function of the ripeness of the seeds and the conditions of storage. Seed dormancy is probably "enforced" by the environment.

Haigh (1936) believes that high temperature and/or intense light induced germination and Hitchcock et al. (1949) agreed that high temperature encouraged germination. Barton and Hotchkiss (1951) believe that a combination of light and warm temperature is necessary for the germination of the seed of E. crassipes.

Obeid and Tag El Seed (under publication) studied some of the factors that may affect seed germination. They believe that the best laboratory germination was in clay soils, rich in organic matter, under less than 3 cm depth of water, in light. There are interactions with water depth, soil depth, soil type, organic deposits, light and temperature. No germination was observed in "clean" water (cf Forsberg 1965) nor in pure sand (cf Pettet 1964). The seeds were found (Obeid & Tag El Seed - under publication) to germinate fairly well in water under a depth of 2.5 cm and in the soil only when scattered at the surface. However, if buried one cm in the soil no germination ensues. The seeds germinated when they were exposed to the natural diurnal fluctuation of temperature and illumination. They also germinated at continuous light under low oxygen tension and low redox potentials. These authors believe that the germination of the seed of E. crassipes is likely to be affected by the specific conditions prevailing in its natural habitat, especially along the shoreline and particularly in the immediate vicinity of the decaying hyacinth plants. These factors are basically : water depth; soil type and bank deposits; and light and/or temperature. Storage conditions of the seeds before germination affect the results. Wet-storage favourably affects both the rate and ultimate germination (almost 100 %). Dry-stored seeds tend to germinate sporadically and dry-storage for more than 8 months caused germination to drop to less than 40 %. Wetting, drying and rewetting gave complete and quickest germination. After 2 years of dry-storage, 78 % of the seeds were still viable . Parija (1934) found that the seeds of E. crassipes can remain viable for a few years. Tag El Seed and Obeid (1973) asserted that "it is significantly strategic for the seed of E. crassipes to rapidly germinate under wet-storage conditions provided that a favourable habitat is available. However, the dry-stored seeds have acquired another "ecology" and their slow and erratic germination in response to dryness can not be considered an unsuccessful strategy for it enables this plant species to evade the possibility of total extermination by one environmental hazard or another".

Tag El Seed (1972) found that 2,4-D does not seem to adversely affect the germination of the seed of E. crassipes. Complete germination was obtained even when the seeds were immersed in a solution containing 2,304 p.p.m. 2,4-D for 5 hours. Spraying the soils, infested with waterhyacinth seeds, with 256 p.p.m. 2,4-D also failed to inhibit germination. This is, perhaps, due to a protective seed testa. Hence, despite the use of 2,4-D as the classical herbicide in combating this weed, it does not seem to be effective in inhibiting seed germination. This resistance to 2,4-D might as well be considered as part of the tolerance of this weed and hence a tool of success as a colonizing species.

Obeid and Tag El Seed (under publication) concluded that the seed of E. crassipes is likely to germinate in lagoons, khors and river banks whenever the very specific conditions for germination prevail. Indeed, seedlings of E. crassipes can be observed along the Nile banks in Sudan from Jebel Aulia in the North to further than Malakal in the South.

Penfound and Earle (1948) have studied the germination stages and the development of the seedlings of E. crassipes. They reported that the cotyledon completely disappears in about 20 days, by which time, the plantlet will have produced 4 to 6 ligulate leaves about 15 mm in length. In 30 days the seedling will have produced 7 to 8 ligulate leaves with incipient floats; 10 days later float leaves are produced and the seedlings are readily recognized as waterhyacinth plantlets. Robertson and Thein (1932) reported that in about 60 days from germination most of the leaves produced will be of the float type and the plant is by then mature. Hitchcock et al. (1950) reported that the young seedlings of E. crassipes require anchorage in a wet, yet solid medium for about 4 weeks, until they can grow as floating plants. It was suggested that the ligulate-leaved juvenile plants have different nutritional requirements from mature floating rosettes. These authors concluded that the development of mature individuals from seed is likely to be limited by unfavourable growing conditions rather than conditions unsuitable for germination.

Tag El Seed (1972) suggested that the development of young seedlings into mature individuals is affected by a number of factors, mainly the medium in which they grow, rains, floods and drought. He believes that some of the seedlings can get established, expand and act as colonizing units for they can multiply rapidly by vegetative propagation. He concluded that the role of the seed is significant-initiating primary infections and agumenting the magnitude of infestations of the Nile. The seed being viable for a few years and resistant to 2,4-D, can remain a permanent menace for new infestations ensuring the continuity of this weed species.

4. Vegetative propagation and Productivity

Undoubtedly the prolific rate of vegetative propagation is responsible for the weediness and success of E. crassipes as a colonizing species. The plant managed to cover an area of 1000 kilometers in 2 years in the Sudanese Nile system (Tag El Seed and Obeid 1973).

In Louisiana Penfound and Earle (1948) isolated 10 plants and found them to vegetatively reproduce 1610 plants in 3 months. In Sudan Obeid (1962) placed two plants in a deserted swimming pool and found them to give 30 plants in two months and 130 plants in three months.

This fantastic ability for vegetative propagation is perhaps mainly due to the plant's startling rate of photosynthesis. Westlake (1963) considers the waterhyacinth to be the most or one of the most productive photosynthetic organism(s). Yount (1964) found this plant to produce organic matter at the rate of 28 gm of carbon/sq. mt/day in Florida. In some favourable habitats in the Nile and Louisiana this plant species may produce as much as 110 to 115 mt organic matter/ha (Westlake 1963). On the other hand, Penfound and Earle (1948) found that during active growth plants can double their number fortnightly, the floating mats extending by as much as 0.5 to 0.75 mt/month. At this rate of multiplication 10 "individual" plants would have produced 655,360 plants equivalent to a solid acre during one growing season which in Louisiana extends from at least March 15 to about November 15. They also found the total fresh weight of an eight year old mat to vary from 56,660 kg/ha (123 tons/acre) in winter to 75,700 kg/ha (184 tons/acre) in summer. In California, Bock (1968) found that this plant species could produce organic matter at rates comparable to those of the tropics. Indeed, Harper (1970) wrote : "the growth of population is particularly startling in aquatic weeds, and the waterhyacinth may multiply at such a rate in the Congo that it has been observed passing Leopoldville at the rate of 150 tons an hour (despite the expenditure of 50 million francs a year in attempts to keep the river clear)".

The possession by this plant species of the dual mode of reproduction is certainly advantageous as the two methods complement the effect of each other and thus enable the plant to be that famous and ubiquitous colonizing species.

5. Competitive ability

The symposium on the problems of E. crassipes in Africa (C.C.T.A./C.S.A. 1957) observed :

(1) that there is no particular or well known antagonism between E. crassipes and the various plant associations on the rivers of Central Africa, that Eichhornia invasion is mainly limited to free spaces among or in the neighbourhood of the associations, and that it penetrates only to a small extent into Vossia and Echinochloa formations.

(2) that only two concrete cases of antagonism have been

observed : beds of Pistia stratiotes on the Congo, regressing before an Eichhornia invasion, and the martime Telanthera association, along the high water mark near the estuary of the river, in process of disappearing under an accumulation of decaying Eichhornia, carried down by the river and left on the beach by the outgoing tide.

Bishai (1961) and Chadwick (1961) believe that E. crassipes modifies the substrate in which it grows. Bock (1968) reported that in California and in other places E. crassipes often forms more or less closed stands within or upon which certain other species are able to live. According to Gay (1958 and 1960), Vossia cuspidata, Pistia stratiotes, Azolla species, Cyperus papyrus and Lemna species may be found growing within Eichhornia crassipes on the White Nile and they were sometimes replaced by it. In North Carolina and the Gulf Coastal States of North America Alligator weed (Alternanthera philoxeroides) may sometime replace E. crassipes as the dominant weed but as a result of its different growth habit, alligator weed does not compete with E. crassipes or other floating weeds unless it is firmly anchored in a suitable substrate (Sculthorpe 1967). Gay (1958) claimed that Pistia stratiotes abundant in the White Nile before the advent of the waterhyacinth, had been virtually eliminated from some regions. Also, Little (1966) had observed that both E. crassipes and P. stratiotes were competing in the middle of Lake Apanas in Nicaragua. Tag El Seed (1972) found that E. crassipes sometimes replaced P. stratiotes in mixed cultures. He advanced the notion that the possession of a large leaf canopy enables E. crassipes to occupy the substrate surface, encroaching on the smaller Pistia plants and impounding light from them. Eichhornia being tolerant to a wide range of habitats, particularly to pH is expected to have a better competitive ability than Pistia - a feature that adds to the success of Eichhornia as a colonizing species. Indeed, Baker (1965) wrote : "nevertheless in Jamaica where it had been introduced, it appears to be spreading more aggressively than a native species of the same genus *Eichhornia paniculata* Solms eventhough *E. paniculata* sets abundant seeds (for it is self-compatible) and has vegetative reproduction as well".

Certainly a plant possessing a number of outstanding traits, mainly : a wide range of environmental tolerance, morphological plasticity, an efficient reproductive strategy, a fantastic rate of organic productivity and a good competitive ability is sure to succeed as a weed and an adventive colonizing species which is spreading in a plague-like manner all over the globe.

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POPULATION DYNAMICS OF THE WATERHYACINTH IN THE SUDAN

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INTRODUCTION

Much work has been done on the waterhyacinth - Eichhornia crassipes (Mart.) Solms. throughout the world including the Sudan. However, there is yet little known about the various ecological factors contributing to the success of this weedy species and aggravating the infestation of the White Nile and its tributaries in the Sudan.

This contribution is meant to, broadly, summarize the work which has been done on the population dynamics of this weed species in the Sudan. It is envisaged that studies on the population dynamics of the waterhyacinth would help to throw somelight not only on the productivity of this plant species - which is fairly known - but basically on the changes that take place in its temporal and spatial distributions as affeced by the various environmental factors. In other words, these studies endeavour to answer the questions "where does the plant come from ? when does it come ? how much of it comes ? and where does it go ?".

To achieve this it was necessary to investigate the various environmental characteristics of the White Nile and its tributaries which affect the reproductive capacity and other biological attributes together with the temporal and spatial patterns of distribution of this plant species.

Population dynamics -- applied to waterhyacinth in the Sudan - means the study of plant distribution in the infested area and the change of this within a certain period of time e.g. within one year.

FACTORS AFFECTING THE POPULATION DYNAMICS OF THE WATERHYACINTH

The factors that affect the population dynamics of the waterhyacinth can be broadly classified into :

(i) external factors
(ii) internal factors

Three external factors are recognized. These are geography and climate - which are generally known to influence the distribution of a plant or an animal population; and since the waterhyacinth is an aquatic plant, the hydrology of the White Nile and its tributaries has to be taken as a third important factor.

Geography and climate can be considered as the main factors to limit the distribution of the waterhyacinth in the Sudan. The climate and hydrology of the infested area with its seasonal changes (e.g. rainy and dry seasons; high and low floods) are mainly responsible for the numerical (biomass) and spatial change of distribution of the plant in the different parts of the area.

The internal factors of the plant (innate characteristics), such as mode of reproduction, lifecycle, plasticity, etc... enable the plant to react under the influence of certain environmental changes within genetically fixed limits, in an endeavour to survive and preserve its species. In this respect the waterhyacinth is considered the most renowned of all aquatic plant species and the contribution by Tag El Seed in this volume outlines the mode of adaptation and tools of success that contributed to this renown.

Therefore this work is confined to the investigation and assessment of the climatic data such as temperature, rainfall, relative humidity, wind speed and direction; as well as the hydrological data such as discharge, waterlevel and current speed of the infested area.

Water quality might also be an important factor in the biology of the waterhyacinth. However, it is not dealt with here and shall be dealt with separately in the near future.

The geographical description of the infested rivers forms the third point of the triangle which forms the frame in which the special investigations about the plant behaviour (e.g. vegetative reproduction; drift of the floating plant) are placed.

EXTERNAL FACTORS

Geography

The geographic features of the area which are of direct relevance to this investigation are the rivers and the inundated areas. A brief description of these is given here.

Bahr El Jebel is a defined river when it enters the Sudan plain near Juba. Its further course is northwards up to Bor and north-north east up to Lake No. A few side channels are present on the first 200 km. From Bor onwards the river splits up into numerous side channels and lakes creating the so - called 'Sudd'. Nevertheless two main channels can be distinguished : Bahr El Jebel in the west and about 8 km apart the New River in the east. They join near Shambe (430 km from Juba). The latter has been used for the steamer traffic for a couple of years since the Jebel is chocked by vegetation. This swampy area is about 500 km long and at least 15 km wide. In the rainy season it even extends up to 50 km, specially in the reach of Zeraf Cut 1 (700 km river distance from Juba).

The Zeraf Cut 1 connects the Jebel with the Zeraf tail (Cut 11 has been out of function shortly after its digging in 1913). The Zeraf flows in a northerly direction and joins the White Nile near Tonga (halfway between Lake No and Malakal). The Zeraf is swampy at its first third. The area then becomes more and more dry and from Fanjak to the mouth the river meanders in a well distinguishable bed.

About 640 km from Juba, near Adok the last big channel joins the Jebel. Although being surrounded by swamps, the river is well defined without any side channels. Only a few lakes are connected to the river up to Lake No.

At Lake No (about 840 km from Juba) the Bahr El Ghazal which comes from the west, and is formed by the Jur river and the Bahr El Arab, joins Bahr El Jebel. The river which is now called the White Nile bends eastwards, keeping this direction for the next 150 km. Close to Malakal, where the Sobat river enters the White Nile, the river turns northwards again. This direction is kept for the next 800 km up to the junction with the Blue Nile at Khartoum, except for a bend at Melut.

The Sobat comes from the southeast with wide meanders floating in a deep bed without any lake or side channel. The river is mainly formed by the rivers Baro, Gila and Akobo coming from the Ethiopian Highlands and the Pibor river which comes from the south. Gila, Akobo and Pibor are also forming a swamp at their lower course.

The lengths of the rivers are :

Bahr El Jebel (Juba to Lake No)	840 km
Bahr El Ghazal	200 km
Bahr El Zeraf	270 km

White Nile	960 km
Sobat	350 km
Baro from Gambela	200 km
Pibor from Pibor Post	350 km

The total length of the infested rivers is 3170 km. This does not include several other infested areas particularly the rivers Akobo and Gila in addition to several khors (oxbows) and the numerous waterways in the swamps.

Hydrology

The hydrology of the White Nile and its tributaries is characterized by three outstanding features :

(i) almost all the water is coming from the mountains which surround the Sudan plains (Lake Plateau and the Ethiopian Highlands);
(ii) the slopes of the rivers are very flat (White Nile 1.7 cm/km and Sobat 4 cm/km; and
(iii) there is a big water loss, which influences the waterlevel changes between high flood and low flood together with the summer rains (maximum in August).

This is why the discharge in the rivers shows an annual fluctuation. Therefore within one year the different areas show different pictures : like changes in river width; formation of swamps when spilling over the banks; and dried out khors - depending on topography, rainfall and discharge. Figure 1 (d) gives an idea about the differences in waterlevel and the times of low and high flood in several sites of the river system.

The big difference in waterlevel in the Sobat is due to the summer rains and the defined bed of the river where the water spills very late at high level. The small differences in the 'Sudd' can be explained by the fact that the water in Bahr

El Jebel spreads into side channels and spills early at the beginning of the flood. The change of waterlevel in the White Nile is mainly dependent on the rise and fall of the Sobat. Indeed, the waterlevel at Malakal and Renk corresponds with the waterlevel at Doleib Hill, close to Sobat mouth. The earlier high flood at Kosti and Jebel Aulia Dam can be attributed to the effect of the Dam.

Climate

The whole infested area is described climatically as an area of semi-tropical summer rains. However, the area which is situated between Lat. 5° N and Lat. 16° N (mean achsle Long. 32° E) shows remarkable differences (cf. Fig.1); e.g. the mean temperature in Juba is 27° C, in Malakal 28° C and at the Jebel Aulia Dam 30° C (Fig. 1 a); the rains fall in Juba for about 9 months, starting in March, in Malakal the rain starts in April and lasts about 7 months, whereas at the Jebel Aulia Dam it rains for only three months (Fig. 1 b). Also, the amount of annual rainfall decreases gradually as one proceeds northwards being 1000 mm in Juba, 900 mm in Bor, 780 mm in Malakal, 400 mm in Kosti and only 200 mm in Jebel Aulia (Fig. 1 a).

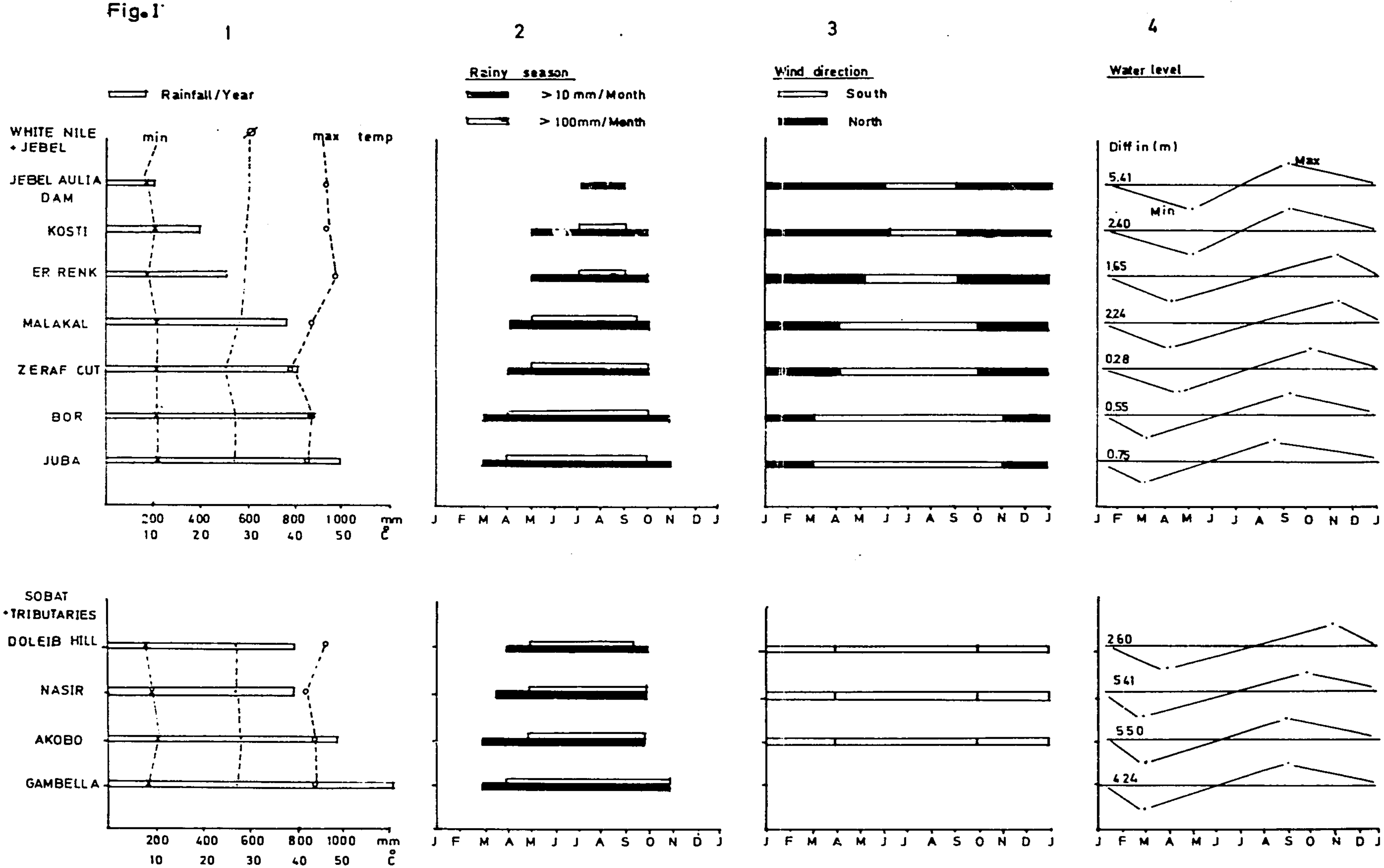
The two main wind directions (south and north) are associated with the moist (rainy) and dry seasons of the year. This means that the wind blows from the south in Juba from March to November and at the Jebel Aulia Dam from July to September (Fig. 1 C). Thunderstorms accompany the rainy season as well with a peak at the beginning and at the end.

The relative humidity as a result of temperature and rainfall is low in Juba for a much shorter time than at Jebel Aulia Dam.

RESPONSES OF THE PLANT TO THESE INFLUENCES

The influence of climate

Fig. 1



1
2
3
4
Rainfall / Year
Rainy season
> 10 mm / Month
> 100mm / Month
Wind direction
South
North
Water level
WHITE NILE + JEBEL
min
max temp
JEBEL AULIA DAM
KOSTI
ER RENK
MALAKAL
ZERAF CUT
BOR
JUBA
200 400 600 800 1000 mm
10 20 30 40 50 °C
J F M A M J J A S O N D J
Diff in (m)
Max
Min
5.41
2.40
1.65
2.24
0.28
0.55
0.75
SOBAT + TRIBUTARIES
DOLEIB HILL
NASIR
AKOBO
GAMBELLA
2.60
5.41
5.50
4.24

It seems that vegetative reproduction is the main modus of reproduction of the waterhyacinth, specially in the south. Although the experiments have recently been started and only in a small scale, it can be said that the climate has an important effect both on the growth and the vegetative reproduction of the plant.

The experiments which were carried out in December 1974 and January 1975 at Jebel Aulia Dam area and at Malakal gave the following results :

The average number of plants produced at Jebel Aulia Dam was 6 out of one within 79 days. The plants had small leaves, ball - like bladders and were less than 10 cm high. The whole group of 7 plants covered an area not greater than 15 x 15 cm.

On the other hand, at Malakal the plants were bigger in size (20-30 cm) high, with elongated bladders and leaves about 100 cm^2. More important, the average number of plants produced out of one plant was 54 within one single month.

When these figures are converted, applying the reproduction formula used by Bock (1969); the values obtained were :

Jebel Aulia $X = 1.025$

Malakal $X = 1.139$

The rate of $X = 1.11$ means doubling of the plant number every week.

Since the actual weather data were not available at this time, the 30 year averages were taken for the comparison of the climate at the two sites. Unfortunately the data did not indicate a statistical difference between Jebel Aulia and Malakal. The reason for the small difference might be due to the fact that the Meteorological Station at Malakal is situated at the airfield where the ground dries out and heats up considerably during the dry season. The experiment was carried out at the river, where one expects a higher relative humidity. Obviously, the weather is much drier at Jebel Aulia Dam than at Malakal.

Experiments, which are being carried out at the moment at both places (Khartoum instead of Jebel Aulia) show equal differences in plant growth. Meteorological data are now being collected directly at the experimental sites. These data indicate up till now a clear difference in relative humidity between the two places.

The floating waterhyacinth with its sail-like leaves is very sensitive to wind action. Since there is a diurnal fluctuation in windspeed-the wind being fairly low during the night, rising during the day reaching a maximum at about 2.00 p.m. and then decreasing again towards sunset - one can expect almost no influence of the wind during the night. Whereas the influence can be quite important during the day, the annual change of wind direction (north and south) is important mainly on the White Nile.

For the other rivers e.g. Bahr El Jebel, Sobat and other tributaries wind does not seem that important, because these rivers meander very much thus changing their direction considerably. In addition to it, the Jebel flows between 4-6 m high walls of vegetation in a narrow bed. Furthermore, the wind speed in the 'Sudd' is much lower than e.g. in Juba or Malakal.

Dependent on wind speed and direction and the direction of the river, the wind can support the waterhyacinth drift downstreams, push the plants ashore or into lagoons and is even able to hold the plant back against the current, provided it is not too strong.

The influence of river hydrology

Once becoming a floating plant - torn off by wave action, wind or current - the waterhyacinth is taken downstream by the current. The drift speed is of course a direct function of the current speed. Since there is an annual increase and decrease in the river discharge, the speed of the current is changing too. The waterhyacinth drifts almost with the same speed as the current. This means, provided there is no wind, that the waterhyacinth moves during September in Sobat at the rate of about 90 km/day - thus travelling the distance from Nasir to the Sobat mouth in 3-4 days. In low flood when the current speed is about half the plants take about a week to reach Sobat mouth. It might be interesting to study, in several sites, the effects of wind as antagonizing or promoting the effect of current.

Also, the annual fluctuation of the discharge produces an annual change in waterlevel. Where the banks are flat, the river - width increases at rise and shrinks at fall of the river level. Thus, lagoons and khors (oxbows) are created in flood which dry out in the rainless season. Waterhyacinth plants which are living in the lagoons, mostly blown into them, have enough water and space during flood to grow. But when the waterlevel falls many of these plants dry out and die due to lack of water supply through the roots. The dry climate, prevailing at the time, helps this drying out.

CONCLUSION

This contribution tried to describe individually the factors which act on the waterhyacinth as well as the responses of the plant to these influences. It also tries to put together the facts and observations, in an endeavour to draw the picture referred to at the beginning of the this article.

There is low to medium infestation in the area betwəen Juba and Bor. Infestation is heavy in the reach of New River and Jebel up to Adok due to the numerous lakes and waterways in this swampy area. In the stretch Adok to Lake No the infestation is low again being restricted only to the river itself. Ghazal has a low amount of waterhyacinth. From Lake No to Malakal, the White Nile is accompanied by a few parallel lagoons showing a medium infestation. The degree of infestation of the White Nile from Malakal to Jebel Aulia Dam is medium to high, depending on the season. The Sobat itself has a small amount of waterhyacinth most of the year. However, the tributaries which form the swamps at the Ethiopian border are highly infested.

The climate in the swamps is favourable for the plant to multiply all the year round. Restriction is only given in the lagoons at falling waterlevel when little silt is carried with the water, and the water is clear with only a small amount of nutrients for the plants growing in deeper water. The plants at the banks of the watercourses and at the shores of the lakes are having enough nutrients because most of them are rooting in the ground. Waterhyacinth break off constantly from these strips along the banks and shores drifting then, mainly with the current out of the swamps into the main watercourse, e.g. Bahr El Jebel. So the number of floating waterhyacinth is increasing downstreams. From Adok onwards, little amount of waterhyacinth is added. But Bahr El Zeraf and Sobat contribute a large number of floating waterhyacinth- this amount being, also, dependent on the season. When the level rises in the rivers and swamps much more waterhyacinth break off the banks and float downstreams.

When this waterhyacinth reach the White Nile the influence of the wind can be seen clearly. The plants are blown ashore and many of them disappear into the lagoons from the river, also supported by the current when the water flows into these lakes at rising waterlevel. As long as the wind blows from the south, the waterhyacinth are able to reach Jebel Aulia Dam. As soon as the wind changes in the north they stop drifting towards the Dam since the current is very slow from Kosti onwards. More and more waterhyacinth get stuck on the shallow banks or they are taken off by the lagoons. Since the reproduction rate is very low in the north not many waterhyacinth are added to those which came from the south. So, the amount of drifting waterhyacinth on the White Nile decreases again after the rainy season. When the river falls by the end of the year the amount of waterhyacinth in the lagoons decreases also because those places dry out. In the swamps the number of floating waterhyacinth decreases too, whereas the amount of waterhyacinth at the banks increases. The weak current, less thunderstorms and the banks which are more shallow when the waterlevel is low, enable those plants to grow less disturbed.

Since, Sobat rises first the amount of floating waterhyacinth out of this river is high in March, April and May. The contribution of Bahr El Zeraf is high in July and August and the contribution from Bahr El Jebel is at its maximum in September. Bahr El Ghazal does not contribute much waterhyacinth.

The whole phenomenon can be summarized as follows :

Waterhyacinth are produced in the swamps throughout the year slightly increasing in number at low waterlevel. At the rise of the waterlevel many of waterhyacinth are flushed out into the White Nile. In this river they drift downstreams as long as there is south wind or no wind. Even at south wind the waterhyacinth are taken up by the khors and lagoons along the river. The uptake increases with the change of the wind-direction, going southwards as the change of wind direction goes southwards too. The amount of floating waterhyacinth decreases at falling level and more and more waterhyacinth in the lagoons along the White Nile dry out.

Hence, although the investigations are not completed yet it can be stated that the population dynamics of the waterhyacinth in the White Nile and its tributaries is regulated first by the discharge and waterlevel of the rivers and the wind, second by the climate (relative humidity) and furthermore by the water quality.

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CONTROL OF WATERHYACINTH
INTRODUCTION

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Since 1894, when the waterhyacinth clogged many streams in Southern Louisiana (Wunderlich 1962), efforts to eradicate and/or control this weed has started. "The Army Corps of Engineering have been engaged in a war with certain weeds, beginning with waterhyacinth for the past 65 years" (Blackey 1966).

In his fight against waterhyacinth Man has used various means : (i) mechanical; (ii) manual; (iii) chemical; and (iv) biological.

(i) Mechanical means

Many mechanical machinery units were devised in the past 70 years for use in controlling waterhyacinth. These units vary in their functions. Certain boats were operated to cut their way into dense mats of waterhyacinth. Conveyer machines were used to pick the material from the streams and place it on the banks of the waterways to get killed by drying up (Wunderlich 1964). Mechanical mowing and rolling are widely practised in the control of weeds of irrigation ditches (Seaman 1958).

There are many disadvantages inherent in mechanical means of control. These were summarized by Sculthorpe (1967) in the following :

1- There is the risk of incomplete coverage of the infested area.
2- There is the risk of re-infestation by seeds or vegetative fragments.
3- There is the need for frequent repetition of the treatment.
4- There is the risk of greatly disturbing the aquatic environment.
5- There is the high cost of labour.

Wunderlich (1968) gave the cost of control of the unwanted surface in the States as $ 12 per acre when chemicals are used and between $ 25-35 when mechanical means were applied. These figures, of course, need some revision after the fantastic rises in the prices of all commodities.

In countries like ours we are faced with the facts that the machines themselves are very expensive, spare parts are expensive too and in remote areas transfer of fuel (when available) is a very difficult endeavour - all of these add to the list of the disadvantages inherent in the mechanical means of control.

(ii) <u>Manual means</u>

Sculthorpe (1967) dealing with hand clearing states that "......... weeding and cutting by hand is perhaps still the most economical method of removing isolated groups of plants and the small marginal populations of ditches, canals and ponds.". Nevertheless, in the Sudan with the waterhyacinth spreading in a river length of 3170 km in addition to the various lakes, lagoons and the Sudd area, hand clearing cannot cope with the magnitude of infestation. Hence, manual control is very localized in its application (cf. Beshir 1975). Indeed, Heinen and Ahmed (1964) wrote "Even though labour costs are relatively inexpensive, effectiveness of such methods leaves much to be desired and is not encouraged...... and the need for manual control will continue but only in selected and specific areas.". Two local experiences for manual picking were carried out, in co-operation between the Ministry of Youth and the Plant Protection Administration, at El Dueim and Kosti to clean infested areas by youth camps. Calculating the cost of the camps and the area cleared showed the high cost of hand clearing compared to the use of chemicals.

(iii) Chemical means

Many chemicals have been used in the control of waterhyacinth before the beginning of the use of growth hormones in 1946. Parija (1934) used barium chloride; Bouriquet (1949) tried copper sulphate and sodium and calcium arsenates; and the U.S. Army Corps of Engineers tried sodium arsenate in 1902 (Wunderlich 1962).

These chemicals were found to be either ineffective in killing waterhyacinth or they were found to be toxic to other plants and animals.

Hildebrand (1946) was amongst the first to discover the effectiveness of growth hormones especially 2, 4-D (2, 4-dichlorophenoxy acetic acid) in controlling waterhyacinth. Zimmerman *et al.* (1950) were pioneers in making large scale trials with 2, 4-D on waterhyacinth.

Since then, the literature on the herbicidal treatments and properties of 2, 4-D increased rapidly. The research being done covers : formulations of 2, 4-D; effective dosages; methods of application; effects on animal and plant populations; and morphological adaptations of waterhyacinth plants to the sprays (for details, see Dissogi 1974).

(iv) Biological means

Many scientists feel that it is high time for biological control to take part in control programmes of waterhyacinth.

This is because of the high cost of mechanical and chemical control means; because of the environmental hazards caused by chemicals; and because of the many varying local conditions which prevent effective spraying.

Many authors have asserted that biological control would be the best method for control in the future (Anon 1957; Bock 1968; and Wild 1961). However, it appears that relative success has, hitherto, accompanied research activities in biological control.

The following organisms showed signs of success in controlling waterhyacinth : the fungus, Fusarium equiseti (Cda.) Sac. (Banerjee 1942); sea cow or manatee (Allsopp 1961; and Lapham 1964); the mite, Septanychus tumidus (Viscosa 1949); the snail, Marisa cornuarietis (Seaman and Porterfield 1964); Arthropods (Coulson 1971); other insects (Bennet 1970) and the fungi, Alternaria eichhorniae, Myrothecium roridum and Rhizoctonia solani (Charudattan 1973).

The difficulties which face research in biological control seem to be time, money and the limited number of personnel involved.

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CONTROL OF WATERHYACINTH IN THE SUDAN

BY

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The spread of the waterhyacinth in a number of waterways in the Sudan has threatened a number of national interests and that had called for the creation of a National Council for Waterhyacinth Control.

The members of this Council are senior officials selected from departments of direct and indirect involvement with the problem, such as the River Transport Department, the Joint Permanent Technical Commission for Nile Waters, Ministry of Finance, Ministry of Local Government, the Plant Protection Administration. The Council is chaired by the Undersecretary Ministry of Agriculture, Food and Natural Resources. The function of the Council is to act as a policy-making board and to facilitate for the control operations in so much as to allocate funds for campaigns, look into problems relating to the procurement of chemical herbicides, purchase of spare parts, transportation of equipment etc... In effect, its function is to make it possible for the Waterhyacinth Control Section of the Plant Protection Administration, which is entrusted with the fight against the weed, to carry out successful control operations.

The cost incurred annually in the control of the waterhyacinth is now (1975) close to a million Pounds, most of it is paid in hard currency for the purchase of equipment and chemical herbicides.

CONTROL MEASURES AND OPERATIONS

Currently the control measures in the Sudan comprise four major forms; a/chemical control, b/manual removal of waterhyacinth, c/public education and d/legislative action. Due to the lack of specialized mechanical devices no mechanical control is being done.

Chemical control

This has been used as the main control measure since it proved to be the most efficient and cheapest under Sudan local conditions. It is primarily done by spraying with a liquid amine-form of the 2, 4-D herbicide, containing 6 lb. of active ingredient per U.S. gallon.

The largest areas along Bahr El Jebel, the Sobat River and tributaries are sprayed by means of fixed-wing aircrafts. It was found that about 4 lb. of active ingredient applied over one feddan of waterhyacinth gave satisfactory results. This solution is obtained by diluting two-thirds of a gallon of the concentrated herbicide with three and one-third gallons of water. The swath pattern and the speed and discharge rate of the spray equipment on the planes are adjusted to apply the four-gallon-mixture to one feddan of waterhyacinth.

Only in the dry months of the year - December to March - could aerial spraying be conducted, since during the rainy season the muddy soil conditions prevent the construction of landing strips for the fixed-wing type of aircrafts. Permanent landing strips are lacking almost every-where in the South except in three major airports.

Rough, temporary landing strips could only be prepared during the dry season and thousands of feddans of the weed could then be effectively treated. This has been particularly so in the last few years when it became possible to move freely in the South and to reach a considerable part of the infested area. For example, in 1970 only around 11,846 feddans of the waterhyacinth could be sprayed by aircrafts, while in 1973 the area treated has increased to about 128,494 feddans.

To circumvent the problem relating to the lack of landing strips for the fixed-wing aircrafts, a two-Helicopter unit has been introduced in the combat against the waterhyacinth. Working from self-supported floating basis, this unit was meant to penetrate and spray inaccessible areas in the 'Sudd' Region.

The two Helicopters carried out some limited scale spraying operations during March-April, 1975, but it is hoped that their action could be intensified in the coming years since such target-directed aerial application proved to give better control results and it is at the same time more economical.

However, during the rainy season spraying is mainly carried out by means of river campaigns which are actually mobile, water-borne, self-sustaining units. They carry beside the personnel, food, fuel, the herbicide and spare parts necessary for the work of the campaign. Each unit consists of a paddle-wheeled steamer, a living barge, a storage barge and six to eight spray launches. These launches can move freely from one place to another as long as the waterlevel in the streams is not critical. In each spray launch a high-pressure, high volume, spray pump, powered by a diesel engine is mounted. The metering of the chemical is done by means of an automatic metering device which consists of a small suction hose through which the chemical is metered into the main water suction line ahead of the pump. The amount of the chemical used is controlled by a disc located in the small suction hose with a changeable orifice to allow as much or as little chemical to pass. It has been found that a mixture containing 4 lb. of active ingredient of 2, 4-D in 150 U.S. gallons of water is satisfactory to treat one feddan of waterhyacinth.

Such river campaigns can in fact reach places of infestation which could otherwise be difficult to reach by means of aircrafts or land vehicles. They are efficient in removing hyacinth blockages in small streams and hence render it possible for steamers and local boats to find their way from one point to another. Many a remote area in the South would have been completely isolated and faced with the threat of famine and other problems, had it not been for the operations of these river campaigns. Twenty to forty thousand feddans of waterhyacinth are annually sprayed by these campaigns.

Manual removal of the waterhyacinth

These operations take place in locations where spray drift may endanger other field crops, or vegetable and fruit gardens. Of particular importance is the cotton crop which is grown along the banks of the White Nile in the area extending from Dueim up to Renk.

In this region the waterhyacinth is to some extent, manually removed and destroyed. Inherent in the use of this method are two important factors, the wind direction and the waterlevel in the river.

Around April and till September or October the wind blows from the south, thus helps to bring mats after mats of the drifting waterhyacinth downstream and up to the north-most limit at Jebel Aulia where the Dam presents a physical barrier against further movement of the weed. Concurrently, the waterlevel in the main stream starts to recede and that is around April before the flood season commences late in July, and so the water in the <u>khors</u> and small side arms of the river dries up, leaving huge amounts of the weed stranded on the shores and dry water courses. For more details of the population dynamics of waterhyacinth refer to the contribution by Jurgen Freidel in this Volume.

Manual labourers, provided with forks, burning devices and other implements, are then distributed along both banks of the river to collect the weed which is then left to dry under the sun before it is burnt up. Such procedure secures not only the destruction of the mature plants, but also their seeds and seedlings which could otherwise remain as potential sources of reinfestation. These campaigns are stopped at the onset of the rainy season in July.

By late June considerable amounts of waterhyacinth begin to accumulate at Jebel Aulia Dam and the drift of the weed continues as long as the Southerly Winds prevail. Maximum accumulation is reached around September. Spray launches, supplied with 2, 4-D are then ready to carry out the necessary spraying against the waterhyacinth.

Other boats, stationed behind the Dam patrol the northern limits of the White Nile up to its confluence with the Blue Nile, collecting and destroying waterhyacinth plants that escape through the sluices of the Dam. Continued patrolling is also extended north of Khartoum in the main River Nile.

It is interesting to note that when the wind direction changes again, and that is around October, most of the length of the White Nile between Jebel Aulia and Kosti becomes waterhyacinth-free, since the floating mats are driven southwards by the prevailing Northerly Winds.

In connection with these factors the construction of river-barriers in strategic locations is being considered as an auxiliary method to the mechanical and/or the chemical control.

Legislative action.

It is prohibited by law to transport a whole plant of the waterhyacinth or portions of it to clean areas. This law was introduced mainly to protect the Nile River and other uninfested tributaries as well as the canals of the Gezira and Managil Schemes from being contaminated. Inspection and checking points on roads leading to sensitive irrigated areas have been established. Waterhyacinth Control Supervisors have been given authority to enforce these laws.

Public education

It was deemed essential to enlighten the public about the hazards of this weed. This is carried out by means of posters, and occaisonally through the Press, Television, broadcasting services and other means of communication. A film depicting all phases of the control programme has been prepared and is being shown throughout the Sudan. A more recent one is being made for the Television. The Officers in charge of the ground campaigns, explain to the villagers, whom they come in contact with, the danger of the spread of the weed and the penalties pertaining to such actions as possession, transportation and careless disposal of the weed in clean areas.

Thanks to all these efforts that after eighteen years the waterhyacinth infestation is still only confined to the White Nile and the already infested tributaries in the South.

Obstacles and efforts

Unfortunately, these control operations are constantly faced with difficulties. Adverse weather conditions marked by a long rainy season, strong winds and very high temperatures in the Southern Region, are by far the most serious deterrents to the control activities.

Lack of all season serviceable roads, of permanent landing strips for aircrafts, of available spare parts for spraying equipment plus the occasional shortages in the amount of herbicide, are just but a few examples in a long series of obstacles.

Nevertheless, efforts are continuously being made to improve and raise the standard of the control operations. More and better equipped spray-launches have been acquired and added to the original fleet, although the attempts to fix the broken ones are always hindered by the lack of necessary spare parts.

The Agricultural Fleet of the Plant Protection Administration, with Sudanese Pilots flying Cessna and Piper aircrafts and trained in waterhyacinth spraying, participates to some extent in the control operations. However, the Cessna and Piper Planes, being short-range aircrafts, are not suitable to carry out spray operations over the vast expanse of the 'Sudd' region. Therefore, between 3 to 5 far-range aircrafts are hired every year for that purpose.

Screening of new herbicides is being done at Jebel Aulia Research Sub-station in order to keep up with new developments in the field of herbicides and to find an adequate alternative to 2,4-D which can be used in places where 2, 4-D sensitive crops are grown.

A Laboratory for Waterhyacinth Research has just been established at the H.Q of the Waterhyacinth Control Section at Khartoum North. Equipment for the Laboratory has been supplied by the German Technical Aid.

All these efforts are geared towards reducing the infestation to a tolerable level in an endeavour to minimize its harmful effects.

International and bilateral aids

The history of such aids dates back to the first years of the waterhyacinth invasion to the Sudanese Nile System.

When attention was first called to the presence of the waterhyacinth in the Sudan in 1958, the Sudanese Government became very concerned and appointed a Committee to advise on how the problem should be approached. It was then recommended to contact different agencies and Governments faced with similar problems to solicit their expert advice on how best the problem should be tackled.

One of the first places contacted was the Congo (now Republic of Zaire) where Belgian Scientists had also been working on the problem of the waterhyacinth. The Belgian Government designated an Expert, Mr. Buyckx of the National Institute of Agronomic Studies in the Congo, to visit the Sudan and carry out a survey of the infested White Nile and its tributaries. At the time the survey was made the waterhyacinth had succeeded in infesting a considerable stretch of the White Nile, from Bor to Jebel Aulia, a distance of about 850 miles.

The Belgian Expert advised that a control programme should immediately be laid down and that 2, 4-D should be used for spraying infested areas. He also recommended that regular inspection of steamers passing from an infested area to a clean one should be carried out and that public information campaign should be started so that the local people become aware of the danger of the spread of the weed.

Another Belgian Expert, Mr. P. de Kimpe, also helped in writing specifications for spray boats, spray equipment and herbicides necessary for the control operations.

In 1960 the Government of the United States was also approached to assist in the fight against the waterhyacinth. An Expert, Mr. J. Hodgson of the U.S. Agency for International Development arrived in the Sudan and helped in developing an organizational plan for the control of the waterhyacinth, and he demonstrated the first boat spraying.

In 1961, Mr. Heinen, also of the U.S.A.I.D. arrived in the Sudan to help in the execution of the waterhyacinth control programme. His duties ranged from administrative to operational field technique and equipment maintenance.

The recommendations made by the different experts who visited the Sudan established the basis on which the control operations were developed and carried out in the years that followed. During the second half of the 1960's and early 1970's little or no help was received from abroad except for the continuing financial contribution of the Arab Republic of Egypt, made through their membership in the Joint Permanent Technical Commission for Nile Waters. The contribution has reached 300 thousand Pounds in the last fiscal year, 1974-1975. The same amount has been offered for the current fiscal year, 1975-1976. The sum amounts to almost one third of the total expenditure of the hyacinth control budget, and is spent in purchasing the herbicide, for hiring aircrafts for aerial spraying campaigns, and also to pay the cost of running the river campaign units, maintenance and repair cost of boats and a variety of other purposes. Salaries of the waterhyacinth control personnel and the purchase of equipment is paid for from the general budget of the Plant Protection Administration.

In 1973 the Federal Republic of Germany offered to help in the fight against hyacinth. A joint Project was laid down by the Sudanese and the German Governments, which was of a technical and scientific nature. It was directed towards improving the control of the waterhyacinth by replacing the old, broken down equipment with new and better control facilities, and also by introducing and developing new techniques in the control programme. Already a considerable number of new spray launches has been prepared. The German Experts are studying the possibility of using the river-barrier system and the introduction of mechanical harvesters in our control arsenal. The possibility of introducing bio-agents for waterhyacinth control in some suitable locations within the infested area will be investigated. Scientific studies of the ecology and population dynamics of the weed are now under way. The results of all these studies will in the end help in developing a sound strategy for the control of the waterhyacinth.

Reference has been made to "Heinen, E.T. and Ahmed S.H. (1964). Waterhyacinth Control on the Nile River, Sudan. Information Production Centre, Dept. of Agric., Khartoum.".

BURNING AS A SUPPORTING TREATMENT FOR CONTROL OF WATERHYACINTH

BY

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INTRODUCTION

In the Sudan direct control measures against waterhyacinth comprise chemical spraying with 2, 4-D and manual removal using forks and rakes. The latter method though more time-consuming and more expensive, yet, is inevitable under certain circumstances. For example, chemical spraying is restricted during the cotton growing season (July to March); it is also restricted in the breeding sites of fish between January and May, in the vicinity of vegetable and fruit gardens along the river bank and near villages as a precaution against polluting domestic water supplies.

Hence, the unrestricted and environmentally safe manual removal of waterhyacinth is used throughout the year and wherever heavy infestation creates a serious problem.

Masses of manually removed waterhyacinth are normally piled into large heaps along the dry river banks. Also, natural accumulations develop as a result of the sharp drop in waterlevel, in low-flood, cutting off extensive marginal communities of waterhyacinth from the main course. These flat accumulations are most evident around bends, in shallow side streams and depressions.

During the dry period (January to June) under the desiccating heat of open sun, both forms of accumulation (i.e. heaps and carpets) are destined to dry into readily combustible matter. Routine head-burning has been the usual land campaign activity during this period. The dry fluffy combustible debris is burned in order to guard against possible reinfestation by seeds borne in ripe capsules of dry plants.

EXPERIMENTAL

Field experiments were designed to test the efficiency of routine burning which is intended to destroy seed crop contained in dry accumulations (flat and heaped) of waterhyacinth; introduce the Back burning Procedure in an attempt to improve burning operations; and to test the effects of burning on regeneration of waterhyacinth from seed.

1. Testing the efficiency of routine burning

The results suggest possible ammendments of burning practices in order to promote the efficiency of burning debris of naturally and mechanically removed waterhyacinth. It is recommended that early burning, in March, serves several desirable purposes : (1) it safeguards against large scale dispersal of seeds, (2) destroys vegetatively dormant forms which would rejuvenate on the onset of the rainy season, (3) the rainy season, coupled with higher atmospheric humidity retards the process of effective burning, causing incomplete destruction.

11. Backburning

The findings of this study may be summerized as follows:-

a- Viable seed crop contained within dry hyacinth matter experiences a high degree of destruction under excessively hot and more lasting fire associated with backburning heaped components.

b- Flat accumulations respond favourably to backburning.

The success in both (a) and (b) is indicated by evident and almost complete destruction inflicted by high temperature and longer duration.

III. The effects of burning on regeneration from seed

Experimental evidence has shown that a considerable crop of viable seed is contained in the litter accumulating along the banks of the White Nile, during low flood season. Germination experiments conclude that burning destroys a large proportion of seed crop and consequently supresses threat of reinfestation. Hence if properly carried out, burning management can control spread of waterhyacinth. This objective may be achieved through adopting backburning technique on heaped masses of waterhyacinth litter.

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UTILIZATION OF WATERHYACINTH
INTRODUCTION

BY

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Little and Henson (1967) reported "the best way to dispose of a weed is to make use of it, to turn it into a crop. Where weeds are a serious menace and the cost of control by mechanical means or by herbicides is beyond local resources, then utilization of the weed as a means of revenue becomes even more desirable. Water weeds may come into this category and well-known examples of serious infestations are those of waterhyacinth (Eichhornia crassipes) on the Nile and the Congo, and Salvinia on Lake Kariba.".

A handbook on the utilization of aquatic plants was compiled and edited by Little (1968). In this, he asserted that "it is surprising to find how little information on the constituents of these plants is available in the World's literature.".

For waterhyacinth, utilization was suggested (Dissogi 1974) as manure (Finlow and Mclean 1917); as fuel in India (Mclean 1921); as compost (Howard 1925; and Watson 1947); as fodder (Hora 1951; and Chatterjee and Hye 1938); as raw material for industry e.g. paper and plastic industry (Mclean 1917 and Nolan and Kirmse 1974); as power gas and power alcohol (Sen 1931; and

Sen and Chatterjee 1931); and as a protein source (Pirie 1967).

However, it is commonly believed that the utilization of waterhyacinth may often be impracticable, or uneconomic, because of the fact that the plant has such a high water content as to make it too expensive to harvest. If it can be harvested (and a variety of efficient machines are available for this purpose) then its utilization might be seriously looked into.

Pirie (1960) in his contribution 'waterhyacinth : a curse or a crop ?' asserted that his communication is a plea for some re-orientation of thinking in areas suffering from, or threatened with, waterhyacinth; there is a case for directing some research towards finding uses for the pest instead of concentrating all efforts on its eradication. The practicability of the uses mentioned has not been established and difficulties may arise with some of them. But the quantity of waterhyacinth is now so large, and so much effort is already being put into dragging it from waterways, that it would seem reasonable to set up a unit to study all the possibilities.

In the Sudan some effort has been done on the utilization of waterhyacinth. This is given in the following two contributions.

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STUDIES ON THE NUTRITIVE VALUE OF WATERHYACINTH
(EICHHORNIA CRASSIPES MART. SOLMS.)

BY

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INTRODUCTION

Many methods have been adopted for the control of *Eichhornia crassipes*; the most important of which is the chemical method using 2, 4-D. Other measures of control are the mechanical and biological methods. However, none of these methods proved to be highly effective and the weed continued to exist and spread. The failure to eradicate the weed completely despite the great costs involved (about a million Sudanese Pounds in the Sudan in 1975) led scientists to think about alternative means of offsetting part of the costs. Consequently one of the avenues tackled in this respect was feeding the plant to animals, and a number of trials have been conducted in different countries to test the feasibility of using the weed as a feed. When waterhyacinth was fed with a low quality roughage to cattle (Chatterjee and Hye 1938) the animals lost weight (28 to 66 lbs) and only after linseed cake was added to the ration did the animal's conditions start to improve and gains in weight obtained. The results indicated clearly that waterhyacinth feeding is dependent upon its supplementation with feedstuffs rich in protein. This was confirmed by Hossain (1959) who reported loss in weight and diarrhoea in animals fed on waterhyacinth alone and improvement in the condition of these animals when some cakes were fed. Loosli et al. (1954) attributed the low feeding value of waterhyacinth to its high water content and advised against its use alone except in the case of very scarce feed supply. Kamal and Little (1970) working in the Sudan reported several possible ways and means for its utilization. These ranged from its uses as animal feed or mulch for weed control in cotton and horticultural crops, to its possible use as compost. Chalmers (1968) carried out a preliminary study of the nutritive value of waterhyacinth in this country and concluded that it is comparable to many of the local hays and straws, so far as its crude protein content (on dry matter basis) is concerned. She also, suggested, that ensiling the weed would not be a sound proposition because of its high moisture content which approaches 90 per cent. Furthermore, she reported against the possibility of pelleting dried hyacinth prior to feeding, and seemed to be in favour of grazing the hyacinth in the fresh form by allowing Livestock, mainly cattle, direct access to the areas where the weed could be found.

The present series of studies has been planned with the objective of making a precise evaluation of the nutritive value of waterhyacinth under the Sudan conditions, and of studying the possibilities of its use alone, or with other feeds, in feeding ruminants during the dry season.

MATERIALS AND METHODS

(A) Digestibility trials :

Four rams (Sudan Desert Sheep) about two years of age and weighing between 68 and 74 lbs were used in the present study. The rams were fitted with harnesses and bags, for faeces collection, and allocated randomly into two groups before being housed individually in digestibility crates designed for urine collection. Drinking water was made available all the time.

Waterhyacinth, for feeding to the rams, was obtained fresh every morning from the banks of the White Nile at about 3 kilometers south of Jebel Aulia Dam. This collection site was chosen because it had never been sprayed with 2, 4-D and because of the uniformity of the waterhyacinth stands. The material for all the seven digestibility trials was obtained from the same place.

Following the process of cutting, the plant material was carted to the experimental site and a random sample of whole hyacinth plants was taken for botanical analysis. The material was then randomly divided into two lots. The plants from one lot were cut to separate the lamina from the shoot. The other lot was also cut up, firstly the shoots being separated from the roots, secondly the shoots being chopped into small pieces each about 1-1½ inches in length. Thus prior to feeding to the animals the waterhyacinth was available in two forms : (a) chopped lamina, (b) chopped shoot (i.e lamina + petiole). After thoroughly mixing, separately, each of the two types of waterhyacinth material, two grab samples (one from each type), each of 500 gm were weighed and taken to the laboratory for dry matter determination. Immediately after this, two samples, one from each type of waterhyacinth feed, each weighing about 5 kg, were weighed into separate bags. The weighed content of each sack was fed to one ram. The chopped lamina portions were fed to one group of rams and the chopped shoot was fed to the other group.

Each experimental period lasted for 10 days in which no faeces or urine collections were made. The length of the preliminary period was chosen to ensure the adaptation of the animals to the harnesses, bags and crates, and the rumen micro-organisms to the feed being consumed by the animal (Lloyd, Peckham and Crampton 1956). Feed was offered <u>ad. libitum</u> at 8.00 a.m. Food residues were collected-just before feeding at 7.30 a.m.- dried, weighed and the amount deducted from the dry matter weight of the food offered. Daily subsamples of food being offered and residues of each sheep were treated in a manner similar to that described by Osman and Donasoury (1963).

Urine and faeces from each animal were collected separately every day at 7.30 a.m. and treated in a manner similar to that described by Abou Akkada and el-Shazly (1965).

Food and faeces were analysed according to the Methods of Analysis of the Association of Official Agricultural Chemists, Anon. (1965). Total nitrogen in urine was estimated by the micro-kjeldahl method described by el-Shazly (1958).

On the first day following the end of each experimental period (i.e the 11th day), two samples of rumen liquor were obtained from each ram by means of a stomach tube (Abou Akkada and Osman 1967). The first sample was collected just before feeding (i.e 7.45 a.m.) and the second sample 3hrs after feeding. After straining through two layers of gauze, the before-feeding collection from each ram was divided into two equal samples. One sample was further subdivided into two portions. One portion was incubated in vitro for 1 hr with 1 gm of dried and ground sample of the feed being given (el-Shazly and Hungate 1965). The other portion, which was intended to act as a control, was incubated in vitro without the addition of any food. The gas evolved from both incubated samples was recorded at 5-minute intervals. The total amount of gas evolved in 1 hr was then assessed from the regression equation relating time to amount of gas evolved. The difference in gas production in 1 hr between the control and the portion incubated in vitro with 1 gm of food was then taken to be proportional to the net growth of rumen micro-organisms (el Shazly and Hungate 1965). The second samples of the before-feeding collections were kept in a deep freeze while awaiting analysis for the estimation of ruminal ammonia. Concentration of ruminal ammonia was determined by the method described by Abou Akkada and el Shazly (1964, 1965). Blood sample were also obtained from the Jugular vein of each ram before feeding and 3 hrs after feeding for determination of urea nitrogen concentration by the method of Abou Akkada and el-Shazly (1965).

Statistical analysis were as given by Snedecor (1957).

(B) **Feeding trials:**

32 lambs (Sudan desert sheep) about one year old and of weight varying between 50 and 55 lbs were used in the feeding trials. They were divided randomly into four groups of eight animals. The initial weight of each lamb was obtained after an overnight fast. This trial lasted for eight weeks during which the four groups of lambs were randomly fed on one of the following feeds :

(1) Fresh waterhyacinth; (2) Humra: this is a mixture of local dried desert grasses composed mainly of Dactyloctenium aegyptium, Schoenefeldia gracilis, Eragrostis pilosa, Aristida funiculata and Aristida sp. The material for the trial was collected from an area about 5 kilometers west of Jebel Aulia Dam; (3) concentrate: this is a mixture of 50 % berseem hay (Medicago sativa) Arabian Strain, 30 % dura grain (Sorghum vulgare) and 20 % cotton seed cake.

The 1st group of lambs was fed waterhyacinth only. The second group was given humra as the sole feed. The third and fourth groups were fed waterhyacinth plus the concentrate, and humra plus the concentrate respectively. The roughages (waterhyacinth and humra) were offered ad. libitum to the four groups while the concentrates were offered to the third and fourth groups at levels that were predetermined , in accordance to Morrism standards, to satisfy the maintenance requirements for crude protein.

The lambs were accomodated in a shed. Each animal was fed individually with free access to drinking water and salt licks. Roughages were chopped, thoroughly mixed and offered to the lambs at 8.30 a.m. Concentrates were offered at 5.00 p.m. Residues were collected every morning and the dry matter intake of each lamb was calculated using the procedure already outlined. Lambs were weighed at the end of each week to determine the weekly change in Liveweight.

RESULTS AND DISCUSSION

(A) Digestibility trials:

1. Botanical analysis:

The betanical changes which occurred in **waterhyacinth** plants throughout the seven experimental periods extending from 25 October, 1970 to 15 April, 1971 are shown in Table 1.

Table 1. Botanical analysis of waterhyacinth throughout the seven experimental periods

Periods	Petiole length (cm)	Petiole dry matter weight gm/plant	Leaves number per plant	Lamina dry matter weight gm/plant	Lamina area sq. cm/ plant
1st. 25.10 - 2.11.71	36.9	18.5	7	8.0	154.0
2nd. 20.11 - 27.11.71	31.7	13.5	8	7.5	129.9
3rd. 20.12 - 27.12.71	30.5	12.7	7	7.6	131.5
4th. 20.1 - 27.1.72	31,2	12.3	8	4.3	126.5
5th. 20.2 - 27.2.72	25.6	11.2	8	4.9	123.5
6th. 20.3 - 27.3.72	20.3	11.1	7	3.7	109.5
7th. 15.4 - 22.4.72	13.5	10.5	8	3.2	91.5
Mean	27.10	12.83		5.60	123.78
S.E. (±)	2.51	1.02		0.77	12.21

It is clear that petiole length and weight as well as lamina weight and area decreased continuously from the first period to the seventh period. The laminae number varied from period to period but it did not show any systematic change with time. The optimum vegetative growth rate of waterhyacinth occurred during the period from October to December while the lowest growth rate was during the month of April.

The gradual decrease in the vegetative growth rate is an explicable phenomenon because October, when the first experiment was conducted, is the time of the year when proliferating luxuriant plants are carried by river current, aided by southern winds, to Jebel Aulia Dam area. From October onwards, gradual retardation in growth rate occurs partly as a result of the piling up of the plants into a thick mat south of the Dam, and partly due to the onset of the cold weather. During the March-April period, which constitutes the peak of the dry period, the plant usually fades and dries out. By the beginning of the rainy season the weed starts to flourish again.

2. Chemical composition:

The dry matter content of waterhyacinth was found to vary from 10-18 per cent in the lamina and between 8-14 per cent in the shoot. Similar results were reported by Chalmers (1968).

The chemical composition of the lamina and the shoot throughout the seven experimental periods are shown in Table 2 (p. 111). The protein and ether extract contents of the lamina were higher than those of the shoot and the highest percentages of protein were obtained during the 6th and 7th periods-the time of minimum vegetative growth rate. On the other hand the shoot was richer than the lamina in crude fibre and nitrogen free extract. One of the striking features of the composition of this aquatic plant was its high ash content which was higher than that usually encountered with the more conventional feedstuffs.

Table 2. Chemical composition of the lamina and the shoot of waterhyacinth throughout the 7 experimental periods (expressed as percentage of dry matter).

Periods	Crude protein		Crude fibre		Ether extract		Ash		Nitrogen:free extract	
	Lamina	Shoot	Lamina	Shoot	Lamina	Shoot	Lamina	Shoot	Lamina	Shoot
1st. 25.10 - 2.11.71	12.1 (1.1)	7.5	16.7	20.7	2.2	1.3	15.2	17.3	53.6	53.2
2nd. 20.11 - 27.11.71	9.8 (1.8)	6.9	15.8	18.2	1.7	1.1	20.7	19.8	52.1	54.0
3rd. 20.12 - 27.12.71	5.6 (0.9)	9.2	17.9	16.4	0.9	1.1	23.5	19.2	52.0	54.1
4th. 20.1 - 27.1.72	11.8 (1.2)	9.4	14.3	19.5	0.8	0.8	21.1	15.4	52.0	55.0
5th. 20.2 - 27.2.72	9.6 (1.0)	6.6	14.0	18.3	1.4	1.1	28.7	22.8	46.3	51.2
6th. 20.3 - 27.3.72	16.6 (0.9)	9.9	17.1	20.0	1.4	1.4	19.7	18.6	45.2	50.1
7th. 15.4 - 22.4.72	14.9 (1.2)	7.8	17.5	20.0	2.1	1.7	22.9	27.5	42.6	43.1
Mean	11.5 (1.2)	8.2	16.2	19.0	1.5	1.2	21.7	20.1	49.1	51.5
S.E. (±)	2.06	0.49	0.59	0.55	0.21	0.21	1.55	1.49	1.63	1.55

The figures between the brackets are the corresponding crude protein percentage in the petiole.

Results in Table 3 (p. 113) demonstrate the statistical analysis on some of the results already presented. It is shown that the correlation coefficient between lamina dry weight and lamina area was significant (r = 0.83). This means the bigger the area, the greater the dry matter content in the lamina. The correlation coefficient between lamina weight on dry matter basis and the lamina crude protein showed a significant negative correlation (r = - 0.68). No significant correlation was obtained between the lamina dry weight as a proportion of the total dry matter weight of the shoot and the lamina area. On the other hand highly significant negative correlation was obtained between the lamina dry weight as a proportion of the dry weight of the whole shoot and the lamina crude protein content (r = 0.82). This shows that the bigger the lamina area per plant, the heavier was the dry matter content, but the lower was the crude protein content.

3. Nutritional value

Dry matter intake values from both lamina and shoot through the 7 experimental periods are given in Table 4. (p. 114). The intake from the lamina was higher than that from the shoot. The low intake from the shoot was due to its higher moisture content which limits the amount of dry matter that can be consumed. The results show that low dry matter intake levels do parallel with the periods of high moisture content in both lamina and shoot.

The results outlined in Table 5 (p. 115) show a higher organic matter digestibility for the shoot than the lamina. The digestibility of the proximate constituents of the shoot also showed higher values in comparison to that of lamina. Both lamina and shoot had shown their highest digestibilities during the third, fourth and fifth periods, the time of optimum vegetative growth of waterhyacinth.

Table 3. Correlation coefficients between lamina dry weight, lamina area and lamina crude protein percent and correlation coefficients of lamina dry weight as a proportion of dry weight of shoot, lamina area and lamina crude protein percentage

X	Y	Correlation Coefficients (r)
Lamina weight (dry matter basis)	Lamina area	r = 0.83**
Lamina weight (dry matter basis)	Lamina crude protein percentage	r =-0.68*
Lamina dry weight as a proportion of shoot dry weight	Lamina area (sq. cm)	r = 0.55 N.S.
Lamina dry weight as a proportion of shoot dry weight	Lamina crude protein percentage	r = 0.82**

* Significant at P = 0.10

** " " P = 0.05

N.S. Not significant

Table 4. Intakes of dry matter (gm/day) by sheep given lamina and sheet during the 7 experimental periods.

Periods	1	2	3	4	5	6	7	Mean
Lamina	415.7	507.9	562.8	1125.9	1241.2	380.3	434.6	572.6
Sheet	415.7	378.8	402.4	843.9	937.7	246.1	383.7	441.9

Table 5. Digestibility coefficients of five constituents of lamina and sheet during the 7 experimental periods.

Periods	Organic matter		Crude protein		Crude fibre		Ether extract		Nitrogen: free extract	
	Lamina	Shoot	Lamina	Shoot	Lamina	Sheet	Lamina	Shoot	Lamina	Sheet
1st. 25.10 - 2.11.71	53.7	59.8	44.9	47.0	44.8	59.3	77.5	76.8	57.3	61.3
2nd. 20.11 - 27.11.71	52.9	67.8	45.6	46.0	46.0	65.6	63.6	65.9	56.7	70.0
3rd. 20.12 - 27.12.72	51.5	56.4	48.6	57.6	55.7	51.3	48.4	77.6	53.6	57.5
4th. 20.1 - 27.1.72	73.2	83.4	74.4	83.5	67.9	81.4	70.0	85.0	74.8	84.1
5th. 20.2 - 27.2.72	68.0	79.2	73.1	72.6	70.2	78.2	78.6	84.3	71.9	80.4
6th. 20.3 - 27.3.72	42.3	61.8	45.4	57.8	38.8	63.4	50.5	68.6	42.0	61.7
7th. 15.4 - 22.4.72	52.4	59.6	51.4	43.7	43.1	60.1	49.4	75.5	45.3	61.7
Mean	56.3	66.9	54.9	58.3	52.4	65.6	62.6	76.2	57.4	68.1
S.E. (±)	1.40	3.98	4.98	5.63	4.73	4.16	5.01	2.72	4.67	3.94

The high digestibility coefficients observed with all ingredients of the sheet compared to that in the lamina can not be explained on the basis of crude fibre content which was higher in the former than the latter. The high fibre content of the sheet should have resulted in lower digestibility values for its contents than that of the lamina, a fact contrary to what had been obtained. In this respect one should not, however, lose sight of the prevailing low dry matter intake from both types of feed which might have resulted in this unexpected result.

Table 6 (p.117) represents the results of the in vitro rate of fermentation, changes in concentration of ruminal ammonia and blood urea as measured just before feeding and 3 hrs after feeding on lamina and sheet of waterhyacinth throughout the 7 experimental periods.

The volume of gas produced by a lamina substrate was greater than that produced from a sheet substrate. The greater in vitro rate of fermentation resulting from the lamina in comparison to the sheet (Fig. 1), which is taken as an expression of the net growth of rumen micro-organisms (el-Shazly and Hungate 1965), is an indication of the more efficient utilization of protein degradation products of the lamina by ruminal micro-organisms.

To explain this observed difference between the lamina and the sheet with respect to in vitro gas production rate, the correlation between the nitrogen content of the lamina expressed as a deviation from the nitrogen content of the sheet, and the volume of gas produced by the sheet was examined. The correlation coefficient obtained was negative ($r = -0.58$) and not significant. This finding made it difficult to attribute the observed differences in gas production brought about by the lamina and the sheet to the differences in their protein content.

Fig. 1

In Vitro Rate of Fermentation

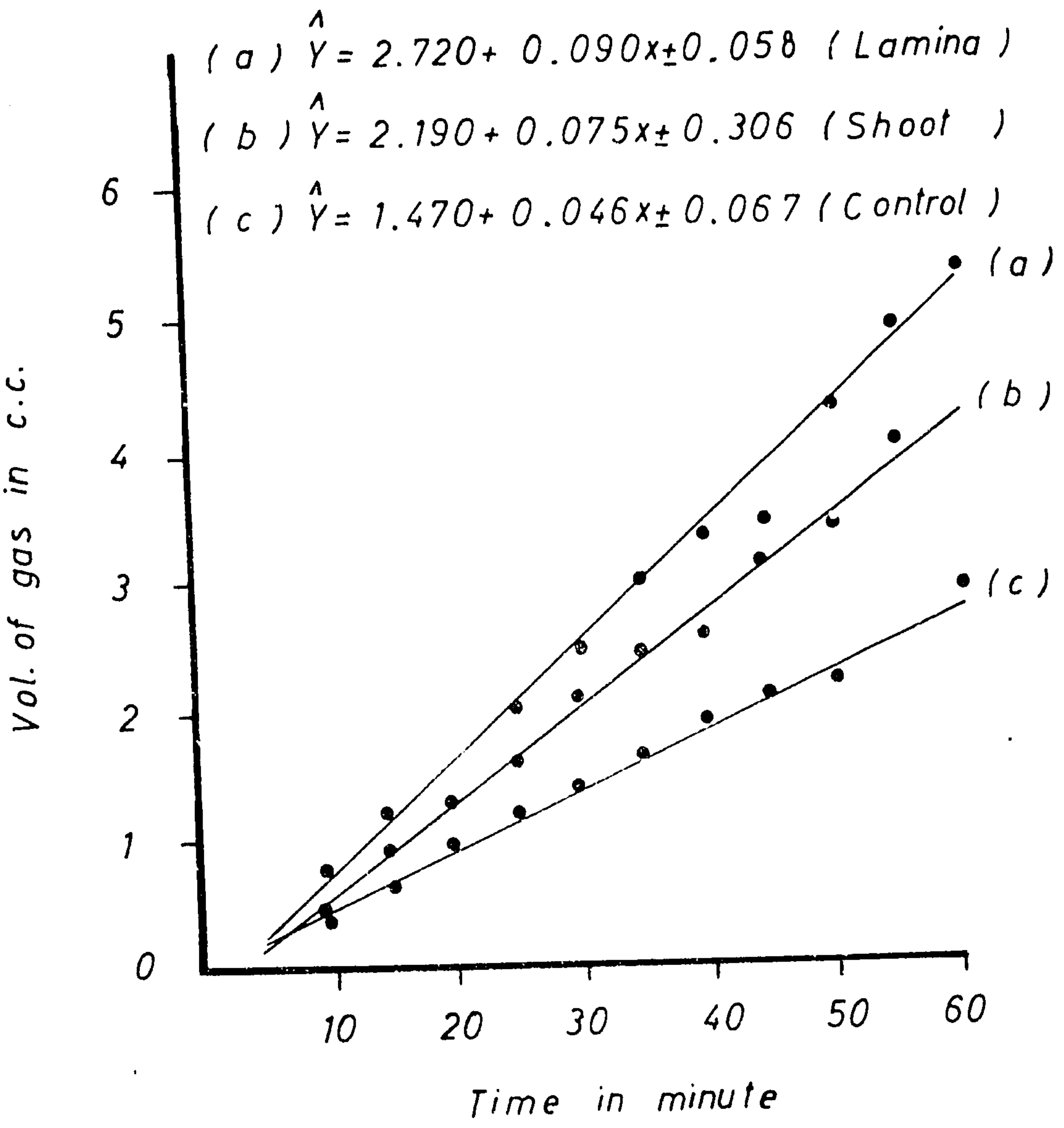

Table 6. Gas produced, change in the concentration of ruminal ammonia and blood urea of sheep fed on lamina and shoot through the 7 periods

Periods	Gas produced (ml) after 1 hr		Change in concentration of ruminal ammonia mgN/ 100 ml		Change in blood urea urea mgN/100 ml	
	Lamina	Shoot	Lamina	Shoot	Lamina	Shoot
1st. 25.10 - 2.11.71	2.76	1.87	0.67	0.27	0.78	- 0.39
2nd. 20.11 - 27.11.71	3.33	2.24	0.64	0.44	1.02	- 0.37
3rd. 20.12 - 27.12.71	2.59	1.61	0.57	0.40	0.27	- 0.21
4th. 20.1 - 27.1.72	2.51	1.16	0.50	0.36	0.52	0.11
5th. 20.2 - 27.2.72	2.53	1.73	0.39	0.33	0.63	0.20
6th. 20.3 - 27.3.72	1.49	0.85	0.52	0.16	0.86	0.27
7th. 15.4 - 22.4.72	2.09	1.11	0.42	- 0.27	1.16	0.59
Mean	2.47	1.51	0.53	0.24	0.75	0.03
S.E. (±)	0.23	0.22	0.42	0.88	0.12	0.13

The changes in the concentration of ruminal ammonia expressed in mgN/100 ml as measured just before feeding and 3 hrs after feeding, was significantly higher ($P > 0.001$) for the lamina than the shoot (Table 7). As the rate of ammonia production in the rumen depends mainly on the degree of solubility of protein (Lewis 1960; Annison 1956; el-Shazly 1958; Mc Donald 1962), it was concluded that the lamina had more soluble protein than the shoot. This high soluble protein content of the lamina in comparison with that of the shoot was also reflected in the digestible crude protein which was also found to be higher for the lamina Table 8 (p. 119).

Table 7. Mean squares for in vitro rate of fermentations, changes in ruminal ammonia and blood urea.

Source of variation	in vitro gas production	Ruminal ammonia	Blood urea
Between periods	1.08***	0.01**	0.29**
Between feeds (i.e lamina and shoot)	6.48***	0.59***	3.61**

** Significant at P = 0.01
*** " " P = 0.001

The present study also showed that blood urea levels were significantly ($P > 0.001$) higher on feeding lamina than on feeding shoot. This result was in agreement with the observations made with ruminal ammonia, since ruminal ammonia concentrations were found to be paralleled by similar changes in blood urea concentrations (Abou Akkada and Osman 1967).

The nutritive value was expressed in terms of nitrogen

Table 8. Nitrogen retention, digestible crude protein and total digestible nutrients in lamina and shoot throughout the 7 experimental periods

Periods	Nitrogen retention %		Digestible crude protein		Total digestible nutrients	
	Lamina	Shoot	Lamina	Shoot	Lamina	Shoot
1st. 25.10 - 2.11.71	2.7	1.6	5.3	3.3	43.1	50.8
2nd. 20.11 - 27.11.71	1.8	1.8	2.8	3.9	36.6	55.3
3rd. 20.12 - 27.12.71	0.3	- 2.0	0.9	5.3	26.3	46.8
4th. 20.1 - 27.1.72	4.2	- 1.0	8.8	7.8	58.7	71.2
5th. 20.2 - 27.2.72	3.6	- 0.4	5.2	4.8	50.8	62.4
6th. 20.3 - 27.3.72	3.6	1.2	6.5	3.9	26.6	35.7
7th. 15.4 - 22.4.72	4.1	2.6	7.7	3.4	35.5	44.9
Mean	2.9	0.5	5.3	4.6	39.7	52.4
S.E. (±)	0.57	0.62	1.07	0.64	5.2	4.90

retention, digestible crude protein and total digestible nutrients (Table 8). The nitrogen retention values, expressed as a percentage of the total nitrogen consumed were generally higher with the lamina than with the shoot and the difference between the two was highly significant (P > 0.001, Table 9). This finding was in accordance with the expectation which was based on the lamina higher level of intake and protein content. However, when examining the present results in the light of what had been reported by Abou Akkada and Osman (1967) that nitrogen retention was negatively correlated to ruminal ammonia and blood urea concentrations, one could notice the discrepancy between the two observations. This lack of agreement between the results of the present work and those of the latter authors could have resulted from the fact that the waterhyacinth is different from the feedstuffs (legumes) upon which their deduction was drawn.

Table 9. Mean square components for nitrogen retention, digestible crude protein and total digestible nutrients for seven periods between lamina and shoot.

Source of variation	N-retention	Digestible crude protein	Total digestible nutrients
Between periods	6.74***	12.12*	528.38***
Between feeds (i.e lamina & shoot)	36.46***	6.17N.s.	1044.21***

* Significant at P = 0.05

*** " " P = 0.001

N.s. Not significant

The lamina was also superior to the shoot in terms of digestible crude protein. The lowest values of digestible crude protein were obtained in the third period which was also the period when the nitrogen content of the lamina was lowest. The values of total digestible nutrients (TDN), were on the other hand significantly higher ($P > 0.001$) in the sheet than in the lamina (Table 9). This high TDN value of the sheet, compared to lamina, may be attributed to its higher fermentable carbohydrate content; a proposition that can be confirmed by the fact that the highest TDN values in the sheet were obtained in the fourth period when the nitrogen free extract was at its maximum.

(B) Feeding value:

The results of this work indicated clearly that waterhyacinth could not provide the optimum nutritional requirements for the animals, partly due to its low protein content and partly due to its high moisture content. These factors made it difficult for the animals to consume a sufficient amount of dry matter to satisfy their nutritional needs. For this reason, the idea of utilizing waterhyacinth as a supplement arose and so it was fed alone or in addition to a concentrate. These two procedures of feeding were compared with feeding humra alone or humra supplemented with concentrates.

It is evident from Table 10 (p. 122) that the lambs on waterhyacinth alone consumed the least amount of dry matter, digestible crude protein and total digestible nutrients, which were far below their maintenance requirements. The amount consumed by the 2nd group (i.e humra alone) was also below the animal's maintenance requirements. The third and fourth groups which were given concentrates in addition to roughages were on the other hand provided with ingredients in excess of their maintenance requirements.

At the beginning of the feeding trial, each group of animals consisted of eight lambs. During the eight weeks period,

Table 10. Intakes of dry matter, digestible crude protein and total digestible nutrients by lambs given waterhyacinth, humra, waterhyacinth plus concentrates and humra plus concentrates (mean values for 8 sheep).

Group	Ration	Dry matter consumed lb. Roughages	Concentrates	Dry matter consumed as percentage of live-weight	Digestible crude protein lb.	Total digestible nutrients lb.
1st group	Waterhyacinth	0.46		0.8	0.02 (.09)	0.24 (1.00)
2nd group	Humra	0.93		1.6	0.02 (0.09)	0.29 (1.00)
3rd group	Waterhyacinth plus concentrates	0.41	1.61	2.9	0.13 (0.09)	1.02 (1.00)
4th group	Humra plus concentrates	0.79	1.21	3.5	0.19 (.09)	1.10 (1.00)

Figures between brackets are the corresponding requirements for maintenance.

the lambs in the 1st group died. Their deaths started in the 3rd. week till the beginning of the last week, when none of the lambs in this group were alive. The lambs of the 2nd group (on humra) also lost weight continuously while the third and fourth groups (i.e. roughages plus concentrates groups) were gaining throughout the trial.

The deleterious effect resulted from feeding waterhyacinth alone may be due to its low palatibility which is induced by its high potash content (Hossain 1959) and the incidence of diarrhoea that affected the animals from the 3rd week of the trial. Hossain (1959) attributed the inducement of diarrhoea to the high alkali and the high moisture percentages. Waterhyacinth supplemented with a concentrate gave satisfactory results as shown by the performance of the 3rd group of lambs Table 11 (p. 124). This finding indicates the importance of feeding waterhyacinth with a protein rich supplement as has also been demonstrated by Chatterjee (1938) and Hossain (1959). The fourth group, which was fed on humra and concentrates, performed best.

It can be concluded from this work that both waterhyacinth and "humra" are very poor quality roughages that can not be fed as the sole feed to ruminants. Consequently it is logical to recommend feedings both roughages, only together with other constituents, which are rich in protein and high in dry matter content in case of waterhyacinth. If one has to choose between humra and waterhyacinth, one would no doubt recommend "humra". Feeding waterhyacinth to replace "humra" could be of special value along the banks of the White Nile, particularly in the dry season and years of low rainfall when the grasses are scarce.

In trying to feed waterhyacinth, attempts must be made to improve the intake level. This could be done by spraying it with melasses after leaving it to wilt, or after drying and grinding. The grinding of the dry material is essential

Table 11. Average change in weights (lbs.) of lambs per head per week for eight weeks (feeds offered, waterhyacinth for group I, humra for group II, hyacinth plus concentrates for group III and humra plus concentrates for group IV)

Weeks	1st group	2nd group	3rd group	4th group
1st. week	- 0.50 (8)	+ 3.60 (8)	± 0.38 (8)	+ 3.13 (8)
2nd. week	0.00 (8)	- 0.49 (8)	± 1.00 (8)	+ 2.50 (8)
3rd. week	- 3.17 (6)	+ 0.25 (8)	+ 0.24 (8)	+ 2.38 (8)
4th. week	- 0.25 (4)	+ 1.62 (8)	+ 3.75 (8)	+ 2.50 (8)
5th. week	- 3.75 (4)	- 1.62 (8)	- 0.75 (8)	+ 3.13 (8)
6th. week	- 2.00 (3)	- 2.75 (8)	+ 0.75 (8)	+ 1.37 (8)
7th. week	- 1.50 (2)	- 1.63 (8)	+ 0.62 (8)	+ 1.13 (8)
8th. week	- (0)	- 1.25 (8)	+ 1.38 (8)	+ 0.37 (8)

Figures between brackets are the number of lambs in each group during each of the eight weeks of the trial.

as the dried waterhyacinth is extremely tough to be consumed without any further processing. Further work is planned to investigate the use of urea and molasses in enhancing the nutritive value of waterhyacinth.

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UTILIZATION OF WATERHYACINTH (EICHHORNIA CRASSIPES) AS MULCHING MATERIAL

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INTRODUCTION

The appearance of waterhyacinth in the White Nile was first reported in 1958 by G.V. Wickrama and P.A. Gay. The plant in 1960 infested an area of 1,000 miles of the White Nile including the stretch from Juba to Jebel Aulia Dam, the whole length of the Sobat River and Bahr ez Zeraf and many of the side lakes and tributaries especially in the 'Sudd' region (Heinen and Ahmed 1964).

A few months later big quantities of the plant accumulated in Jebel Aulia Dam forming a thick carpet. About 50 million tons of the plant material were removed annually from the river. This quantity of plant material represents approximately a hundred million pounds of nitrogen that could be recovered and used profitably. A project between the Republic of Sudan and United Nations Organization was initiated for eradication and utilization of these huge quantities of this plant material.

This contribution describes the utilization of dry waterhyacinth as a mulch that affects weed control and soil moisture reservation.

MATERIALS AND METHODS

A thoroughly infested area with sedge (Cyperus rotundus) was chosen. Four quantities of 0, 20,40 and 60 kilogram of the plant material per plot (3 x 3.7 m.) were applied and replicated thrice in randomized blocks design. The mulch was then left undisturbed for three weeks after which it was removed and observations were made.

(a) Weed control

Random samples of 20 uniform sound sedge tubers were dug from each plot at the end of the experiment. The tubers were then planted in dishes, daily counts were made of the number of tubers that gave visible leaves. The time required for 50 % of the tubers to sprout was estimated.

Leaf length was also measured daily for a period of two weeks and the mean growth rate per day was calculated (Table 1.).

Table 1. Number of days for 50 percent sprouting and the mean growth rate of leaves of sedge subsequent to mulch treatments.

Treatment	Mean days to 50 percent sprouting	Mean growth rate (mm per day)
Control (no mulch)	6.56	5.20
20 kgm. per plot	6.52	5.00
40 kgm. per plot	8.00	3.10
60 kgm. per plot	9.25	3.00

The visible effect of the mulch on the sedge was remarkable. The intensity of smothering (burning) was marked and increased with increase in the mulch material per unit area. On the other hand penetration of the grass leaves up the depth of the mulch decreased with increase in the mulch material. The time required to 50 % sprouting increased with increase of the mulch quantity and the mean growth rate was very much reduced with increase in mulch material.

These results were due to the insulating effect of the mulch causing lack of light. The slow rate of regeneration of leaves was due to the relatively less food stored in these tubers because of the burning of the tops.

(b) Soil moisture reservation

Soil moisture content was determined at three soil depths namely 0-½, 6 and 12 inches. Samples were taken from each block twice per week for a period of one month using the standard Gravimetric Sampling method.

Table 2. Effect of the mulch on soil moisture reservation at different soil depths.

(per cent moisture)

Treatment	Soil Depth (inches)		
	Surface (0-½)	6	12
Control (no mulch)	14.78	15.01	21.11
20 kgm per plot	17.25	20.87	22.25
40 kgm per plot	22.35	22.36	23.89
60 kgm per plot	22.07	25.94	26.24

Table 2. shows that the amount of water kept by the soil was positively correlated with the weight of mulch applied per plot. The effect being mainly due to reduction of evapotranspiration. The moisture content at the soil surface (0-½ inch) was increased by about 33 % when applying 60 kgm of the mulch material per plot. At the depth of 12 inches the variation in moisture content between the control and 60 kgm was small compared with that of the surface, this is mainly because the upper surfaces were exposed to more evaporative conditions and also they acted as self-mulching to the lower surfaces.

(c) Plant analysis

The waterhyacinth was analysed for P, N, K and Ca content and this was compared with other plant materials. Table 3. shows that the waterhyacinth has high phosphorus (P), average nitrogen (N) and potassium (K) and poor calcium (Ca) content. Because of the high content of phosphorus vegetable growers in the White Nile area, where considerable amounts of the plant material are removed from the river, may use the sundried plant material as mulch and the ash as a source of plant food.

Table 3. Chemical analysis of the plant material

Plant Material	Per cent			
	P	N	K	Ca
Waterhyacinth*	0.42	1.03	1.81	0.02
Alfalfa	0.24	2.37	2.05	1.47
Barley	0.23	1.17	1.35	0.26
Horse-bean (straw)	-	1.38	-	-

* Our own analysis. Source of other data is Feeds and Feeding by Morrison (1951).

CONCLUSIONS

Results obtained showed the possible utilization of dried parts of waterhyacinth plant as mulching material for weed control, source of feed for plants and an effective means for evapotranspiration reduction.

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SOME EFFECTS OF <u>EICHHORNIA CRASSIPES</u> (MART.) SOLMS ON THE PRODUCTIVITY OF THE WHITE NILE

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Knowledge of successive modifications of water characteristics is essential for many aspects of river biology. Very few studies along these lines, were made on the Nile; the most important of which are those by Talling (1957) and Bishai (1962).

It will be noted that the first of the above two studies on water characteristics of the White Nile was undertaken a few years before waterhyacinth became endemic on the Nile. The second was undertaken with the view of assessing the impact of the waterhyacinth invasion on the productivity of the Nile.

The aim of the present study is two-fold : a comprehensive assessment of water characteristics of the White Nile and its tributaries, and a comparison of the present new data with those of Talling (1957), Bishai (1962) and others; to discover, the long term impact, if any, of the waterhyacinth on productivity, 16 years after its infestation of the White Nile. The comparison is made with respect to spatial succession of water characteristics and longitudinal succession of zooplankton as the criteria indicating the change in the White Nile ecosystem.

The data presented are based on surface samples collected from free flowing water along the White Nile between Juba and Jebel Aulia Dam, a distance nearly 1800 kilometers. Samples for zooplankton counts were collected simultaneously. The analysis of the physico-chemical properties of water was carried out by the standard methods described by Mackreeth (1963).

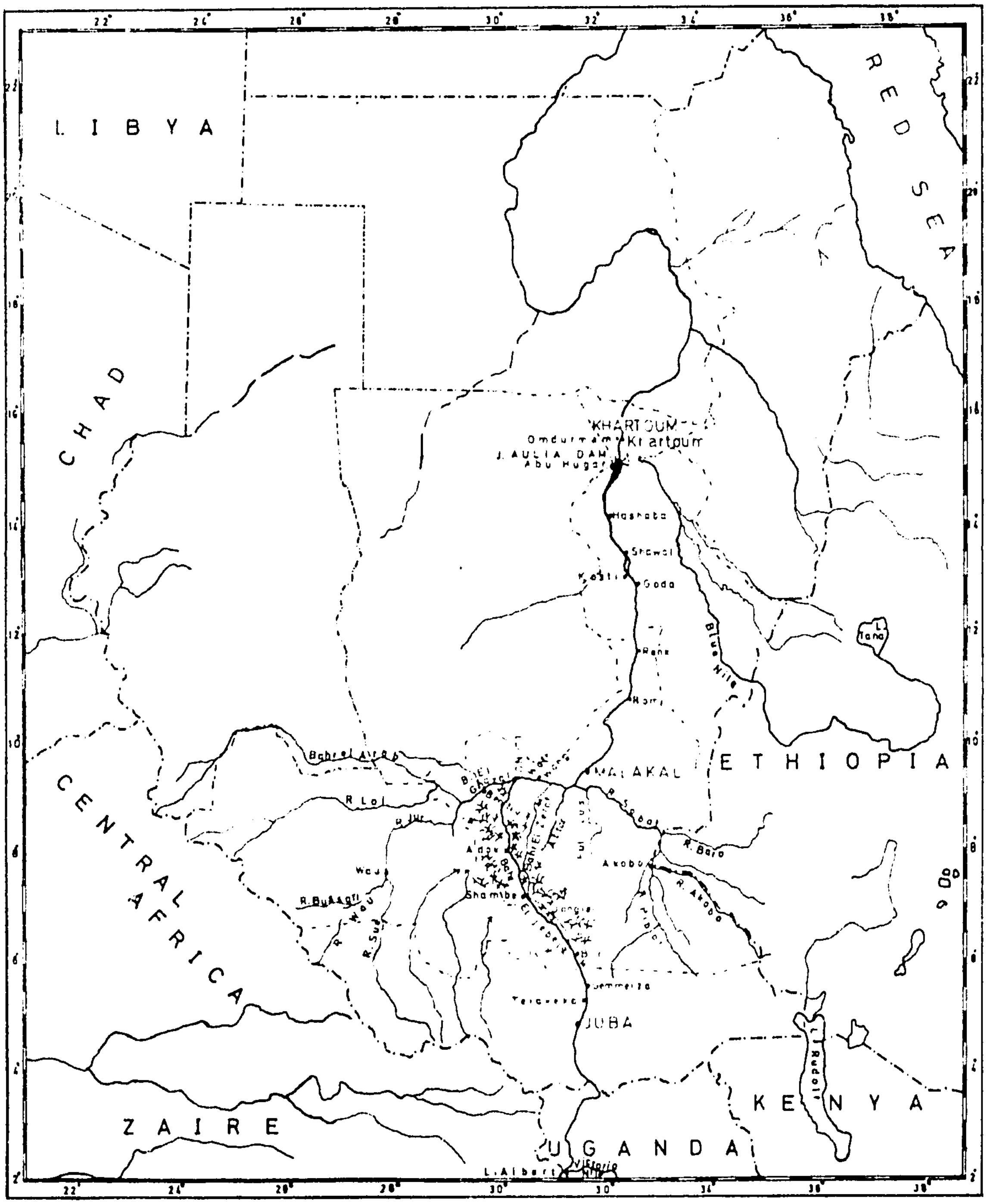
A comprehensive description of the Nile Basin can be found in the classic works of Hurst (1950, 1952), Hurst and Phillips (1932) and more recently by Hammerton (1972). The History of infestation of the Nile by the waterhyacinth is given by Obeid and Tag El Seed (1973) together with the ecology of the weed, its reproductive strategy and the methods of control (Tag El Seed and Obeid 1973, 1975).

SPATIAL SUCCESSION OF WATER CHARACTERISTICS

River Sobat, Bahr el Ghazal and Bahr el Zeraf were the tributaries studied (see Map 1). The influence of any tributary depends on its characteristics and the volume of water contributed to the main channel. The main features of the longitudinal succession of water characteristics along the river are shown in Table 1 (p. 135).

The water characteristics of Bahr el Jebel before entering the 'Sudd' are best represented by the station at Gummeiza. During the passage of water through the swamp, as it does along Zeraf, significant modifications take place. The effect is an increase in the total dissolved salts (shown by values for conductivity) and in the concentrations of calcium, magnesium, sodium, potassium and silicon. Phosphate, on the other hand, is depleted in the swamp while pH, nitrate-nitrogen and nitrite-nitrogen remain more or less unchanged. The increase might be attributed to the increased rate of evaporation in the swamp.

This agrees with the findings of Talling (1957) except



Map1. The White Nile and its tributaries – Sudan.

Scale 1: 8000000

Km 100 0 100 200 300 400 500 Km

Table 1. Water characteristics of the White Nile between Khartoum and Juba, during April-June, 1973

	Gummeiza	Bahr el Gedid	Shambe	Adok	Wath Wang	Bahr el Zeraf	Below Kher Attar	Below Sobat	Rom	Renk	Goda	Shawal	Hashaba	Abu Hugar
distance from Khartoum (km)	1697	1562	1374	1168	915	876	849	830	635	482	343	262	198	72
temperature (°C)	29.0	29.0	29.0	29.7	29.4	29.1	28.4	28.9	29.4	29.0	29.4	28.8	26.0	27.0
pH	7.8	7.5	7.7	7.6	7.9	7.8	8.0	8.0	8.5	8.5	8.6	8.7	8.9	9.2
transparency (cm)	-	25	20	30	35	70	40	35	25	35	30	40	40	30
conductivity (mho/cm)	150	160	190	190	160	220	180	240	175	175	250	200	200	200
alkalinity (m-eq/l)	-	23	22	-	-	22	55	28	-	30	29	36	35	33
dissolved oxygen (mg/l)	5.3	5.2	4.0	5.0	5.8	5.0	5.6	5.6	6.2	6.0	6.7	4.7	8.0	9.0
calcium (mg/l)	8.1	8.1	8.2	12.6	-	13.1	12.4	9.8	10.0	9.4	9.8	10.6	12.0	13.0
magnesium (mg/l)	5.9	5.9	5.6	3.2	-	9.8	9.5	8.0	7.9	8.9	8.8	8.9	7.7	10.3
sodium (mg/l)	20.0	18.0	15.0	20.0	19.0	24.0	7.5	12.5	12.5	13.0	13.0	15.0	18.0	32.0
potassium (mg/l)	8.3	6.5	5.3	6.3	8.5	10.0	12.5	11.0	6.8	7.0	7.0	8.5	5.5	12.5
phosphate (mg/l)	0.088	0.066	0.088	0.044	0.044	0.044	0.088	0.044	0.088	0.088	0.088	0.088	0.088	0.067
nitrate-nitrogen (mg/l)	0.05	0.05	0.10	0.15	0.10	0.05	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05
nitrite-nitrogen (mg/l)	0.002	0.002	0.002	0.003	0.002	0.002	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001
silicon (mg/l)	10.0	12.0	15.0	12.5	10.0	22.5	10.0	12.5	10.0	10.0	10.0	1.25	12.5	15.0

that values for pH and dissolved oxygen did not change while those for silicon showed an increase. This might be attributed to instability in local conditions in the river, or the time of sampling but is rather difficult to conceive as being due to the invasion by waterhyacinth.

The contribution of Bahr el Ghazal in terms of annual discharge is not very significant. It is in the magnitude of 0.6×10^9 m^3 (Hurst and Phillips 1932). Nevertheless, the study of its water characteristics is very important since it is the only major tributary which has not been successfully invaded by waterhyacinth.

Bahr el Ghazal and tributaries show (Table 2 p. 137) distinctive physico-chemical properties, namely high conductivity, pH, alkalinity, calcium, magnesium, sodium, phosphate, nitrate-nitrogen, nitrite-nitrogen and silicon. This agrees with the trend found by Bishai (1962) although he gave higher values for dissolved oxygen, alkalinity and transparency and lower values for conductivity, pH, nitrate-nitrogen, phosphate and silicate. These differences might be attributed to some local modification like mixing with swamp water or season of sampling but it is unlikely that they have much biological significance in the river.

The increase in the values for pH and dissolved oxygen and decrease in conductivity, alkalinity, sodium, potassium, phosphate, nitrate-nitrogen, nitrite-nitrogen and silicate at Lake No is probably due to the increased photosynthetic activity of the rich phytoplankton flora (Talling 1957; Gronblad et al. 1958).

The second series of results, based on samples collected during June-July 1975, indicate a profound trend of longitudinal modification in the physico-chemical characteristics of this tributary. This is shown by the increase in values for pH, conductivity, alkalinity, calcium, magnesium, sodium and silicon and a decrease in potassium and phosphates towards Bentiu on

Table 2. Water characteristics along Bahr el Ghazal during April-June 1973 and June-July 1975

	Bentiu	Bahr el Ghazal (10 km upstream)	Lake No	Bentiu	River Jur	River Bussari
date of sampling	14.5.73	15.5.73	14.5.73	21.6.75	2.7.75	2.7.75
temperature (°C)	30.0	28.6	30.0	28.6	31.8	-
pH	8.4	8.2	9.4	8.1	8.3	8.0
transparency (m)	0.6	0.2	0.3	-	-	-
conductivity (mho/cm)	250	200	150	350	35	30
alkalinity (m-eq/l)	37	35	20	223	65	55
dissolved oxygen (mg/l)	6.0	5.1	7.8	-	-	-
calcium (mg/l)	11.4	11.3	12.4	14.1	9.6	9.6
magnesium (mg/l)	5.8	7.2	7.8	5.75	3.6	3.7
sodium (mg/l)	35.0	26.0	20.0	18.9	16.0	14.3
potassium (mg/l)	8.5	6.5	5.3	6.4	5.3	7.1
phosphate (mg/l)	0.266	0.266	0.044	0.05	0.05	0.06
nitrate-nitrogen (mg/l)	1.30	0.70	0.25	-	-	-
nitrite-nitrogen (mg/l)	0.026	0.014	0.005	0.002	0.002	0.002
silicon (mg/l)	43.8	46.3	35.0	15.0	6.0	6.0

Bahr el Ghazal. This confirms the influence of the water contributed by swamps and the role of phytoplanktonic activity. It also reveals seasonal and annual fluctuations in conductivity, alkalinity, sodium and silicon.

Due to the small discharge of Sobat at the time of sampling, only slight modifications in the water characteristics of the main stream of the river, below the junction, are noticed (Table 1). These are : decrease in values for transparency, alkalinity, calcium, magnesium, sodium, potassium, nitrate-nitrogen, and nitrite-nitrogen and an increase in the value for silicate ions. The physico-chemical properties of Sobat agree with those outlined by Talling (1957) and Bishai (1962) except for minor differences, especially for conductivity and oxygen.

The water characteristics of Sobat and two of its tributaries, (Pibor and Akobo) are shown in Table 3 (p. 139). The table reveals that modifications take place along the tributaries of the River. This is shown by an overall increase in the concentrations of the various ions and the drop in the concentration of the nitrogen ions.

The Jebel Aulia Reservoir.

Talling (1957) and Bishai (1962) have both reported an increase in pH and the dissolved oxygen content in the Jebel Aulia reservoir. A corresponding decrease was noticed for conductivity, transparency, nitrate-nitrogen, ammonia, phosphate and silicate. This was most noticeable in the last 50 kilometers above the Dam, while alkalinity increased in that region. Bishai (1962) attributed the depletion of nitrate-nitrogen to its uptake by the waterhyacinth.

The present results show fluctuations in physico-chemical

Table 3. The water characteristics of River Sobat, Pibor and Akobo during April-June 1973

	River Sobat (above Khor Fullus)	River Pibor	River Akobo
date of sampling	1.5.73	7.5.73	7.5.73
temperature (°C)	28.6	-	-
pH	7.6	8.1	8.1
transparency (m)	0.3	-	-
conductivity (mho/cm)	76	130	130
alkalinity (m-eq/l)	12	25	25
dissolved oxygen (mg/l)	5.5	-	-
calcium (mg/l)	10.2	13.1	13.1
magnesium (mg/l)	3.9	8.0	6.1
sodium (mg/l)	5.2	5.0	5.0
potassium (mg/l)	2.3	6.5	6.3
phosphate (mg/l)	1.330	0.088	0.088
nitrate-nitrogen (mg/l)	0.05	0.15	0.20
nitrite-nitrogen (mg/l)	0.001	0.003	0.004
Silicon (mg/l)	20.0	12.5	5.0

properties towards Jebel Aulia reservoir (Table 1). Some of these persist only short distances downstream and may therefore probably be due to local conditions. Increases in the dissolved oxygen, pH, potassium, sodium, silicate and magnesium and the decrease in nitrate-nitrogen, nitrite-nitrogen, phosphate, alkalinity and conductivity are apparent at Abu Hugar (72 kilometers above the Dam.)

The values given; in the present study, for pH, dissolved oxygen, transparency, alkalinity and silicate are higher than those given by Talling (1957); while those for phosphate and nitrate-nitrogen are lower. On the other hand conductivity remains unchanged.

This gives a further dimention to the suggestion of Bishai (1962) that the trend of spatial modification of water characteristics is still preserved after the invasion of the river by waterhyacinth, whose only effect on the White Nile ecosystem appears to be the depletion of nitrate-nitrogen (in addition to nitrite-nitrogen and phosphate ions). This is in agreement with Gossett and Norris (1971) who found waterhyacinth to deplete nitrogen and phosphorus from the ecosystem "to the extent that it stores excess of these elements in the floats".

THE ZOOPLANKTON

Critical knowledge about the productivity of the White Nile is still lacking. The only data on the longitudinal succession of zooplankton are those given by Monakov (1969) and Rzoska (1973).

Recently, samples of zooplankton were taken with a Friedinger (Luzern) sampler of two litres capacity from surface, middle and bottom levels at midstream. All samples were taken from free flowing water. Qualitative samples were taken with standard zooplankton nets supplied by the Freshwater Biological Association, Widermere. Species of zooplankton were counted separately ; juveniles and nauplii were not separated.

River plankton

The lake sources of the White Nile are rich in zooplankton (Green 1971). Thirty one species of Cladocera have been recorded from lakes Victoria, Albert and Kyoga in addition to seven species of copepods and fourty eight of Rotatoria. Densities of more than 6,000 individuals/m^3 are not infrequent.

These pure associations of plankton are apparently destroyed in the falls and rapids before reaching the Sudan plains. When the river enters the "Sudd" region it carries traces of plankton and is rich in detritus. Rzoska et al. (1955) suggested that these traces in the form of "survivors and resting stages" may contribute to the slow buildup further downstream. Rzoska (1973) gave a list of crustacean species that never reach the Sudan. This is not an unusual phenomenon in African rivers e.g. the Blue Nile (Talling & Rzoska 1967; El Moghraby 1972).

Features of the distribution of zooplankton are shown in Table 4 (p. 142).

No evidence for resting stages or survivors was found in Bahr el Jebel above Shambe. Pure associations of Moina dubia (Guerney and Richard) and Mesocyclops leuckarti (Claus) were found in the river below Shambe. Contrary to what Rzoska (1973) suggested, there was no evidence in the present data of reproduction. Rather the zooplankton, found, would have drifted from the rich fauna in the lagoons and marginal vegetation in the 'Sudd' region. The current, in this stretch is too swift to allow the creation of new generations in the running water itself.

Table 4. The longitudinal succession of zooplankton in the White Nile, during April-June 1973

Sampling station	Distance from Khartoum (km)	Zooplankton (nos./1 m^3)	Remarks
Juba	1762	0	On Bahr el Jebel
Gummeiza	1697	0	
Bahr el Gedid	1562	0	in the 'Sudd' region
Shambe	1374	700	
Adok	1169	1400	in the 'Sudd' region
Wath Wang	915	600	on the White Nile
Below Attar	849	1750	
Below Sobat	830	0	
Rom	635	0	
Renk	482	500	
Geda	343	200	within the influence of the Dam
Shawal	262	13600	
Hashaba	198	12250	
Abu Hugar	72	49500	in Jebel Aulia Reservoir

According to Monakov (1969) the marginal vegetation supports a rich fauna. He counted eleven crustacean species and several rotifers in addition to water insects and their larvae. He found that the biomass of Entomostraca was 10-100 fold greater between the floating mats of waterhyacinth than in the open water.

The sign of buildup of pure plankton, further downstream, is indicated by finding a larger number of individuals and species. However, the zooplankton remains thin and monotonous for a long distance downstream. Species found at Goda are Ceriodaphnia dubia (Richard), Ceriodaphnia cornuta (Sars = rigaudi Richard), Moina dubia, Mesocyclops leuckarti and Thermodiaptomus galebi (Barrois). It is worthwhile noting that there are no nauplii or rotifers in this stretch of the river.

The tributaries

I did not find any zooplankton in samples collected from Bahr el Zeraf although limnological conditions are similar to those in Bahr el Jebel.

The slow-flowing Bahr el Ghazal is the richest tributary in zooplankton. Moina dubia, Mesocyclops leuckarti, Diaphanosoma excisum (Sars) being the most abundant species. Thermocyclops neglectus (Sars), Thermodiaptomus galebi and Ceriodaphnia cornuta were found, in addition to nauplii and the retifers Asplanchana brightwelli (Gosse) and Brachionus quadridentatus (Ehrb).

The density of zooplankton found in lake No, 50 kilometers upstream on Bahr el Ghazal and at Bentiu were respectively 17,000, 8,500 and 1,100 organisms per 1 m^3. This agrees with the longitudinal trend of distribution outlined by Monakov (1969).

The zooplankton of River Sobat is more diverse although less in quantity than the main channel of the White Nile. Maximum numbers of zooplankton were always found in the bottom levels of the river. *Moina dubia* and *Diaphonosoma excisum* were the most abundant species. Females carrying eggs were often found.

The Jebel Aulia Reservoir

Brook and Rzoska (1954) Rzoska, Brook and Prowse (1955), Prowse and Talling (1958) and Monakov (1969) emphasized the impact of Jebel Aulia reservoir in enhancing plankton development. The effect of the reservoir extends some 350 kilometers above the dam and is more pronounced in the lower region of the reservoir. In the lake-like conditions dense pure plankton was dominated by blue-green algae and Cladocera. The seasonal fluctuations in densities of plankton were closely correlated to the regime of the reservoir.

Present data show an increase in the order of 20-120 in densities of zooplankton over those in the river upstream. The main species found in order of abundance are : *Moina dubia*, *Ceriodaphnia cornuta*, *Thermodiaptomus galebi*, *Ceriodaphnia dubia*, *Diaphonosoma excisum*, *Mesocyclops leuckarti* and nauplii.

Present data compare numerically with those presented by Rzoska (1968) and Monakov (1969). Nevertheless the data are not enough for the formulation of concrete conclusions.

When comparing data given by Rzoska *et al*. (1955) with those from the routine sampling, carried out by the Hydrobiological Research Unit, of the plankton exported from the reservoir, it is evident that a significant decrease in numbers of Entomostraca has taken place (65 % over the period of five months). Rotifers have become insignificant in number. This might partly be due to the entanglement of zooplankton to the roots of the hyacinth (Yousif 1974).

THE FISHERIES

The White Nile is quite productive of fish. There are 104 species belonging to 23 families and 51 genera of fish in the Nile. The taxonomy and characteristics of the fish fauna have been described in detail by Boulenger (1907) and Sandon (1950). However, Statistics on fish potential, distribution and ecology are still in the exploratory stage. Data available from several sources (Bishai 1961; El Moghraby 1973) and from direct communication with fishermen reveal that there is a decrease in catch rates (unit effort per fisherman) in the past few years. They attribute this to the invasion of the river by waterhyacinth.

As a matter of fact the presence of waterhyacinth has some favourable effects on the life of some fish species. The waterhyacinth at the margin of the river and in _khors_ and lagoons provide suitable shelter for spawning, of such species as the Nile Perch (_Lates niloticus_). The slow current with marginal vegetation and inside floating mats offers protection to the larval and young stages of fish. Zooplankton, which is the main item of food at this stage, is also available within the roots of waterhyacinth.

On the other hand, waterhyacinth seems to have an adverse effect on the life of other fish species. For example _Tilapia nilotica_, which is a very important commercial species, digs into the bottom and incubates its eggs. Under thick mats of waterhyacinth in _khors_ and lagoons, accumulation of decayed roots which may top up to several feet (Hammerton, personal communication) leads to depletion of oxygen. These unfavourable breeding sites affect the breeding potential of this fish species and leads to a general reduction in its population size.

DISCUSSION

It has always been assumed that the notorious waterhyacinth disturbs the environmental balance in infested ecosystems. It hinders navigation, blocks irrigation pumps, hampers fishing operations and eliminates marginal grass, on which cattle graze. Also waterhyacinth harbours vectors of schistosomiases, provides favourable breeding sites for Anopheles mosquitoes and decreases productivity by depleting nutrients.

The results described above offer a picture less dismal. From a limnological point of view waterhyacinth does not seem to disturb the environmental balance to the extent of greatly decreasing the productivity of the White Nile ecosystem.

The waterhyacinth is a very successful weed which has a wide range of tolerance to variations in physico-chemical conditions. As shown above, a great deal of modification takes place during the seaward flow of the White Nile and tributaries. The water properties exhibited at Jebel Aulia are a resultant of all these interactions. These show lower values for nutrients and higher values for the other elements. The enrichment of the various ions, including silicon, is probably due to the uptake of salts by waterhyacinth when stranded at the margin of the river or in the swamp. The elements are liberated when waterhyacinth drifts and subsequently decays. The increased depletion of the nutrients is not unexpected but it does not seem to have any limnological significance as to limit plankton development.

The trend of longitudinal succession of water characteristics is still the same as that found by Talling (1957) eighteen years earlier. The depletion of nutrients due to phytoplanktonic activity is more significant than that due to the presence of waterhyacinth as shown by the data for Bahr el Ghazal. Contraray to what Bishai (1962) has outlined there was no decrease in values for pH or dissolved oxygen in the reservoir.

The presence of mats of floating and marginal *Eichhornia* creates favourable habitats for the development of zooplankton by slowing down the water current velocity in the vicinity (cf. Rzoska 1973). Monakov (1969), Yousif (1974) and Adam (1975) found that the total biomass of zooplankton actually increased after the invasion of the river by waterhyacinth.

The decrease in the density of zooplankton exported from the Jebel Aulia reservoir as compared to values given by Rzoska *et al.* (1955) may give a false impression since the zooplankton get entangled to the roots of waterhyacinth.

The effect of waterhyacinth on fish is certainly not adequately monitored. These effects vary from one species to another depending on their breeding and feeding habits, and their movements and distribution along the rivers, *Bahrs*, lakes, *khors* and lagoons of the Nile basin.

The effect of control operations, through spraying 2, 4-D, is that the plankton and juvenile fish entangled to the roots of waterhyacinth die with the weed. Apparently the effect of the herbicide is restricted to the top layers of water (cf. River Sobat). Fortunately the powers of recovery of Tropical rivers are great and the amount of herbicide used is small compared to the volume of discharge of the White Nile.

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