

## FURTHER DEVELOPMENT OF THE MODEL

Because of the simplicity of this model and the lack of sufficient data from a single source, firm recommendations could obviously not be made on the basis of the simulations described above. Considerable detail is still needed to include such important aspects of the system as the use of nitrates, nitrites, and ammonia by the plant community, as well as the remineralization rates for both nitrogen and phosphorus compounds. The effects of varying depths in the body of water, of the size of the lake, and of the presence of aerobic and anaerobic zones within the lake are also important considerations.

In addition, several factors which might affect the outcome of the model have not been taken into account. The timing of a kill to coincide with winter frosts might increase the effectiveness of the partial-kill spray. Removing the weeds mechanically might help keep the regrowth under control.

An evaluation of waterhyacinth control methods in such a system should include a consideration not only of the biological system but of the economic system as well, taking into account inflationary rates which we are now experiencing in the prices of herbicides and which we might expect to continue. One approach to this would be to include in the model a set of pathways that would outline the expenditures of energy, human energy as well as energy used in manufacturing, to indicate a baseline energetic cost per hectare of different waterhyacinth con-

trol methods. Included in this sub-model might be the energy conserved in the system by utilization of mechanically harvested waterhyacinths as food, fodder, or fertilizer.

It is hoped that this general model demonstrates that it is possible not only to investigate a wider variety of situations than might be feasible under field conditions but also to determine which of several proposed experiments might yield the most useful information. In diagramming the system and identifying the most important variables, therefore, it is possible to emerge with a more complete understanding of the system. Just as important, a better idea of the critical measurements that are necessary may be obtained, enabling one eventually to reach more valid decisions on control policies.

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# The Ecology Of Waterhyacinth In The White Nile, Sudan

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## ABSTRACT

Infestation of the White Nile system by waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) can be classified into three major consecutive phases of a cyclical nature. These phases are related to seasonal changes in certain important environmental factors, resulting in an annual cycle. It is shown here that the periodic rise and fall of infestation is based on the responses of waterhyacinth to the optimum conditions of high flood season and adversities of low flood, respectively. In the former case, the whole stretch of the White Nile becomes littered with vigorous populations. This dense infestation gives rise to great difficulties for navigation, fishing, and irrigation. In the latter, however, waterhyacinth populations retreat and become confined to sporadic occurrences in the perpetually infested swamps of the Sudd-Sobat complex.

## INTRODUCTION

Waterhyacinth has been infesting the Sudanese White Nile system since 1958 (4). Throughout its short history in the Sudan, waterhyacinth has been found to follow a rhythmic annual cycle of infestation. The critical part of the cycle occurs when the greater portion of the White Nile system is subject to epidemic infestation which lasts over a period of 3 months. Under the optimum conditions of high flood (August to October), the infestation soars to its peak. At this time, the distribution of the plant reaches its maximum extent, and the remarkable vitality of populations results in a massive cover of floating waterhyacinth. This picture contrasts strongly with the insignificant vegetational aspect which prevails during the low flood season, when the infestation declines to its minimum both in space colonized and overall vegetative vigor. At its

lowest level, over two-thirds of susceptible habitats become virtually free of waterhyacinths, apart from feeble and sporadic aggregations.

The effect of season upon the yearly cycle of infestation has been documented.<sup>1, 2, 3, 4</sup> The impact of each of the operative factors upon the dynamics and biological processes of the infestation cycle have been dealt with in very general terms. However, the elements of flood, current, and wind have been generally accepted as the principal factors that govern the overall cyclical mechanism of waterhyacinth infestation in the White Nile system.

In this paper, the above generalizations have been further investigated, to explain how each of three major successive phases of the annual cycle is affected by (a) the direction and extent of waterhyacinth drift and (b) vegetative vigor as indicated by the rates of vegetative multiplication and seed regeneration. It is of interest and practical significance to determine the yearly environmental variations that in sequence trigger vigorous vegetative activity, create population outbreaks, sustain a state of periodic high infestation magnitude, then cause a progressive thinning of free-floating populations with dwarfing of individuals, and eventually impose a remarkable upstream retreat of the stunted free-floating forms. The final stage in the sequence is when natural occurrences become limited to sparse, much diminished habitats in the swampy upper reaches of the White Nile system.

### GEOGRAPHICAL DISTRIBUTION

The distribution of waterhyacinth in the Sudan is governed by the rhythmic annual cycle of infestation. The duration of infestation, its seasonality and level of magnitude are the principal criteria for presenting an ecological classification of natural occurrences. The stretch of the White Nile has been divided into three major regions (Figure 1). Region I, between latitudes 4 and 9°N, includes the swampy upper reaches that are subjected to perpetual infestation. In view of evident differences in infestation magnitude within this region it seems necessary to distinguish three zones. In Zone 1, waterhyacinth populations exhibit their best vegetative performance, greatest flowering capacity, and maximum reproductive potential as indicated by the abundance of colonial forms throughout the year. Relative to the above, Zone 2 signifies an intermediate position while Zone 3 invariably shows the lowest level of growth in Region I.

Region II which is between latitudes 9 to 13°N, is susceptible to only seasonal infestation. This is attributed to (a) heavy downstream drifts discharged from Region I during high flood and (b) erratic upstream movement created by retreating infestation back into Region I; the

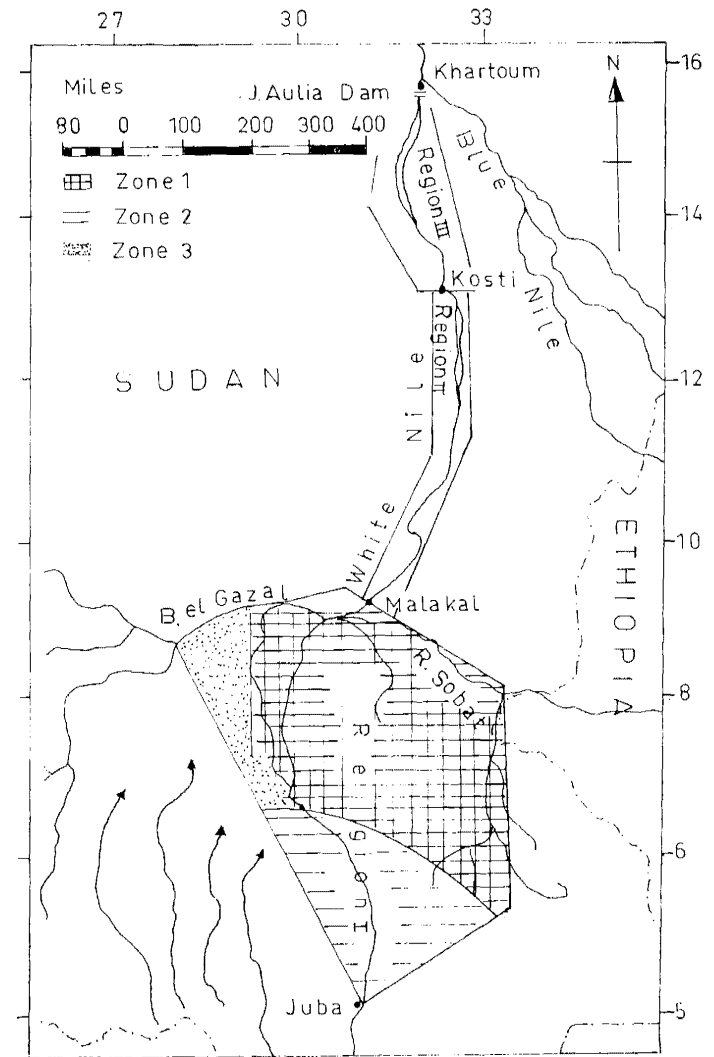


Figure 1. Regions of the White Nile system susceptible to waterhyacinth infestation.

latter condition prevails during the beginning of low flood season.

Region III, latitude 13 to 15°N, includes various habitats in the Jebel Aulia dam basin, and infestation is confined to the high flood season. Vegetative and reproductive vigor of the waterhyacinths are greatest during the flood peak.

### CYCLE OF INFESTATION

A general trend from Region I to Region II in the seasonal variations of certain important environmental factors (Table I) may perhaps explain the annual rhythm of rise and fall in waterhyacinth infestation. Correlations between the combination of physical factors (flood, direction and force of wind and velocity of current) on the one hand, and the mechanism of the yearly cycle of infestation on the other, are summarized in Figure 2. Furthermore, both reproductive capacity and performance appear to have close correlation with the seasonal trend of relative humidity (Table I). The following account outlines the rhythm of the annual cycle with reference

<sup>1</sup>Bebawi, F.F. 1972. Studies on the ecology of *Eichhornia crassipes* (Mart.) Solms in the Sudan. MS. Thesis, Univ. of Khartoum pp. 65-74.

<sup>2</sup>Chadwick, M.J. 1961. Some observations on the ecology of *Eichhornia crassipes* (Mart.) Solms. 8th. Ann. Rep. Hydrobiol. Res. Unit, Univ. of Khartoum pp. 23-28.

<sup>3</sup>Hammerston, D. 1967. White Nile survey. Distribution and movement of *Eichhornia crassipes*. 14th. Ann. Rep. Hydrobiol. Res. Unit, Univ. of Khartoum, Sudan pp. 12-15.

<sup>4</sup>Heinen, T.T. and Ahmed, S.H. 1964. Waterhyacinth control on the Nile river, Sudan. Information Production Centre, Ministry of Agriculture, Sudan pp. 8-17.

to three major consecutive phases. The seasonality and duration of each phase were primarily determined according to obvious vegetational features (magnitude, direction, and vegetative vigor of drifts). The phases coincide with (a) the beginning of the flood season, (b) the relatively short span of the high flood season and, (c) the prolonged duration of low flood, respectively.

**Phase I (June to July: beginning of flood season).**

The cycle of infestation is initiated by rejuvenation of

dormant waterhyacinth populations lodged in the swampy Sudd-Sobat complex (Figure 1). Vegetative activity is triggered by the ideal medium of silt-rich alkaline flood water (1,2,3,4,5,6,7), conditions of high atmospheric humidity (Table 1) and warm temperature (34°C). Observations recorded during the course of the present investigation have shown that the prevailing fairly strong northerly winds (9 Km/hr) and increasing speed of current (0.8m/sec) cause the dislodging of stationary regenerating colonial forms, help to fragment coherent masses into smaller units,

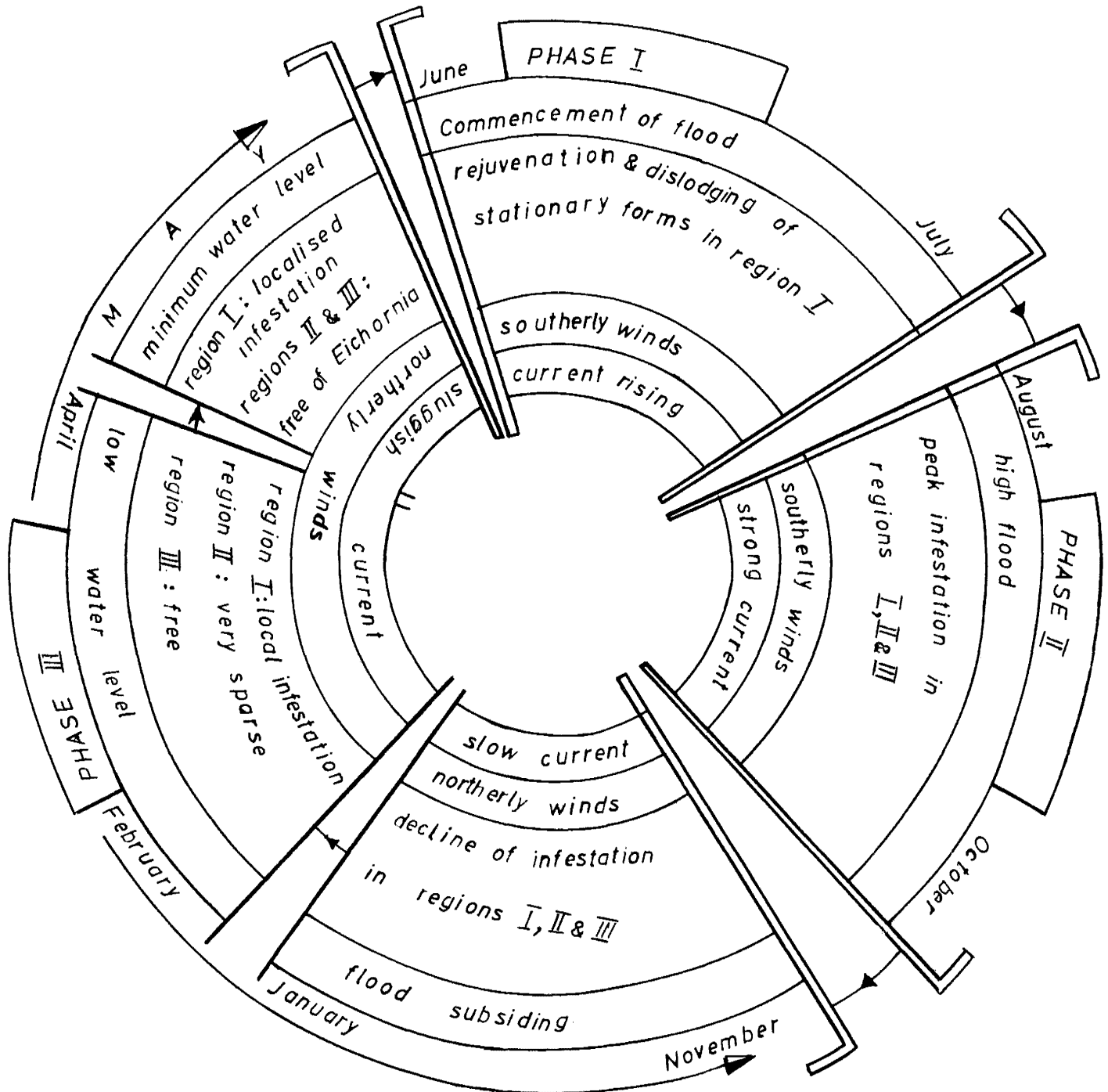


Figure 2. Yearly infestation cycle of waterhyacinth in the White Nile system. Region 1. Swamps with perpetual infestation. Region 2. Main course receives outbreaks from region 1 and carry back-drifts from region 3. Region 3. Dam basin, seasonal accumulation habitat for outbreaks; periodically free during low flood and northerly wind season.

TABLE 1. SEASONAL CHANGES IN MEAN VALUES FOR SELECTED ENVIRONMENTAL FACTORS IN THE WHITE NILE SYSTEM.<sup>a</sup>

Infested area	Phase	Flood water level (cm)	Direction and velocity of wind(Km/h)	Speed of current(m/sec)	Relative humidity (%)
Region 1.	1. commencement of flood season (June to July)	12	southerly 9	0.8	77
	2. high flood season (August to October)	13	southerly 8	1.0	77
	3. low flood (November to May)	12	northerly 10	0.3	51
Region 2.	1. commencement of flood (June to July)	11	southerly 9	0.6	61
	2. high flood (August to October)	12	southerly 12	0.8	68
	3. low flood (November to May)	10	northerly 17	0.2	31
Region 3.	1. commencement of flood (June to July)	13	southerly 11	0.2	42
	2. high flood (August to October)	16	southerly 12	0.4	54
	3. low flood (November to May)	13	northerly 18	0.1	20

<sup>a</sup> Mean values for 10 years, (1962 to 1972): Sudan Met. Office and Ministry of Irrigation, Sudan.

and continuously disperse the abundant new clumps over the water surface. Eventually the surface is covered with small, actively mobile aggregations of waterhyacinths. The ensuing rise in water level extends the territorial boundaries of the swampy ground, thus providing new favorable habitats which subsequently are invaded by vegetatively vigorous waterhyacinth populations. The trend toward greater coverage advances with season and progresses to an almost complete carpet in the Sudd-Sobat complex.

Continued vigorous multiplication, extending beyond the maximum spacial capacity of the Sudd-Sobat complex, inevitably creates occasional erratic discharges of components into region II; subsequent fast currents accompanied by strong southerly winds facilitate more frequent downstream releases of surplus components. This marks the beginning of the catastrophic outbreaks. Henceforth, the originally free region II begins to experience low magnitude infestation, derived from the over-congested Sudd-Sobat complex.

#### Phase 2 (August to October, high flood season).

This phase consists of a set of consecutive stages that eventually build up to a condition in which all three regions of the White Nile system experience the full impact of high infestation. The commencement of this phase is generally marked by a series of frequent outbreaks consisting of small colonial forms and clumps released from the over-stocked Sudd-Sobat complex. The overall bulk of masses transported downstream progressively increases with the advance of flood season: the mobility, directly influenced by, and proportional to the speed of the current and wind velocity, is facilitated by the accompanying

abundant flood water. The trend of sporadic infestation-drift eventually develops into a rapid and almost continuous movement of free-floating communities. As a result, Region II begins to accommodate dense aggregations, predominantly consisting of relatively large juvenile patches. Further downstream, in Region III, infestation commences in the form of occasional, later becoming frequent, drifts transported downstream from Region II. The ensuing greater mobility of masses is attributed to the favorable conditions associated with the advance of flood season. The general aspect in Region III eventually becomes similar to that described in the former region. In addition, in both Regions I and II, waterhyacinth exhibits profuse flowering and subsequent vigorous regeneration from seed. This clearly indicates the high vitality of waterhyacinth during peak flood season.

In its northerly movement, however, drifting waterhyacinth populations encounter numerous islands that divert a fair proportion of the masses of weed into innumerable bends, side-streams, shallow banks, and depressions. In such micro-habitats (frequent in both Regions II and III, and throughout the 3 months of high flood, active vegetative reproduction and seed regeneration augment the free-floating communities moving in mid-stream. Consequently, the overall picture of infestation becomes a very densely covered surface throughout the entire White Nile system. While mid-stream infestation predominantly consists of a mosaic of individual clumps, clusters, and colonial forms, the marginal populations invariably build up into heavily compacted aggregations that frequently attain sizes of small islands. Much of the mid-stream infestation-drift advances to reach its goal at Jebel-Aulia Dam where extensive carpets develop and later become compressed into thick impenetrable mats.

### Phase 3 (November to May, low flood).

This phase, which occupies the longest part of the annual cycle, consists of several consecutive stages of progressive decline in the magnitude of infestation. This decline of infestation is influenced by conditions prevailing during the long period of low flood. The factors involved are (a) the gradually subsiding water level, (b) the progressively reduced velocity of current, (c) the gentle counterclockwise shift of wind direction from southerly to northerly and, (d) the advancing season of increasingly unfavorable conditions involving low atmospheric humidity, strong desiccating cool winds, and low turbidity index of the Nile waters. The first sign of decline in the infestation is the appearance of innumerable communities that generally become cut-off from the receding width of the main course; their habitats become shallow, muddy, and eventually dry, and the vegetation is inevitably destined to lethal desiccation. Following that, and perhaps simultaneous with it, is the considerably reduced velocity of current during low flood. Hence, the massive northerly drift, maintained during high flood, relaxes, and is ultimately suspended when the current becomes sluggish. Later in the season, however, northerly winds, shifting from southerly, cause a gentle reversed drift of mid-stream free-floating waterhyacinth. The force of wind is, as a rule, variable and the influence of its southward direction is often modified by the meandering of the main course. In view of this, back-drift is generally erratic, but it eventually transports a substantial bulk of free-floating communities to various upstream locations. The destination of the back-drift is the original site of outbreaks: the Sudd-Sobat complex. There is also an obvious trend towards a much depressed vegetative vigor following the decline in infestation. This trend is evident by the reduction in vegetative reproduction, poor flowering, absence

of seed regeneration, and remarkable dwarfness of individual plants.

Phase III terminates when the greater part of the White Nile system (Region II and III in particular) becomes free of infestation. The diminished swamps of region I, however, continue to sustain habitats that lodge remnants of aggregations originating from both back-drifts and from originally undischarged masses. These localized components survive in a state of vegetative dormancy until the return of the rejuvenating conditions of phase I.

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# Succession Of Aquatic Vegetation In Lake Ocklawaha Two Growing Seasons Following A Winter Drawdown<sup>1</sup>

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### ABSTRACT

Lake Ocklawaha has experienced aquatic weed problems since 1969, the year following impoundment. The lake surface elevation was lowered 1.5 m from September

1972 to February 1973. The May 1973 sampling indicated that the drawdown gave excellent control for coontail, hydrilla, southern naiad, and Brazilian elodea, but there was a substantial increase in waterhyacinth, alligatorweed, smartweed, and waterpurslane. In the November 1973 sampling, hydrilla had increased tremendously in coverage as did pickerelweed, and waterhyacinth; there was however continued control of coontail and Brazilian elodea. By

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