ECO-PHYSIOLOGICAL STUDIES ON PISTIA STRATIOTES, L.

with special reference to its occurrence on the

Volta Lake in Ghana.

A thesis presented by

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in part fulfilment for the requirements for the

M. Sc. DEGREE

of the University of Ghana.

JUNE 1970

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Date: 26-6-70

ABSTRACT

The creation of the Volta Lake in Ghana provides favourable conditions for rapid weed growth. The present report represents an attempt to investigate the interaction between one of the economically important weeds on the Lake, *Pistia stratiotes*. L., and the physico-chemical condition of its environment in the field and laboratory.

Pistia is represented in most reaches of the Lake but only sheltered bays and estuaries in the south are characterized by luxuriant vegetation of the species. Distribution and growth of the plant within these areas are controlled to some extent by the pH and mineral composition of lake water.

Under laboratory conditions, marked influence is exerted by substrate pH and nutrient content on the vegetative reproduction and growth of the plant. Occurrence of optimum vegetative growth at low total nutrient content and pH 5.0 is reflected in the tendency shown by rosettes to grow larger in areas of the Lake characterized by comparatively low degree of mineralization, and pH.

Growth of the plant has been observed to alter the pH and mineral content of the substrate under field and laboratory conditions. The nature of this change in the field depends on the cover of vegetation.

Stranded rosettes which have become rooted in the drawdown area of the Volta Lake are capable of regenerating and may recolonize the lake surface.

Results of these investigations have been discussed with reference to methods of controlling the plant.

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GENERAL INTRODUCTION

The impoundment of the Volta River in Ghana, initiating the formation, in May 1964, of one of tropical Africa's largest lakes, provides unique opportunities for rapid weed growth. The Volta Lake's long dendritic axis stretches for nearly 400 km. (250 mi.) mainly through the low-lying Guinea Savannah and only briefly through a forested zone in the south. The resulting extensive shoreline estimated at 4,880 km. (3,050 mi.), the numerous sheltered shallows characterized by partly drowned riparian vegetation, and easily leached soil are conditions that favour aquatic weed growth (Lawson, 1963; Little, 1966a).

Rapid weed growth on newly formed lakes results from new ecological situations created when the stability of the ecosystem of parent rivers is disturbed (cf. Elton, 1958; Balinsky and James, 1960; Jackson, 1963). This invasion of artificial impoundments by weeds may be greater in the tropics where warmer conditions are combined with more extended growing season. The invasion may be greater still in areas where the terrain is generally flat as in many river basins in Africa (Waddy, 1966) and therefore provide, when inundated, expansive areas of shallow water. The rapid build up of plant nutrients, which occurs as mineral salts leached from newly flooded forest and farm-lands (Jackson, loc. cit.) are added to those released from decaying drowned vegetation (Welch, 1952), further favours weed invation (Little, loc. cit.). Indeed the Volta Lake is known to harbour a wide variety of weeds (Lawson, 1964).

One of the commonest and potentially most troublesome of these weeds is the free-floating water lettuce, <u>Pistia stratiotes</u>, L. (Lawson, 1963). Subramanyam (1962) and Weldon and Blackburn (1967) suggest that the plant reproduces mainly vegetatively, the daughter rosettes tending to remain attached to the parent plant by means of stolons (cf. Wild, 1961). Personal observations as well as those of Little (1966b) show that under certain conditions, the rate of reproduction is so rapid that within a few months a large area of water is covered. A floating plant with this reproductive capacity and capable of forming extensive and tangled mass of matted vegetation can and does pose serious problems on waterways.

One of these problems relates to public health. Several investigators have reported that mats of <u>Pistia</u> serve as the preferred sites of snails and mosquitoes, vectors of encephalitis, filariasis and bilharziasis (see e.g. Seabrook, 1950; [illegible], 1953; Chamberlain et al., 1959; Paperna, 1968). While the completely aquatic larvae of <u>Mansonia</u> mosquitoes are known to obtain their oxygen supply from the aerenchyma in <u>Pistia</u> roots (Burton, 1959), the snails are presumed to derive their food and protection against desiccation from <u>Pistia</u>. Such an infestation of mats often occurs near fishing villages along the Volta Lake (Paperna, 1968; Pierce, 1969).

Large tangled mats of <u>Pistia</u> with extensive surface in contact with the dense medium of water, offer tremendous resistance to boat movement even to the extent of completely preventing it. The situation is worsened when such mats are colonized by Scirpus spp., Cyperus spp. and Ludwigia spp., thus forming a more robust sudd. At present, the Volta Lake Transport Pilot Scheme appears not to have any trouble with Pistia encroaching upon the main channel used by its fleet. Around certain villages, however, rafts of Pistia have created serious transport problems. The situation is particularly serious along the Afram and Pawmpawm arms of the Lake.

The obstruction to boat movement results in diminished fishing activities. Not only do fishermen experience difficulty moving about on the Lake but observations made by the author in collaboration with Entz (Institute of Aquatic Biology, Accra) indicate that a large dense cover of Pistia also reduces or completely prevents wave action and light penetration. Consequently oxygenation of the water by wind-generated mixing and photosynthesis, the growth of submerged aquatics and algae and the invertebrate fauna they support are impaired (cf. Buscemi, 1958; Little, 1966b; Sculthorpe, 1967). Fish may not survive this condition and the result is either mass migration away from the infested areas or large scale mortality.

Large mats of Pistia may drift into and block irrigation channels, hydro-electric installations and harbours. The presence of such rafts in irrigation channels reduces current velocity. This may in turn result in the silting up of the channels (Sculthorpe, loc. cit.).

Finally, a large expanse of water offers great attraction to pleasure seekers and a great deal of foreign exchange may be earned through tourism. Its occupation by Pistia, posing the dangers briefly reviewed above, can adversely affect its use for recreational purposes.

Against the nuisance habit of the plant may be set some benefits which can be derived from the plant. Its ability to accumulate appreciable quantities of plant nutrients (Little, 1968a) probably accounts for its use as green manure, fodder or as a source of fertilizers (Sculthorpe, 1967). Lime, phosphoric acid and potash deficiences of soils in north-east India are reported by the last-mentioned author to be corrected by the application of *Pistia*.

Although dense mats of *Pistia* may cause poor development of invertebrate fauna, sparse distributions of the plant may provide a favourable habitat for invertebrates which serve as food for certain fishes. Petr (1968) reports that some Diptera, Crustacea and Oligochaeta show preference for *Pistia* on the Volta Lake. Where the mat of Pistia is not so dense as to cut off light completely from the water beneath it, the extensive root surface may provide substratum favourable for profuse growth of periphyton; this also provides food for young herbivore fish. Juvenile cichlids (Tilapia, Hemichromis, Pelmatochromis) have been observed actively feeding among *Pistia* roots (Petr, 1967). Such mats may also serve as cover for young fish against predators.

In spite of the real or potential economic importance of *Pistia*, little (Obeid and Chadwick, 1964; Chadwick and Obeid, 1966) seems to be known about the growth of the plant in relation to its environment, particularly under Ghanaian conditions (Hall et al., 1966). The latter group of workers have shown experimentally that growth of the plant is influenced by the mineral composition of culture solution. Similarly the performance of the plant has been shown by the former two collaborators to be dependent on the nitrogen supply and pH of the substrate. These workers noted that the distribution of the plant in relation to pH in nature agreed with their experimental results. Pistia, reports Gay (1958), was abundant on the White Nile. With the adventive spread of Eichhornia crassipes, the species seems to have been virtually eliminated from most regions of the river system. Chadwick and Obeid (1966) suggest that the reason for the antagonism may be found in the response of the two species to the pH of their substrate.

Information on the response of Pistia to environmental factors collected in Khartoum (Sudan) by Chadwick and Obeid in their studies, reported above, and by Hall et al. (1966) under laboratory conditions in Ghana may not directly apply to conditions on the Volta Lake. Our knowledge of the limnological function of the plant particularly as it relates to the physico-chemical condition of the environment is still incomplete. The extent to which the ability of Pistia to regenerate from fragments (Laing, 1968) and from seeds contributes to the recolonization of the Volta Lake by stranded and apparently moribund rosettes is largely unknown. The present investigation was therefore undertaken to contribute further to our knowledge of the relations between Pistia and its environment with particular reference to its occurrence on the Volta Lake. In chapter 1 the distribution and growth of Pistia in relation to the mineral composition and pH of the Volta Lake are described. Chapter 2 covers laboratory experiments under conditions simulating the natural environment. Some effects of *Pistia* on its habitat are examined in chapter 3. Chapter 4 represents an attempt to investigate regeneration in *Pistia* with special reference to how this phenomenon may assist the plant in re-infesting the Volta Lake. The interrelationships of the results from the various investigations and the relevance of these results to the control of the plant are discussed in the last chapter.

The combination of field and laboratory approaches to a problem of this nature is appropriate and justifies the title of this investigation. Until quick and critical methods of field experimentation become available, the ecologist will continue to supplement his field observations with information gained from laboratory experiments.

Sampling sites

Three sites were chosen for investigation. These include Donor in Ajena Bay, Aneta-Vakpo on the estuary of River Deyi and Kponyo on the estuary of River Pawmpawm. These rivers are tributaries which empty into the southern part of the Volta Lake (see map).

The choice was determined by three main considerations;

1) the occurrence of fairly large quantities of *Pistia* forming a more or less continuous mat,
2) the comparatively easy access to these areas and
3) the undisturbed state of the vegetation.

Although *Pistia* is as abundant in the upper reaches of the Afram River as on the selected sites, that area is less accessible and the vegetation there has been sprayed several times. Information collected from such an area is therefore likely to be blurred by the effects of human interference.

MAP OF GHANA SHOWING THE VOLTA LAKE WITH SITES MENTIONED IN TEXT

CHAPTER 1

THE DISTRIBUTION AND GROWTH OF PISTIA IN RELATION TO THE MINERAL COMPOSITION AND pH OF THE VOLTA LAKE

The distribution and growth of plants are to a large extent dependent on such environmental factors as temperature, moisture, light and the physico-chemical condition of the substrate. The importance of these factors would however be determined by the scale of distribution and the type of environment under consideration. Within any one climatic zone mean temperature is unlikely to be a limiting factor (cf. Pond, 1959). The availability of water is unlikely to be an important factor controlling the distribution and growth of plants in an aquatic environment. In such an environment, therefore, the more critical factors may be presumed to be light intensity and the physico-chemical nature of the substrate. In open water habitats, light intensity may however be important only as it determines the depth to which aquatic vegetation can extend (Pearsall, 1920; Shirley, 1945). It thus becomes conceivable that mainly the chemical composition and pH of the substrate would be important in limiting the distribution and growth of floating plants such as _Pistia_ (Pearsall, 1920, 1921; Misra, 1938; Obeid and Chadwick, 1964).

Pistia is widely distributed on the Volta Lake but occurs in large quantities only in the southern part, from a little below Kpandu to Donor near the dam (see map on p.8). This picture is based on a recent (October 1968) aerial survey of the Lake (Pierce, pers. comm.) and on personal observation during extensive travels on the Lake over the period 1964-69.

Its preferred habitat seems to be sheltered bays and estuaries where the partly drowned trees of recently flooded woodlands provide anchorage (plates 1 - 3). Pistia is reported to show similar habitat preferences on the natural Lake Bosumtwi here in Ghana (Whyte, 1968).

Large mats of the plant were also observed building up on the windward side of floating logs in fairly exposed areas, presumably trapped there while drifting with the wind. On a small windswept waterbody, Tokosi Swamp, adjoining River Densu near Accra, mats of Pistia appeared confined to the bank facing the wind. Thus the distribution of floating islands of Pistia like those of Eichhornia crassipes (Gay, 1960) may be influenced by the wind.

Wind and anchorage may account for the restriction of luxuriant vegetation of Pistia to the southern part of the Lake but alone would not explain variation from locality to locality and from season to season in this southern sector. Biswas (1966), Viner (1967) and Attionu (1968) have reported on variations in the mineral composition and pH of the Volta Lake between localities and seasons. These are factors known to influence the distribution and performance of Pistia on the Sudanese Nile (Obeid and Chadwick, 1964) and may be important on the Volta Lake also.

Plate 1. Donor in Ajena Bay - section of the Volta Lake showing a mat of Pistia anchored among partly submerged vegetation, October 1968.

Plate 2. Aneta-Vakpo on River Dayi - a section of the Volta Lake showing a mat of *Pistia* anchored among partly submerged vegetation, January 1969.

Plate 3. Kponyo on River Pawmpawm - a section of the Volta Lake showing a mat of Pistia anchored among partly submerged vegetation, February 1969.

Considerable attention has been paid over the past few decades to the relationship between mineral composition and vegetative growth of plants as a basis for understanding the mineral requirement of plants (see e.g. Lundegårdh, 1941, 1951; Goodall and Gregory, 1947). Indeed the mineral composition of plants may indicate the availability of nutrients in the substrate as has been demonstrated experimentally by Collander (1941), and through field investigations by Caines (1965) and Fish and Will (1966).

The primary aim of the investigation reported in this chapter was to determine the extent to which distribution and growth of Pistia are dependent on the mineral composition and pH of the Volta Lake. Evidence for such dependence has been sought mainly from between-sites and between-seasons correlations in

1) mineral composition of lake water and plant
2) mineral composition of plant and biomass of vegetation, and
3) mineral composition and pH of lake water on one hand and density and biomass of vegetation on the other.

The financial burden of controlling Pistia may be eased by exploiting its chemical stores for agricultural purposes (see p.4). Optimum utilization of the plant along these lines requires as a matter of priority adequate knowledge of variation in mineral composition with season and plant size. Consequently the relationship between the mineral composition of plant and plant size has also been investigated.

General Methods

Sampling Method and Treatment of Materials

Plant and water samples were collected usually between 11.00 and 14.00 hours during the following seasons:

1) end of rainy season (Oct. 24 - Nov. 15, 1968)

2) hermattan, in the middle of the dry season (Jan. 23 - Feb. 12, 1969) and

3) beginning of the rainy season (April 23 - May 14, 1969).

For convenience, these seasons are referred to subsequently as seasons I, II and III respectively.

In view of the extreme difficulty of moving about on water and within a mat of <u>Pistia</u>, it was not possible to sample randomly. A systematic sampling technique was therefore employed (see e.g. Husch, 1963). This consisted in choosing 3 shore to midstream transects, about 20 metres apart, across apparently undisturbed and almost pure stand of <u>Pistia</u>, on the more sheltered southern shore on each site.

Along each transect 5 samples, 2 metres apart, were collected, using a wooden quadrat* 854 sq. cm. in area; the easily disturbed midstream fringe of the mat was avoided. At Donor where the mat was not large enough samples were collected from quadrats thrown unto the mat. To reduce the wide variation observed in samples collected during season I, the sample size of 10 quadrats at Donor and 15 on the other two sites was increased to 20. The three sites were sampled within a short period (3 weeks) in each season to make the samples comparable.

* This was convenient quadrat size available at the time.

Water samples were collected by dipping a 500 ml. polythene bottle to about 10 cm. below the water surface, among the roots. Each water sample was collected from within the quadrat just before collecting each plant sample. The pH of the water was measured soon after collecting the sample, using an E.I.L. (Electronic Instruments Limited) pH meter model 30 C. A millilitre of chloroform was then added to the 500 ml. sample to prevent changes in the chemical condition of the water caused by the activity of micro-organisms during transportation to the laboratory for further analysis.

Only plants whose rosette centres fell within the quadrat were collected, having severed them from those lying outside the quadrat. The roots were flushed in lake water to remove adherent debris which otherwise could influence dry weight estimates. Each sample was packed in a labelled transparent polythene bag. Samples were quickly transported to the laboratory (the journey taking 4 - 7 hours) where they were stored in a freezer at about -10°C to prevent losses due to respiration and decomposition.

From the freezer each sample was quickly defrosted. The plants were grouped into size classes on the basis of shoot length (i.e. longest leaf length) as follows: Class I: 2.0 - 6.0 cm., Class II: 6.5 - 10.5 cm. and Class III: 11.0 - 15.0 cm. The number of plants in each quadrat and class were then recorded. The plants in each class were separated into shoot and root which were dried to constant weight in an oven at 105°C. From the above data the density (number of plants per m^2) and biomass (oven-dry weight (gm.) of plants per m^2)

of the vegetation and the abundance, expressed as % of each sample unit, of each plant size class were computed. Information on the abundance of rosettes in size classes was to be used in describing the vegetation in chapter 3.

Only the shoot portion of oven-dried material was chemically analysed. Attempts to obtain a clear digest from the root portion proved a failure. In cases where the sample was not too bulky all of it was used; otherwise it was thoroughly mixed and reduced to a convenient quantity by quartering. The material was then chopped into pieces small enough to pass through the funnel neck of a mill containing a sieve with a 1 mm. pore size. The ground material was stored in well stoppered and labelled specimen tubes.

Methods of Chemical Analysis of Lake water and Plant Material

Lake water

Potassium, calcium and sodium were estimated with E.E.L. (Evan's Electroselenium Limited) flame photometer. Nitrate-nitrogen and phosphate-phosphorus (P_2O_5-P) were determined according to standard colorimetric methods: phenol disulphoric acid and Deniges' methods respectively using B.D.H. (British Drug House) Lovibond discs (see e.g. Anon., 1960).

Estimates of total mineral content of lake water were obtained by adding together the concentrations of the individual elements (see e.g. Mackereth, 1963). This procedure was preferred to the direct measurement of total ionic concentration as conductivity (Welch, 1952) since information on the individual elements was also required at a later stage in this investigation. That this procedure is justified for the Volta Lake was indicated by the direct relationship between total mineral content and conductivity of lake water (fig.1) (see also Viner, 1967).

Plant material

Immediately before digestion, the ground material was oven-dried for 3 hours at 105°C. and three sub-samples, each weighing 0.2 gm., were wet-digested. Samples for phosphorus, potassium, calcium and sodium determinations were wet-digested using sulphuric, nitric and perchloric acids (Piper, 1950). Samples for nitrogen determination were wet-digested in sulphuric acid using sodium sulphate-catalyst (Shirlaw, 1967). The digest was cooled and made up to 200 ml. with deionized water. The various size classes, as previously described, were separately digested.

Potassium, calcium and sodium were determined colorimetrically as in water samples using E.E.L. flame photometer. Phosphorus was estimated as phosphate (P_2O_5) by the Deniges' method using Unicam Colorimeter (model SP 1300) with filter No.6 (transmission range 620 mu. upwards). Nitrogen was estimated as ammonia by direct Nesslerisation using the same colorimeter with filter No.2 (transmission range 375 - 535 mu.). The actual concentrations of

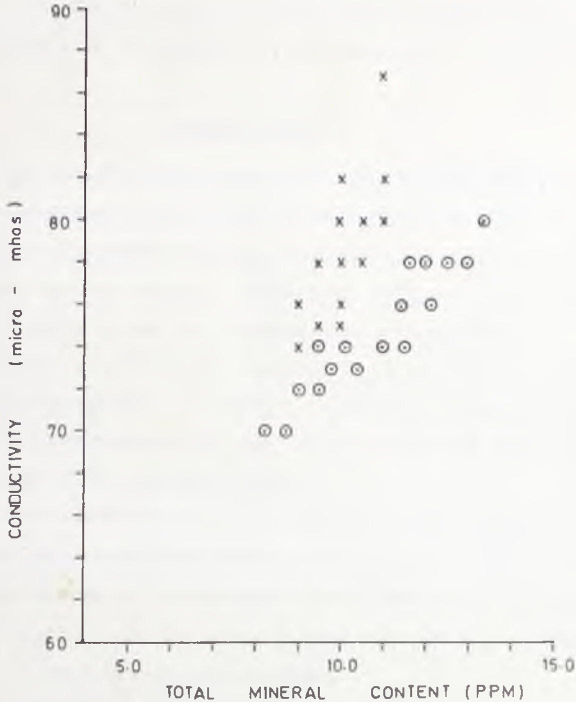


FIG. 1 RELATIONSHIP BETWEEN CONDUCTIVITY AND TOTAL MINERAL CONTENT OF VOLTA LAKE AT DONOR (X) AND ANETA-VAKPO (⊙) DURING SEASON III

phosphorus and nitrogen were read off from a calibration curve based on known phosphorus and nitrogen standards analysed in the same way. The final results (concentration of elements) have been expressed as % of dry weight of plant material.

Treatment of Data

The significance of variation in plant mineral composition with plant size at Donor and Aneta-Vakpo was tested using the analysis of variance technique. At Kponyo where only two size classes were represented, a "t"-test was performed. It has not been possible to test the significance of site-season-size interaction on the mineral composition of plant material on account of insufficient data. In addition to the virtual absence of rosettes at Donor during Season III, only two plant sizes were represented at Kponyo on all sampling occasions.

The concentration of each element in the shoot portion of the entire sample during each season and on each site was obtained by adding together the concentration of that element in the various size classes. Comparative data on water chemistry were obtained from the analyses previously described.

To test the significance of between-sites variation in the mineral composition of plant, using the analysis of variance technique, all the seasons were considered together. Similarly all sites were taken together in testing the significance of seasonal variation. The pooling of data for the statistical analysis became necessary as a result of the way data for the mineral composition of plants were derived. The same reason accounts for the inability of the writer to test the significance of site-season interaction on the mineral composition of plant. Consequently it was considered unnecessary to examine the significance of the combined effect of site and season on the individual element content of lake water.

It was however possible to test the significance of between-sites variation in mineral composition (element by element and total mineral content) and pH of lake water, the density and biomass of vegetation and the weight per plant for each season, using the same technique. Seasonal variation in the above variables was similarly tested for each site. Determination of the significance of the combined effect of site and season on total mineral content and pH of lake water was based on the extent of variation derived from the means of the variables and their standard errors.

Due to the large number of analyses carried out only summaries of the analysis of variance tables and of the other tests are provided. The results are considered as significant at the 5% level of significance ($p < 0.05$). The symbols ** and * have been used to indicate significance at the 1 and 5% levels respectively; N.S. denotes non-significance.

Results

Plant size and plant chemistry

Variation in plant size in relation to the mineral composition of plant at Donor, Aneta-Vakpo and Kponyo for one season is given in tables 1, 2 and 3 respectively. This result is similar to those obtained during subsequent seasons. Results of the statistical analysis are summarized in appendix 1.

Inspection of tables 1 - 3 shows that in several cases, the concentration of elements changes with plant size, the medium size having the lowest concentration. This relationship between the mineral composition of plant and plant size is confirmed by the statistical tests (appendix 1).

The statistical analyses also show that only uptake of phosphorus is significantly correlated with plant size on all sites (appendix 1). There seems to be no justification for concluding that uptake of the other elements is influenced by plant size since significant correlation was obtained only on some sites.

Mineral composition of water and plant, and biomass of vegetation

Figure 2 illustrates variation between sites in the mineral composition (element by element) of lake water and plant, and biomass of vegetation. In figure 3 are shown seasonal variations in the same variables. The mean values from which these figures have been drawn are presented in appendices 2 - 4 together with their standard errors. Appendices 5 and 6 summarize the analysis of variance tables for variations between sites and seasons in the mineral composition of lake water respectively. In appendices 7 and 8 are given respectively

Table 1

The relation between mineral composition of plant and plant size at Donor (Ajena Bay)

Sampling day	24-10-68 (end of rainy season)											
Size Classes*	1				2				3			
Replicates	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
N (% dry wt)	1.00	1.25	1.00	1.08±0.08	0.50	0.50	0.75	0.58±0.08	1.75	1.50	1.50	1.58±0.08
P "	0.15	0.13	0.17	0.15±0.01	0.12	0.14	0.12	0.13±0.01	0.16	0.16	0.18	0.17±0.01
K "	4.60	4.60	4.40	4.53±0.01	3.40	3.60	3.40	3.47±0.01	4.60	4.00	4.40	4.33±0.18
Ca "	2.40	2.45	2.40	2.47±0.02	2.25	2.25	2.40	2.30±0.06	2.40	2.40	2.55	2.45±0.06
Na	0.40	0.45	0.40	0.42±0.02	0.40	0.40	0.50	0.43±0.03	0.40	0.30	0.40	0.37±0.03

*Shoot length ranges for size classes 1, 2 and 3 (as used in tables 1 - 3) are 2.0 - 6.0 cm, 6.5 - 10.5 cm and 11.0 - 15.0 cm. respectively.

Table 2

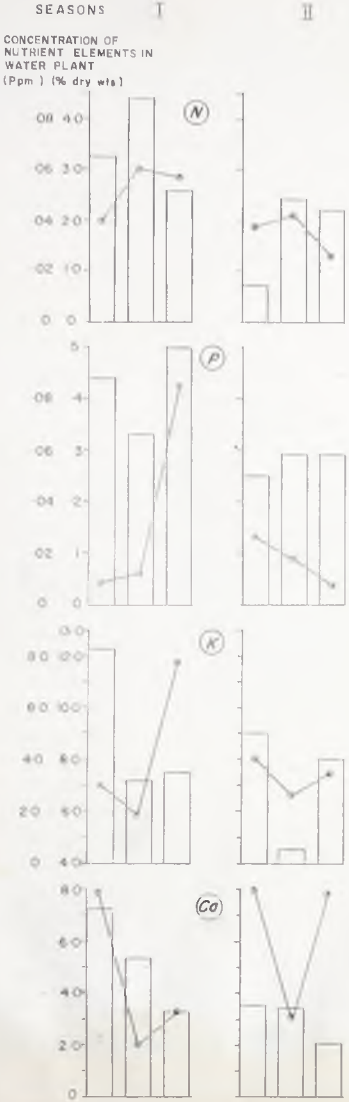
The relation between mineral composition of plant and plant size at Aneta-Vakpo on River Dayi

Sampling day	30-10-68 (end of rainy season)											
Size Classes	1				2				3			
Replicates	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
N (% dry wt)	1.75	1.50	1.50	1.58±0.08	1.50	1.00	1.00	1.17±0.17	2.00	1.25	1.75	1.67±0.22
P "	0.12	0.12	0.10	0.11±0.01	0.14	0.14	0.14	0.14±0	0.10	0.12	0.12	0.11±0.01
K "	2.60	2.20	2.40	2.40±0.01	2.20	2.60	2.40	2.40±0.01	2.40	2.40	2.30	2.37±0.02
Ca "	1.65	1.80	1.80	1.75±0.06	1.80	1.65	1.80	1.75±0.06	1.75	1.75	1.80	1.77±0.02
Na "	0.20	0.23	0.21	0.21±0.01	0.22	0.22	0.22	0.22±0	0.24	0.27	0.25	0.25±0.01

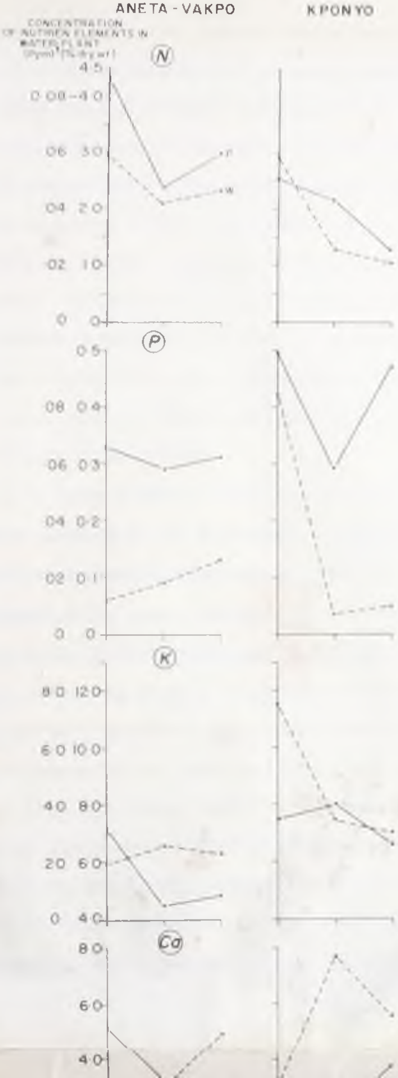
Table 3

The relation between mineral composition of plant and plant size at Kponyo on River Pawmpawm

Sampling day	15-11-68 (end of rainy season)											
Size Classes	1				2				3			
Replicates	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
N (% dry wt)	1.25	2.00	1.50	1.58±0.22	1.00	1.00	1.00	1.00±0	-	-	-	-
P "	0.28	0.28	0.26	0.27±0.01	0.22	0.24	0.22	0.23±0.01	-	-	-	-
K "	3.80	3.80	4.00	3.87± 0.07	3.70	3.80	3.40	3.63± 0.12	-	-	-	-
Ca "	1.75	1.80	1.80	1.78±0.02	1.50	1.35	1.50	1.45±0.06	-	-	-	-
Na "	0.45	0.47	0.50	0.47±0.01	0.38	0.38	0.38	0.38±0	-	-	-	-



SEASONS
I
II
CONCENTRATION OF NUTRIENT ELEMENTS IN WATER PLANT
(Ppm) (% dry wts)
N
P
K
Co


ANETA - VAKPO
KPONYO
CONCENTRATION OF NUTRIEN ELEMENTS IN WATER PLANT (Ppm) (% dry wt)
N
4·5
0·08-4·0
06 3·0
04 2·0
02 1·0
0 0
n
w
P
0·5
08 0·4
06 0·3
04 0·2
02 0·1
0 0
K
8·0 12·0
6·0 10·0
4·0 8·0
2·0 6·0
0 4·0
Ca
8·0
6·0
4·0

summaries of analysis of variance tables for variations between sites and between seasons in the mineral composition of plant.

Since rosettes at Donor during season III were too few for any meaningful chemical analysis, variation between sites in mineral composition of lake water and plant for only the first two seasons is presented and discussed. For the same reason seasonal variation in the same variables at only Aneta-Vakpo and Kponyo is discussed. As Donor appears in a number of considerations to be atypical, conclusions drawn on the other two sites are unlikely to apply to this part of the Volta Lake. However, conclusions drawn on the first two seasons with reference to between-sites variation may wholly or partly apply to season III.

It is quite evident in figure 2 that a majority of the macro-nutrient elements in the lake water and _Pistia_, and biomass of the vegetation show marked variation from site to site. Seasonal variations in the same variables are also marked (fig.3). But while between-sites and between-seasons variations in mineral composition of lake water, and biomass of vegetation have been found to be statistically significant (appendices 5 and 6) such variations in mineral composition of plant have been found to be generally non-significant (appendices 7 and 8). Although the statistical analysis shows that there are no significant variations in plant chemistry, the apparent relationship between the mineral composition of lake water and plant would suggest that in fact the variations in plant chemistry are significant and that there must have been some error in the technique adopted for the analysis of the data. Pooling together of variations that are opposite to each other, for instance, is likely to produce non-significance.

Vegetation parameters, total mineral content and pH of lake water

In figure 4 are illustrated variations between-sites in density and biomass of vegetation, and weight per plant in relation to total mineral content and pH of the Volta Lake. Seasonal variations in the same variables at Donor, Aneta-Vakpo and Kponyo are given in fugures 5, 6 and 7 respectively. In appendix 9, showing site-season interactions ~~between~~ on the above variables, are given as well as the mean values from which the figures have been drawn together with their standard errors. The analysis of variance tables for between-sites and between-seasons fluctuations are summarized in appendix 10 and 11 respectively.

With the exception of variations between sites in total mineral content of lake water during season II, changes in the variables mentioned above with locality (fig.4) and with season (figs. 5-7) appear significant. Generally, variations in vegetation parameters are either directly or inversely related to variations in site factors. The significance of these variations has been confirmed statistically (appendices 10 and 11).

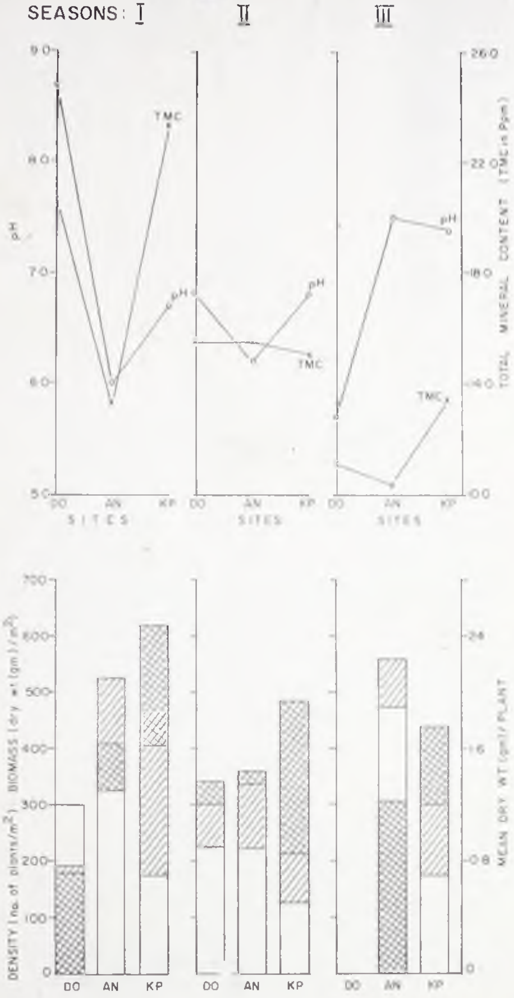


FIG. 4 BETWEEN-SITES VARIATION IN PLANT SIZE [ ] DENSITY [cross-hatched] AND BIOMASS [hatched] OF PISTIA VEGETATION IN RELATION TO pH AND TOTAL MINERAL CONTENT (TMC) OF VOLTA LAKE. DO, AN, KP DENOTE DONOR ANETA-VAKPO KPONYO RESPECTIVELY

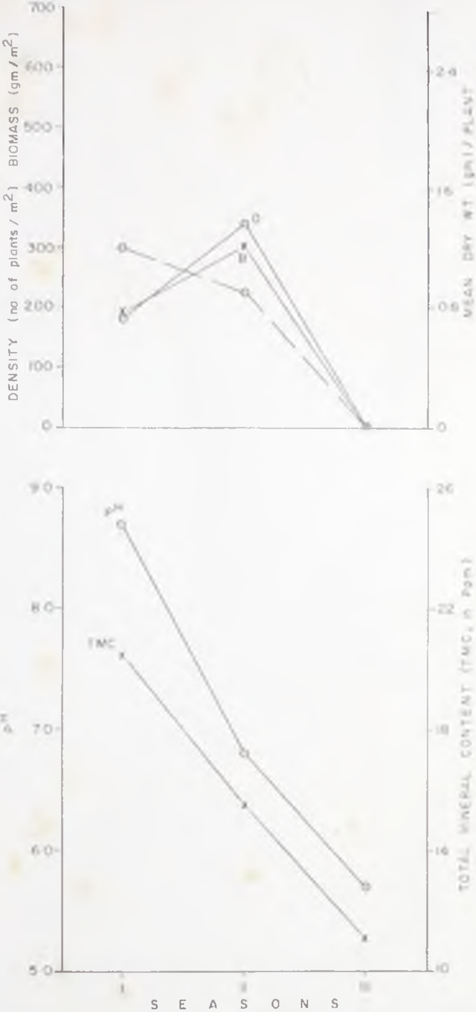


FIG 5 SEASONAL VARIATION IN DENSITY (D), BIOMASS (B) OF PISTIA VEGETATION AND MEAN PLANT WEIGHT IN RELATION TO SITE FACTORS AT DONOR IN AJENA BAY

FIG 6 : SEASONAL VARIATION IN DENSITY (D) BIOMASS (B) OF PISTIA VEGETATION AND MEAN PLANT WEIGHT IN RELATION TO SITE FACTORS AT ANETA-VAKPO ON R. DAYI.

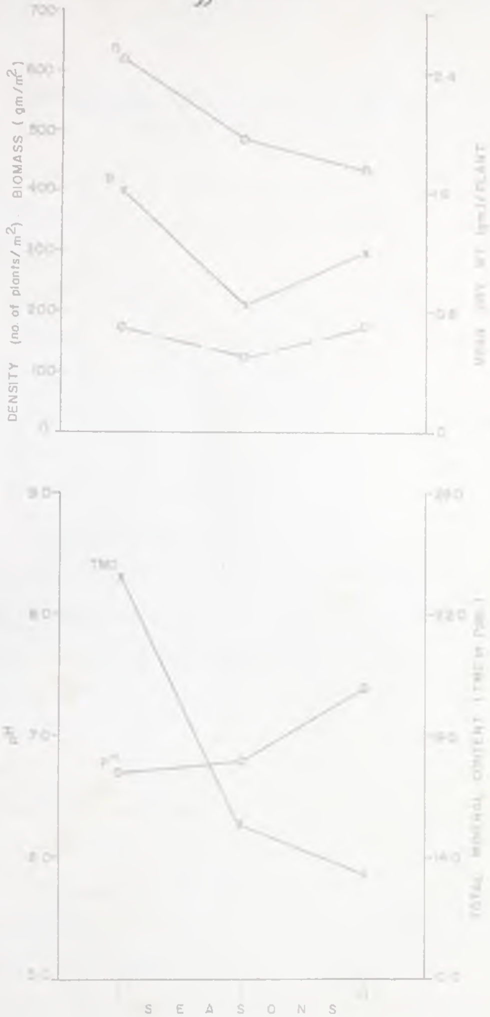


FIG. 7 SEASONAL VARIATION IN DENSITY (D) BIOMASS (B) OF PISTIA VEGETATION AND MEAN PLANT WEIGHT IN RELATION TO SITE FACTORS AT KPONYO ON R. PAWMPAWM.

Site-season interaction on vegetation and lake water characters

Results of the effect of site-season interaction on vegetation and lake water characters investigated are presented, as already stated, in appendix 9.

If changes in the mean alone of each variable with site and season are considered, site-season interaction seems to have exerted marked influence on the characters. The same conclusion is arrived at if the extent of variation between the means is taken into account.

Discussion

Plant size and plant chemistry

The inconsistency in the relationship between plant size and the individual macro-elements other than phosphorus in the shoot of Pistia (appendix 1) may be reflecting some or all of the following:

(1) The fact that the analytical technique used for the other elements (N, K, Ca, Na) may not have been sufficiently sensitive to reveal small differences in the concentration of these elements between the various plant sizes,

(2) the fact that uptake of the other elements may be determined by the peculiar requirement of an individual plant, a disturbance which could have been eliminated by the use of a larger sample size,

(3) the fact that the other elements may be preferentially distributed with reference to the root and shoot of the

plant; the pattern of distribution may change with changes in the phenological status of the plant; if either of these propositions is true, the analysis of the shoot portion alone is unlikely to produce consistent results;

(4) the fact that there may have been "luxury" uptake in instances where non-significance has been obtained.

No definite reason has yet been found to account for the lowest (at Donor and Kponyo) and the highest (at Aneta-Vakpo) concentration of phosphorus in medium-sized plants (tables 1 - 3). One would normally expect nutrient element concentration to increase with increasing plant size (see e.g. Leyton, 1956, 1957; Gordon, 1964). Indeed the relationship between growth and nutrient uptake is grossly complicated. Growth does not depend only on nutrient supply or the ability of the plant to extract nutrients from the substrate but on its genetically or ontogenetically determined growth potential (Tamm, 1964). This complexity underlies the writer's inability to explain without doubt some of the results.

The phenomenon of flowering and fruiting in <u>Pistia</u> is still largely uninvestigated. It is worth noting that under some conditions small as well as large rosettes produce flowers. Under others small but not large rosettes bear flowers. No detailed observation was made on the flowering and fruting state of plants used in this study. It is conceivable that phosphorus uptake by a rosette is determined by its phenological status.

Mineral composition of lake water

Like several tropical lakes (Talling and Talling, 1965), including Kariba (Coche, 1968), the Volta Lake exhibits significant site to site and season to season variations in its total mineral composition (figs. 4-7) (see also Biswas, 1966; Viner, 1967; Attionu, 1968). It is suggested that between-sites variation is very likely to be determined by local differences in the geochemistry of the Volta basin. Data on sectional geochemistry of the basin are unavailable. Seasonal variation on the other hand is probably the result of seasonal discharge of mineral nutrients as soil washings into the Lake (see Attionu, 1968). Seasonality of nutrient regeneration particularly through upwelling of nutrient-rich bottom waters (see Attionu, 1970) and decay of seasonally flooded marginal vegetation are other phenomena which probably account for seasonal variation in mineral nutrients (see e.g. Welch, 1952). Thus the total mineral content of lake water at Donor (fig.5) and Kponyo (fig.7) was highest at the peak of the flood season. Increase in the total mineral content during season II which altered this trend at Aneta-Vakpo (fig.6) might have been caused by release of nutrients due to decay of a "water bloom" (Welch, 1952) that I observed in this part of the Lake. The significant between-sites and seasonal variations in the individual macro-nutrient elements of lake water investigated (appendices 5 and 6) are presumed to be due in a number of cases to the same phenomena suggested for the variations in total mineral content.

Macro-element composition of lake water and plant, and biomass

On the assumption that the argument establishing the significance of variations in plant chemistry is legitimate (see p. 26), the data suggest that differences between the sites in the mineral composition of plant were in general directly related to differences in the mineral content of lake water. Uptake of nitrogen, potassium and sodium was restricted by their concentration in the external medium; that of phosphorus and calcium was only vaguely restricted (fig.2).

Only between-sites differences in plant nitrogen was distinctly and directly related to differences in biomass during season I. Phosphorus, potassium and sodium were inversely related to biomass and calcium bore no relationship to it (fig.2). During season II the concentration of plant nitrogen was a ain clearly and directly associated with, while the concentration of potassium and sodium was inversely associated with biomass. The relationship between biomass and the concentration of phosphorus and calcium was undefined. Thus thedistribution of Pistia on the study sites with reference to the biomass of the vegetation was determined only by the nitrogen content of lake water as it influenced nitrogen uptake. Sites with comparatively high nitrogen were characterized by vegetation of relatively high biomass.

The concentrations of nitrogen, phosphorus and sodium in the shoot of Pistia (on one or both sites) were directly related to the concentrations of these elements in the external medium over the seasons (fig.3). In contrast, the concentrations of potassium, calcium and sodium (at only Aneta-Vakpo) were inversely related to their concentrations in the substrate. It may be concluded that the concentrations of nitrogen, phosphorus and sodium in lake water limited the absorption of these elements by rosettes but that of potassium and calcium did not.

At Aneta-Vakpo on River Dayi, seasonal changes in the concentrations of plant nitrogen, phosphorus, potassium and sodium were directly related to seasonal changes in biomass but calcium did not seem to bear any such relationship to biomass (fig.3). It may be suggested that on this site and at the concentrations of the elements involved, nitrogen, phosphorus, potassium and sodium content of lake water influenced the distribution of Pistia judged in terms of biomass over the seasons through their availability within the plant. The plant produces relatively high biomass during seasons when these elements are well supplied.

A completely different picture was obtained at Kponyo on River Pawmpawm. Seasonal variations in plant phosphorus, calcium and sodium were directly related to biomass while plant nitrogen and potassium were inversely related to it (fig.3). In this part of the Lake therefore, the distribution of biomass of vegetation in time appeared to have been determined by only phosphorus, calcium and sodium.

The data on the relationship between the chemistry of plant and lake water would suggest that the mineral composition in the shoot of Pistia is to a large extent dependent on the mineral nutrient status of the Volta Lake. A similar observation on the dependence of the mineral nutrition of hydrophytes on the mineral nutrient composition of the external medium was made by Fish and Will (1966) working on Elodea canadensis and Lagarosiphon major in two New Zealand lakes.

On the relationship between the mineral nutrition and the performance of Pistia, the results of this investigation indicate that certain nutrient elements are more important in certain areas of the Lake and during certain seasons in determining the vegetative growth and distribution of the plant. The whole phenomenon of the limiting function of nutrient elements has been reviewed by several investigators. It is generally accepted that when one element is limiting and others are available at optimum concentration, changes in growth correspond to changes in the concentration of that element (Liebig's "law"of limiting factors). According to some workers, notably Lundegårdh (1951) increased growth following increase in the concentration of the limiting element is influenced by the concentration of other nutrients. Other investigators (e.g. Macy, 1936) claim that for each element there is a "critical concentration" more or less independent of the concentration of other elements and above which "luxury" uptake occurs and below which growth increases with increasing supply. Still others maintain that where variation in more than one element occurs, the question of balance between nutrients must be taken into account (see. e.g. Thomas, 1945).

Regardless of these differences in interpretation, there is one common feature based on experimental data. Over much of the deficient range of a nutrient element, there is a linear relationship between the concentration of the nutrient element and vegetative growth. When more than one element is limiting but attention is focussed on only one, usually the most deficient, significant relationship is still obtained though the slope of the regression line and the range of the concentration over which it applies may vary according to the concentration of the other nutrient elements. In view of the foregoing, the barely significant or the non-significant relationship between certain nutrient elements in the shoot of *Pistia* and the plant's vegetative growth may have resulted either from interference due to the other elements or to optimum availability of these nutrient elements. It must also be conceded that the relationship between growth and the mineral composition of plants under field conditions may be blurred where a physical factor such as light, rather than a chemical factor is more limiting.

Total mineral content of lake water and vegetation parameters

In addition to marked variation in biomass between the sites over the seasons already reported, there were also significant variations in the density of vegetation and plant size **(appendix.10)**. While density seemed not to bear any relationship to total mineral content of lake water, the relationship between biomass and plant size on one hand and this factor was inverse during seasons I and III. No relationship between the variables was however apparent in season II (fig.4). The distribution of Pistia between the sites in terms of biomass and plant size thus seemed to have been incluenced by the total mineral content of the Volta Lake but was not limited by it, unlike certain individual macro-nutrients.

It is also clearly evident that the density and plant size, like the biomass of Pistia vegetation varied seasonally on the three study sites (figs. 5 - 7; appendix 11). The strongest evidence for such variation was obtained from Donor in Ajena Bay. The density, for instance, was 177 and 340 plants per m^2 during seasons I and II respectively, but during season III there were practically no plants. This remarkable fluctuation in the vegetation parameters at Donor may have res lted from high sensitivity of the vegetation to environmental factors due to its comparatively small cover. The pattern of seasonal variation at Aneta-Vakpo resembled that at Kponyo possibly due to resemblances in the nature of the localities, but differed from that at Donor. The vegetation at Aneta-Vakpo and Kponyo unlike that at Donor was sited on the estuary of a river. Seasonal flushing of the estuary by the rivers may have produced factors of similar influence in the two localities.

Seasonal fluctuation in the abundance and biomass of the vegetation, did not seem to bear any relationship to the total mineral content of lake water at Donor (fig.5). Absence of any relationship may have been due to one or all of the following reasons:

(1) the paucity of samples, and

(2) the fact that total mineral concentration of lake water was not the major controlling factor in this area of the Lake.

The availability of anchorage provided by partly drowned vegetation is believed to be one of the important factors influencing the vegetation at Donor. It is recalled that at the beginning of the rainy season when the lake had receded from areas of standing vegetation, there were hardly any rosettes (fig.5). Plant size was, for some inexplicable reason directly related to total mineral content of lake water.

At Aneta-Vakpo, seasonal changes in density were unrelated to changes in total mineral content of lake water. Variations in biomass and plant size on one hand and this character of lake water on the other were inversely related (fig.6), indicating that although these vegetation parameters were influenced by the total mineral concentration of lake water, they were not limited by it, unlike the majority of macro-nutrients.

The response of the vegetation to site factors at Kponyo was different to that of the vegetation at Aneta-Vakpo, although seasonal changes in the vegetation parameters investigated were similar. Seasonal variations in total mineral concentration of lake water, unlike such variations in phosphorus, calcium and sodium, was unrelated to fluctuations in biomass and plant size (fig.7). Changes in this lake water character appeared to have determined density only in this part of the Lake.

pH of lake water and vegetation parameters

Fluctuations in phytoplankton and hydrophytic producitivity in combination with the decay of flooded marginal vegetation, are likely to produce, in addition to variation in mineral content already reported, variation in pH of the Volta Lake (cf. Welch, 1952). This impact of aquatic plants on the pH of their natural medium is more fully discussed in chapter 3. The extent to which these processess occurred on the various sites and during the various seasons may have determined between-sites (fig.4) and seasonal (figs. 5-7) variations.

The significant differences between the sites as regards the density of the vegetation they supported, does not appear to have been determined by differences in the pH of lake water (fig.4). Relationships between biomass and plant size and pH were inverse during seasons I and II but direct in season III (fig.4). It is thus evident that only the vegetative growth of Pistia was influenced by pH. The highest biomass and largest rosettes have been recorded from Aneta-Vakpo with generally lowest pH (acid) of lake water.

Seasonal variation in pH like that of total mineral content of lake water showed no relationship with density and biomass of vegetation at Donor (fig.5). The reasons may be the same as those suggested for the absence of any relationship between total mineral content and these vegetation parameters (see p.). However plant size was directly related to pH over the seasons, indicating that variation in the size of rosettes was determined by this site factor.

At Aneta-Vakpo, variation between seasons in density of rosettes was inverse to seasonal variation in pH but variations in biomass and plant size were unrelated to pH (fig.6). It thus appears that although pH influenced the abundance of rosettes in this area of the Lake, it did not limit it.

The same conclusion may be drawn on observations made at Kponyo where the vegetation parameters responded similarly to the pH of lake water (fig.7).

On the basis of observations made by Obeid and Chadwick (1964), Chadwick and Obeid (1966), Obeid (1968, pers. comm.) as well as those of the present author, some of the relationships between vegetation and lake water characters described above were to be expected. Within limits, Pistia tends to reproduce vegetatively as its substrate becomes more acid, the threshold at which this happens is however unknown. A large number of small daughter rosettes is produced, resulting in increased density but decreased mean plant size. Decreasing level of overall mineral concentration produces, within limits, results opposite to those of pH.

In a large number of instances, variations in biomass of Pistia on the Volta Lake were directly related to variations in the size of rosettes but were unrelated to the density of vegetation. This relationship has also been shown in pilot and some full scale experiments reported in chapter 2. In contrast to observations made by Chadwick and Obeid (1966), the field observations show that biomass may not always derive from the production of a large number rosettes. Pistia is highly sensitive to intraspecific interference (Obeid and Chadwick, 1964). Under the condition of self-shading which would result at high density of rosettes, photosynthesis would become restricted. Biomass would therefore tend to depend on the vegetative growth of individual rosettes which is favoured by low rather than by high density.

It may be worth noting that besides the significant separate effects of site and season on the vegetation and lake water parameters, site and season also exerted marked combined influence on these parameters (appendix 9).

CHAPTER 2

GROWTH OF PISTIA UNDER CONTROLLED CONDITIONS

Evidence from the field observations reported in chapter 1 suggested that the distribution and growth of *Pistia* on the Volta Lake were to some extent determined by the mineral content and pH of lake water. It was however not possible to determine from these observations the exact response of the plant to both environmental factors partly because of the inconsistency of the relationship. This inconsistency resulted probably from the fact that other environmental factors also influenced the behaviour of the plant on the Lake. To facilitate understanding of the influence of these factors on the plant, information had to be sought from experiments performed under controlled conditions simulating, as far as possible, those operating in the field. This kind of approach has been used successfully by other workers ~~successfully~~, for example Obeid and Chadwick, 1964 and Chadwick and Obeid, 1966. These collaborators in 1964 cultured the plant in a 20% modified Long Ashton Solution at pH levels of 3.0, 4.3, 5.6 and 8.2 in one experiment. In another experiment, plants were cultured at pH levels of 4.0, 5.5 and 7.0 which were combined with 1, 5 and 25 ppm. of nitrogen. In terms of total dry weight, *Pistia* grew better at pH 4.0 and produced a larger number of daughter rosettes than at the other pH values. Increasing amounts of nitrogen produced linear increments in total dry weight but only barely influenced the mean dry weight per plant. By means of such experiments on pH tolerance of *Pistia* and *Eichhornia crassipes*, Obeid and Chadwick (1964) were able to explain the pattern of distribution of the two aquatic weeds on the Sudanese Nile. *E. crassipes* with a pH optimum of near neutral was abundant on the vast stretch of the Nile where the pH was 7.0 and above. *Pistia* with a pH optimum of about 4.0 was poorly represented in this region. However on the Bahr el Gazal section of the Nile where the pH was well below 7.0, *E. crassipes* was markedly less prolific. The "mutual exclusion" exhibited by the two plants on Lake Apanas (Nicaragua) (Little, 1966a) may have resulted from these differences in pH tolerance in addition to the antagonism between the two plants reported by Obeid and Chadwick, (1964).

Preliminary experiments set up to compare growth of *Pistia* in situ (on the Volta Lake) with growth on artificial media* (100% modified and standard Long Ashton Solutions) and on lake water in the greenhouse suggested that:

(1) growth in terms of % gain in total oven-dry weight was better on the modified Long Ashton Solution than on the natural medium in both environments but poorer on the standard solution,

(2) far more leaves and plants were produced in the more mineralised artificial media than in the natural medium in both environments,

(3) plants growing on the artificial media showed greater

* The basic composition of the modified Long Ashton Solution was the same as that used in later experiments (see p. 50); the composition of the standard Long Ashton Solution was as given in Hewitt (1952).

tendency to shedding their roots than those on the natural media, and as one would expect growth in terms of % increase in oven-dry weight of roots was lower on the artificial media than on the natural media.

From another set of pilot experiments designed to select the optimum concentration of modified Long Ashton Solution for subsequent culture experiments, the following results were obtained:

(1) judged in terms of % increase in oven-dry weight, growth appeared to be about the same at 20, 50 and 100% but higher at 10% concentration,

(2) more leaves and plants seemed to have been produced at 50 and 100% than at 10 and 20% concentrations, and

(3) the higher the concentration of culture solution, the greater the tendency to shed roots.

Partly because of the possible inapplicability of results obtained by Chadwick and Obeid to Ghanaian conditions and the inadequacy of experimental data on growth of Pistia under Ghanaian conditions more carefully planned experiments were carried out and are reported in this chapter.

Originally, a large number of environmental factors was to be experimented with but time allowed only the effects of total mineral concentration and pH of culture solution to be intensively investigated. It was however possible to carry out single experiments on the effects of aeration of culture solution, light intensity and day-length on growth of the plant. Although results of these single experiments are not conclusive for various reasons, they are briefly reported below for use in the future.

Results of the experiment in which the culture solutions of medium size rosettes were subjected to varying degrees of aeration were non-significant. The degrees of aeration were achieved by bubbling air from a "Hyflo" aerator model B by means of 0, 1 or 2 pipettes. Growth of the plant under artificial illumination of 0.4, 0.9 and 2.0 Kilolux appeared to have been influenced significantly by light intensity. Response of the plant to photoperiods of 11½, 12 and 12½ hours showed that neither flowering nor vegetative growth of Pistia was determined by daylength.

General Methods

(a) Culture Solutions:

Chemicals used in the preparation of culture solutions were either of the "B.D.H" or "Analar" grade. Metal-distilled water was used in the preparation. Glass-distilled water which is by far more free from metal contamination would have been used but facilities were inadequate for producing large quantities of distilled water required for the large scale experiments reported in this chapter. The basic composition of the culture solutions used was as given below in table 4.

Table 4.

Basio mineral composition of modified Long Ashton Solution ($L.A.S.$) and Arnon and Hoagland (1940) Solution (A & H)

	Weight (gm.) in 10 litres of diluted solution*	
Salt	L.A.S.	A & H
KNO_3	2.02	10.20
$Ca(NO_3)_2$ anh.	6.56	4.92
$NaH_2PO_4 . 2H_2O$	2.04	-
$NH_4 H_2PO_4$	-	2.30
$MgSO_4 . 7H_2O$	3.69	4.90
Ferric citrate	0.245	0.245

* These amounts of reagents in 10 litres of distilled water give a solution strength that has been referred to as 100% concentration for convenience.

(b) Production of Clonal Material:

On the basis of previous experiments, two clones collected from Aneta-Vakpo were cultured in 50% modified Long Ashton Solution to cause them to reproduce a large number of daughter rosettes rapidly; 50% was considered more economical in terms of number of new rosettes produced to the amount of reagents used. What is more, freshly produced daughter rosettes did not seem to do well in 100% solution which yields higher plant number than 50%. Rejuvenation of the parent rosettes after considerable vegetative reproduction was achieved by transferring them into 10% modified Long Ashton Solution for a while. As daughter rosettes were produced, they were transferred into 10% modified Long Ashton Solution which caused them to grow bigger and healthier rather than undergo vegetative reproduction.

(c) Standardization of Plant Material

Growth in *Pistia* is likely to be influenced by the genetic constitution and the size of rosettes. It was therefore considered essential to standardize treatment replicates in terms of these factors. Standardization with reference to genotype, unlike size, generally presented no difficulty. Size is here defined as the amount of organic matter. The extent of correlation between plant size and the following readily measured growth indices was computed:

1) leaf number
2) longest leaf length
3) leaf number x longest leaf length
4) primary root number
5) longest primary root length
6) primary root number x longest primary root length.

Fifty rosettes were used in this exercise. The correlation coefficients, calculated using the original and transformed data, are given in table 5 and the regression line of only the pair which appear to be the most significant is presented in figure 8.

Table 5

Relationship between some growth indices and total oven-dry weight of *Pistia*.

Variables compared	Correlation coefficient
leaf number and dry weight	0.75
log " " and long dry weight	0.81
log " " and " "	0.75
" " and log " "	0.75
longest leaf length and dry weight	0.72
log " " " and log dry weight	0.74
log " " " and " "	0.73
" " " and log " "	0.82
leaf number x longest leaf length and dry wt.	0.89*
log " " x " " " and log dry wt.	0.88
log " " x " " " and " "	0.88
" " x " " " and log " "	0.80
root number and dry weight	0.81
log " " and log dry weight	0.81
log " " and " "	0.77
" " and log " "	0.80
longest root length and dry weight	0.74
log " " " and log dry weight	0.72
log " " " and " "	0.71
" " " and log " "	0.72
root number x longest root length and dry weight	0.80
log " " x " " " and log dry weight	0.79
log " " x " " " and " "	0.72
" " x " " " and log " "	0.79

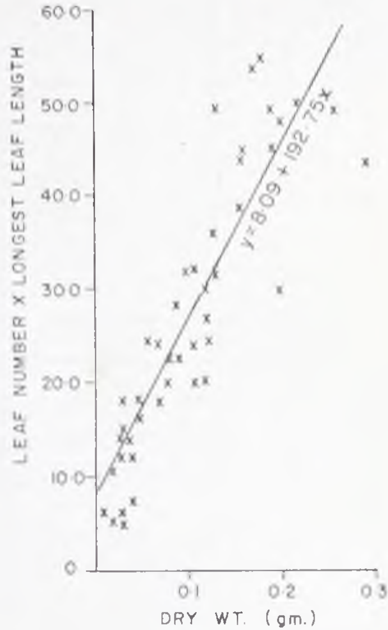


FIG. 8. LEAF NUMBER X LONGEST LEAF LENGTH — DRY WEIGHT RELATIONSHIP IN <u>PISTIA</u>

For the number of observations (50) compared for each pair of variables, the correlation coefficients obtained are significant at the 1% level (Fisher and Yates, 1957). Leaf number x longest leaf length appeared to have given the highest correlation coefficient (asterisked) and was consequently chosen as the best index of plant size. Again, on account of its high correlation with plant size, this combined growth parameter was to be used also as a non-destructive means of recording periodic changes in vegetative growth over the period of the experiments. The high correlation between leaf number x longest leaf length and plant size presumably derives from the fact that this combined factor is the closest approximation to total leaf area which is an important factor determining the amount of organic matter photosynthetically produced. On this basis the rosettes were classified as small, medium, large and extra large as follows:

Size	leaf number x longest leaf length
small	5.0 - 15.0
medium	15.5 - 25.5
large	26.0 - 36.0
extra large	36.5 - 46.5

(d) Experimental procedure

Unless otherwise stated, all the experiments were conducted in the greenhouse at Legon. Two rosettes were cultured in 2 litres of culture solution. The culture solution was contained in plastic basins with just a little over 2 litre capacity. The basins, about 9.0 cm. deep, measured about 20.5 cm. in diameter. Each treatment was replicated four times unless otherwise stated. Although the part of the greenhouse used appeared evenly illuminated, the replicates were arranged in a 4 x 4 latin square to eliminate position effect, except in experiment 4 where this arrangement was impossible. In this experiment randomized block design was used. Experiments were run usually for 16 days, the time when shading of some rosettes by others seemed to become important. At the end of each experiment growth was assessed in terms of several indices.

Contamination of the culture solution with algae epiphytic on the roots and basal portion of the leaves was a source of great concern in the initial stages of this investigation. Attempts to eliminate the algae with 0.1 ppm $CuSO_4$ solution (see e.g. Woodford and James 1963) were successful to a fault. Both the algae and the rosettes died! As an alternative procedure, the culture solution was renewed once every 3 days. Beyond this period, visible growth of algae began to form.

(e) Assessment of growth

Vegetative growth was measured in terms of % increase in leaf number (and sometimes primary root number*), longest leaf length* (and

* These would be referred to subsequently as root number, leaf length, root length.

sometimes longest primary root length*) and in terms of oven-dry weight. Vegetative reproduction was assessed in terms of % increase in plant number. Periodic changes in vegetative reproduction and growth were recorded once every 4 days over the period of the experiment as changes in plant number, and leaf number x longest leaf length respectively.

Leaf length (taken from the leaf base to the highest point on the distal margin) and root length were measured to the nearest 0.5 cm. Leaves and roots were counted if they were 0.5 cm. long and above. Arbitrary limits such as these were indispensable since it was impossible to tell from the exterior whether a leaf, root or plant constituted a physiological unit. Material for the estimation of dry weight was oven-dried to constant weight at 105°C. Weighing was done to the nearest 0.0005 gm.

(f) Statistical analysis of data

All the data in this investigation were analysed statistically. In experiment 1 "Student's" t-test was used to examine differences between the two culture solutions. Determination of the significance of treatment effect in experiment 4 was based on the extent of variation obtained from the standard errors of the means of growth parameters. In all other experiments the analysis of variance technique was used in testing treatment effect.

Experiment 1. Growth of <u>Pistia</u> in two artificial culture solutions: modified Long Ashton Solution and Arnon & Hoagland (1940) Solution.

This experiment was performed to select the more satisfactory (i.e. inducing better growth) solution for subsequent laboratory experiments. The selection was based on the performance of the plant at two widely separated concentrations of each type of culture solution. The basic compositions of the solutions were as given on page 50.

As a result of insufficient clonal material from each genotype for this experiment, 15 rosettes from each of four clones were thoroughly mixed and divided into 20 lots of 3 medium size rosettes each. Four lots were randomly assigned to each of the following treatments.

1) 10% Long Ashton Solution
2) 100% " " "
3) 10% Arnon & Hoagland (1940) Solution, and
4) 100% " " " "

The remaining 4 lots were used for the determination of initial dry weight. The experiment was run for 13 days.

Results and Discussion

Percentage changes in growth per basin and per plant are given in table 6 below.

Table 6

Growth of Pistia in two artificial culture solutions - Long Ashton Solution and Arnon & Hoagland (1940) Solution (Values given for each concentration are mean % changes in growth from 4 basins).

	Long Ashton Solution			Arnon & Hoagland (1940) Solution		
	10% concentrations	100%	Mean	10% concentrations	100%	Mean
leaf number	145	278	212±27	30	190	111±31
leaf length	43	7	25±7	51	10	31±9
root number	112	64	84±11	116	49	82±14
root length	34	12	23±4	25	11	18±3
plant number	0	175	88±34	0	125	63±25
root dry weight	60	32	46±5	43	27	35±3
shoot dry weight	364	194	279±33	255	160	208±18
dry weight per plant	104	15	60±17	54	19	37±7

In testing the significance of differences in the performance of the plant in the two culture solutions using "Student's "t-test, growth at 10 and at 100% concentrations were pooled. The results are presented in appendix 12.

Comparison of mean % changes in growth in the two culture solutions shows that growth appeared to have been influenced by the type of culture solution. With the exception of increase in leaf length, growth in terms of the other indices was better in Long Ashton Solution (table 6). Results of the statistical analysis however shows that significant differences between the two culture solutions were reflected only in leaf number, and dry weight of roots and shoots.

On account of better growth, judged in terms of these three indices, shown by plants growing in modified Long Ashton Solution, and their generally healtheir appearence, this culture solution was chosen for subsequent cluture experiments.

Attention is drawn to the marked differences in growth of Pistia at the two concentrations of each type or culture solution. Vegetative growth appeared to be better at 10% than at 100% but more daughter rosettes appeared to have been produced at the higher concentration. The effect of nutrient concentration on growth of the plant was more fully examined in the succeeding experiment.

Experiment 2. Effect of nutrient concentration of culture medium on growth of Pistia.

The primary aim of this experiment was to determine the most satisfactory concentration of the modified Long Ashton Solution for future experiments.

The main results of earlier experiments summarized on pages 46-48 and of experiment 1 suggested that growth of Pistia would be profoundly influenced by the nutrient concentration of its growth medium. The present experiment was also aimed at testing these earlier observations. It was hoped that light would be shed to some extent on the performance of Pistia in relation to the total mineral nutrient concentration of the Volta Lake.

Materials and Methods

Large-sized rosettes were cultured at the following concentrations of modified Long Ashton Solution: 10, 20, 50 and 100%. The pH of the culture solutions was adjusted to 5.0±0.1 using 5% hydrochloric acid.

Results and Discussion

Mean percentage changes in leaf number per basin and leaf length per plant are given in figure 9.

Leaf number increased with increasing nutrient concentration. Increase in leaf length at 10% concentration was slightly lower than increase at 20% beyond which increase in leaf length decreased sharply with increasing nutrient concentration (Fig.9).

Figure 10 shows mean percentage changes per basin in plant number, root number and in root length per plant.

Production of new roots decreased as the nutrient concentration of the culture medium increased. Root elongation was optimum at 20% concentration; above and below this concentration, changes in root length decreased. Changes in the number of rosettes increased with increasing nutrient concentration (fig.10).

In figure 11 are shown mean % gains in root, shoot and total (i.e. root and shoot combined) dry weight per basin together with % changes in dry weight per plant.

Increments in dry weight of roots, shoots and in total dry weight per basin and of average plant size were highest at 10% nutrient

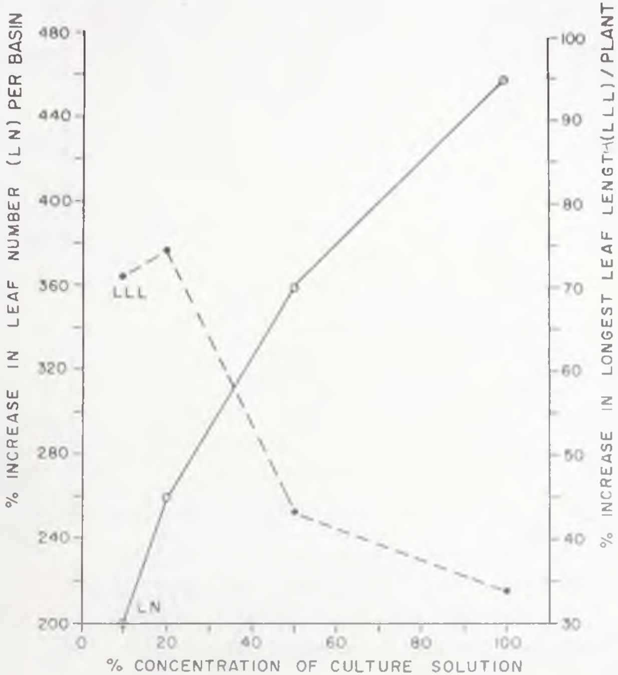


FIG. 9 : EFFECT OF CONCENTRATION OF MODIFIED LONG ASHTON SOLUTION ON GROWTH OF PISTIA

(LEAF NUMBER; LEAF LENGTH)

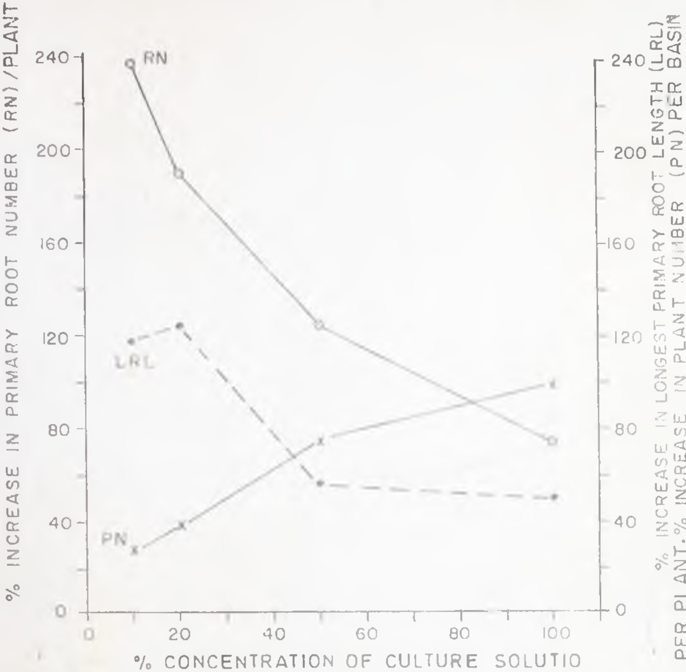


FIG. 10 EFFECT OF CONCENTRATION OF MODIFIED LONG ASHTON SOLUTION ON GROWTH OF PISTIA (PLANT NO. ; ROOT NO.; ROOT LENGTH)

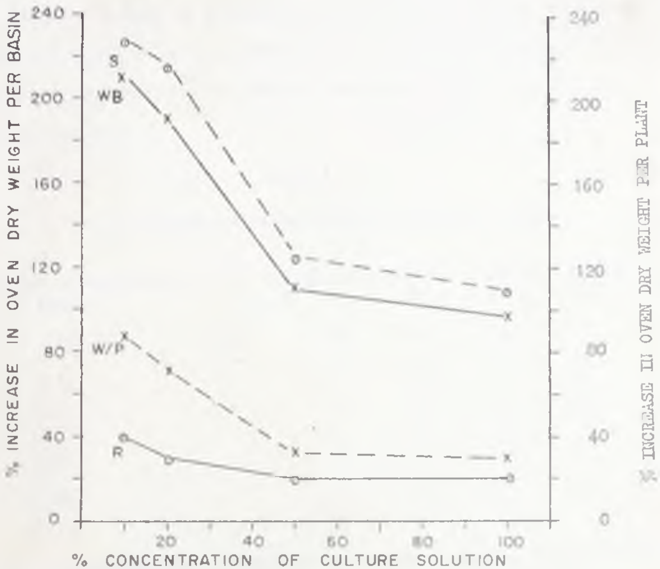


FIG. II EFFECT OF CONCENTRATION OF MODIFIED LONG ASHTON SOLUTION ON THE GROWTH OF PISTIA. (R, S, WB, W/P, DENOTE ROOT, SHOOT, TOTAL WT./BASIN, WEIGHT PER PLANT RESPECTIVELY) concentration and decreased the more concentrated the culture solution became. The decrease was generally sharpest between 20 and 50% concentrations (fig.11). No flowers were produced.

Periodic changes in vegetative growth measured as leaf number x longest leaf length are illustrated in figure 12. Such changes in vegetative reproduction, recorded as increases in plant number, are given in table 7.

Table 7

Mean periodic changes in plant number per basin

Duration of experiment (days)	% Concentration of Culture Solution			
	10	20	50	100
0	2	2	2	2
4	2	2	2	2
8	2	2	3	3
12	3	3	3	4
16	3	3	4	4

Organic matter content of the plants increased linearly with time (fig.12) and new daughter rosettes were produced at every nutrient concentration (table 7) as the experiment ran on.

The analysis of variance tables for these data are summarized in appendix 13.

These results suggest that only the vegetative growth of Pistia was significantly influenced by varying nutrient concentration. This

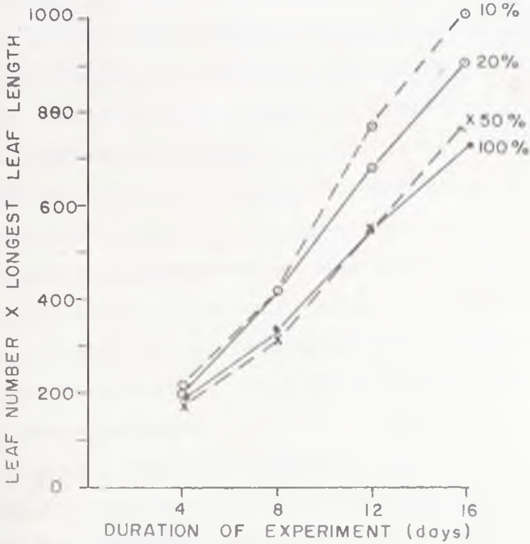


FIG. 12 EFFECT OF CONCENTRATION OF MODIFIED LONG ASHTON SOLUTION ON GROWTH OF PISTIA (Values plotted are means / basin) (PERIODIC CHANGES IN GROWTH)

factor appeared not to have influenoed flowering (see p. 64) and production of daughter rosettes (appendix 13).

The generally linear increase in leaf number and decrease in leaf length (fig.9), root number and length (fig.10), dry weight of roots, shoots, and total dry weight per basin and per plant (fig.11) with increasing nutrient concentration confirm earlier observations on the effect of nutrient concentration on the above growth indices (see p. 48). The inverse relationship between root growth and this substrate factor was to be expected since increasing nutrient concentration increased the tendency to shed roots. A similar observation was made by Chadwick and Obeid (1966) who reported that at high concentrations of Long Ashton Solution, the roots of Pistia became collapsible.

It is worth noting that in contrast to earlier observations, the production of new rosettes was not influenced significantly by nutrient concentration (appen.13) although a trend was apparent (fig.10), suggesting that the use of a larger sample size might have produced significant results. It is also worth noting that in contrast to Chadwick and Obeid's (1966) observation, high plant number was correlated with low total plant material per container. Increase in total plant material seems to have resulted not from increase in plant number but from the vegetative growth of individual plants. These relationships were also observed under field conditions (see p. 44).

It appeared from a pilot experiment that flowering of Pistia would be influenced by the concentration of nutrients in its substrate. Absence of inducement of flowering by low nutrient concentration in the present experiment may be explained by the following reasons:

1) differences in pre-experimental treatment of rosettes used in the two experiments; while rosettes for the pilot experiment were collected straight from the Volta Lake at Aneta-Vakpo, rosettes for the present experiment were produced in the greenhouse,

2) materials for the experiments were collected at different times of the year; differences in their phenological status or seasonal effect on growth may account for differences in the flowering behaviour of the two samples. Ashby (1929) also recognized these factors in an attempt to explain the discordance in the results of two similar experiments performed at different times of the year with the hydrophyte, Lemna, which is ecologically similar to Pistia (Gay, 1958).

Over the period of the experiment, periodic changes in dry weight estimated as leaf number x longest leaf length were highest at 10% concentration and decreased with increasing nutrient concentration (fig.12). This result clearly demonstrates that besides more plant material being produced at lower nutrient concentration, the rate of production also varies inversely with increasing nutrient concentration.

Although the final changes in plant number at the various concentrations were not significantly different (appendix 13), the time of initiation of vegetative reproduction seems noteworthy. The process was initially slow at all concentrations but started much earlier (after the first 4 days) at 50 and 100% and only after 8 days at the lower concentrations (table 7).

It is recalled that the main aim of this experiment was to select the optimum concentration of modified Long Ashton Solution for growth of Pistia. The results of this experiment indicated that growth was generally best at 10% which should have been chosen for subsequent laboratory experiments. Differences in the performance of the plant at 10 and 20% concentrations were however very slight; they were not as marked as between these lower concentrations on one hand and the higher concentrations on the other. Culturing plants at 20% concentration would facilitate comparison of results of the present series of experiments with those of earlier experiments. Mainly because of this, 20% nutrient concentration was selected.

The effects of nutrient concentration on growth of Pistia as observed under controlled conditions agree to some extent with the effects of this factor in nature. The inverse relationship between production of new plant material and nutrient concentration of culture solution (fig.11) is reflected in the relationship between biomass and plant size, and total mineral content of lake water as they varied from locality to locality on the Volta Lake during Seasons I and III (fig.4). The seasonal correlation between the vegetative growth of the plant and the extent of mineralization of lake water at Aneta-Vakpo (fig.6) and between this site factor and the density of vegetation at Kponyo (fig.7) also demonstrate respectively the tendency shown by the plant to grow bigger at relatively low nutrient concentrations and produce a larger number of plants as its nutrient medium becomes richer. The experimental results cannot however be used to explain the relationship between total mineral content of lake water and site to site variation in plant parameters during Season II (fig.4). In addition, the seasonal variation in plant parameters at Donor (fig.5), in density of the vegetation at Aneta-Vakpo (fig.6) and in vegetative growth of the plant at Kponyo (fig.7) in relation to nutrient supply contrast with the response of the plant under laboratory conditions.

Experiment 3. Effect of pH on growth of *Pistia*.

In chapter 1 an attempt was made to relate the distribution and growth of *Pistia* to the pH of the Volta Lake. No consistent relationship was obtained presumably as a result of the multiplicity of factors influencing growth of the plant in nature. On the basis of experimental data collected by Chadwick and Obeid (1966), the vegetation at Donor was expected to be at its densest during season III when the pH of lake water (5.0) was closest to the optimum (about 4.0) recorded for *Pistia*. On the contrary, the vegetation declined to nothing as shown in figure 5 in chapter 1. Indeed it is often difficult to demonstrate the relationship between environmental factors and growth of plants in the field. A more reliable approach of determining such relationships is by means of controlled experiments. The present experiment was therefore set up to obtain information on the response of the plant to the pH of its substrate. This information might help to explain the performance of the plant on the Lake in relation to the pH of lake water. Confirmation of the results of previous experiments was also sought.

Materials and Methods

Rosettes from the large size class were used for this experiment. These were cultured in solutions maintained at pH levels of 3.0, 5.0, 7.0 and 9.0 adjusted to within ±0.1. The adjustment was made using 5% sodium hydroxide (to alkaline pH) and 5% hydrochloric acid (to acid pH) (cf. Chadwick and Obeid, 1966). To compensate for the additional sodium added as sodium hydroxide to produce an alkaline solution, amounts of sodium sulphate equal to that added to the solution maintained at pH 9.0 were added to the acid and neutral solutions (see e.g. Arnon and Johnson, 1942).

Two main considerations underlie the choice of these pH levels:

1) the levels are sufficiently separated so that changes in pH which may be caused by the growth of *Pistia* as reported in chapter 3 may not bring about overlap of the treatments,

2) the range was chosen to include pH levels recorded in the field; this would give more meaning to and facilitate the

exercise of relating experimental results to field observations.

The inclusion of an alkaline pH level within the pH range would raise the question of precipitation of certain nutrient elements and their consequent unavailability to the plant (see e.g. Arnon and Johnson, loc. cit.). Correction of this experimental error would have become necessary if attention was being focussed only on the direct effects of pH and not also on its effect on plant growth through nutrient availability. Besides, precipitation in the alkaline solution became visually recognizable (i.e. appreciable) only at the beginning of the third day at the end of which the culture solutions were renewed and the pH levels re-adjusted.

Results and Discussion

Figure 13 illustrates mean % changes in leaf number per basin, leaf length per plant and in plant number per basin. In figure 14 are shown mean % increases in root, shoot and total dry weight per basin and in weight per plant. Appendix 14 summarizes the analysis of variance of the data.

The figures show that all the growth indices were influenced by the pH of nutrient medium. This conclusion was confirmed statistically (appendix 14).

Growth in terms of most of the indices investigated increased from 'no-growth' at pH 3.0 to a maximum at pH 5.0 beyond which it declined; leaf elongation and root growth were highest at pH 7.0 (figs. 13 and 14). The failure of rosettes to grow at pH 3.0 needs special mention. Rosettes transferred to culture solutions maintained

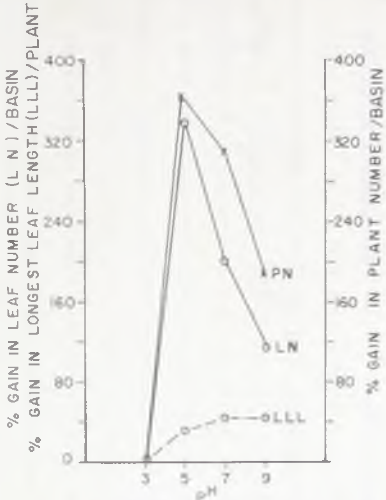


FIG. 13 LEAF NO; & LENTH; PLANT NO.

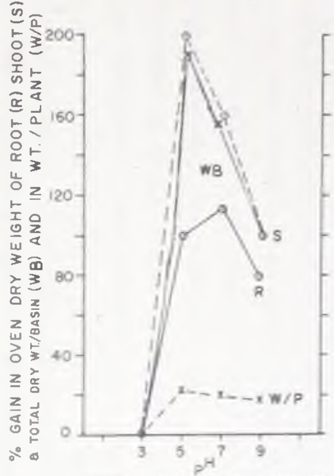


FIG 14 ROOT, SHOOT, TOTAL DRY WT./BASIN; DRY WT./PLANT

EFFECT OF P^H ON GROWTH OF PISTIA

at this pH responded instantly. Within five minutes all the rosettes of leaves had closed up. Three hours later the rosettes of leaves had collapsed, lying flat on the surface of the culture solution. The roots also became soft. Attempts to revive the rosettes by transferring them to culture solutions maintained at pH (about 5.0) know to be favourable were unsuccessful. The rosettes had died.

This observation supports to a large extent results obtained by Chadwick and Obeid (1966). These investigators reported the failure of Pistia to survive at pH 3.0 although, according to them, some amount of growth was possible. It is perhaps pertinent here to draw attention to a similar observation namely that of instant death of the water moss, Fontinalis antipyretica at pH values between 3.0 and 4.0 (Steeman Nielsen, 1952). In the same year, Minshall and Scarthe (1952) demonstrated experimentally that in Eichhornia crassipes, which is similar ecological to Pistia (Gay, 1958), root cell division and elongation decreased markedly at pH values below 4.0. At pH 3.0, these processes proceeded at half the rate at which they occurred at pH 5.0. It is likely that the failure of Pistia to withstand low pH values as observed by Chadwick and Obeid (loc. cit.) is due to poor root growth as they have suggested. In the present experiment where instant death was observed, this explanation is unlikely to apply. The present writer is of the opinion that the occurrence of instant death would suggest that the failure resulted either from direct killing of root cells or from enhanced uptake of toxic substances, for example aluminium as contamination in reagents used in culture solution, under very acid conditions (see e.g. Arnon and Johnson, 1942). pH influences through the inhibition of root growth and nutrient uptake are likely to show delayed manifestations.

The occurrence of optimum growth at pH 5.0 for all practical purposes accords well with data obtained by Chadwick and Obeid (1966) who have recorded the pH optimum of 4.0 for the same species. The general decline in growth beyond pH 5.0 may be due to drastic reduction in uptake of phosphorus which occurs at alkaline reactions (see e.g. Arnon and Johnson, 1942).

It is interesting to note that unlike in the preceeding experiment, in the present experiment the production of maximum plant material corresponded with maximum plant number, as observed by Chadwick and Obeid (1966). This relationship may have occurred in the absence of intra-specific competition. Although a larger number of plants was produced under this experiment, in the preceeding experiment the rosettes were very much larger; on the average 8, medium-sized plants per basin with average % gain in weight per plant of 20 were obtained under this experiment, (see figs. 14 and 16) as against 3 large-sized plants per basin with average % gain in weight per plant of 60 (see fig. 11, table 7) under experiment 2. It thus becomes appearent that intra-specific interference does not necessarily become important only at high plant populations but also at high plant size. In fact the factor that seems to determine mutual interference is area per plant.

Changes in vegetative growth and in vegetative reproduction recorded periodically are presented in figures 15 and 16 respectively.

Reference to figure 15 shows that vegetative growth was constantly highest at pH 5.0 and lowest at pH 9.0, discounting growth at pH 3.0. This indicates that not only was the final growth obtained generally optimum at pH 5.0 but also that the rate at which this was achieved was highest at this pH. A similar trend was shown in vegetative reproduction (fig.16).

Because of the inconsistent response by Pistia to variation in pH of lake water, results of the present experiment can, only in part, account for the distribution and growth of the plant in relation to this site factor on the Volta Lake. The tendency shown by the plant during the first two seasons to grow bigger and produce vegetation of comparatively high density and biomass in localities where the pH of lake water was nearer 5.0 as shown in figures 4 and 7 (chapter 1) may be considered as reflecting the tendency by the plant to grow best at this pH under laboratory conditions. It is remarkable in the light of the experimental results that there were virtually no resettes at Donor during the dry season when the pH of lake water was most favourable (fig.5).

Experiment 4. Combined effect of pH and nutrient concentration of culture solution on gorwth of Pistia.

The results of experiments with mineral nutrient concentration and pH of culture solution showed that both factors influenced significantly

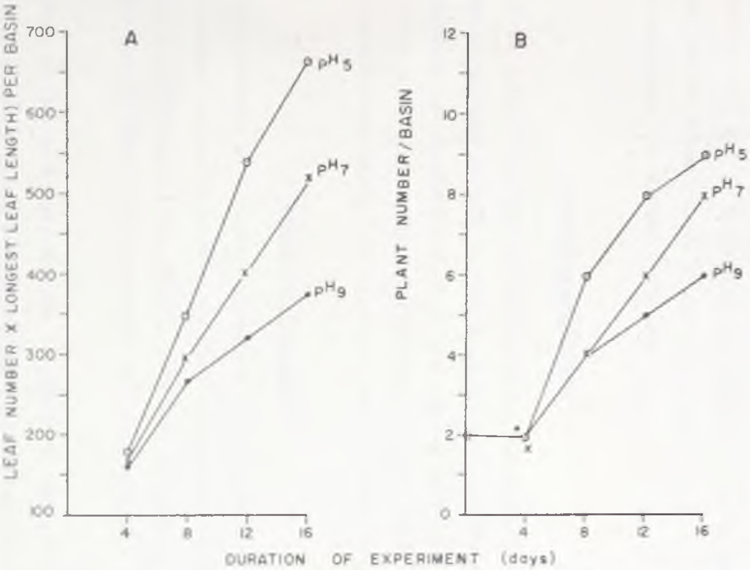


FIG. 15 VEGETATIVE GROWTH

FIG 16 VEGETATIVE REPRODUCTION

EFFECT OF p^H ON A) VEGETIVE GROWTH AND
B) VEGETATIVE REPRODUCTION IN <u>PISTIA</u> (PERIODIC CHANGES)

growth of Pistia and to some extent threw light on the response of the plant to these factors on the Volta Lake. It became desirable to obtain information on how the plant responds to interaction between the two factors. Such an information might lead to a better understanding of the performance of the plant in relation to these factors in the field when the relevant field data become available.

Materials and Methods

On the basis of experiments 2 and 3, medium sized rosettes were cultured at pH values of 5.0, 7.0 and 9.0 which were combined with % total nutrient concentrations of 10, 50 and 100. pH adjustment was made by the method previously described (see p. 70). Each treatment was replicated three times. The experiment was run for 12 days.

Results and discussion

Mean % changes in the growth parameters investigated in relation to pH-nutrient content interaction are given in appendix 15 and illustrated in 3-dimensional figures (figs. 17-25). Note that the scale of total nutrient concentration used in figures 17 and 18 is reversed in figures 19-25.

These figures show that, with the exception of root number (fig.20) and average weight per plant (fig.25), growth in terms of the other indices examined with changes in the pH at constant nutrient concentration of culture solution or vice versa, varied, suggesting that these indices were influenced by interaction between the two factors. However

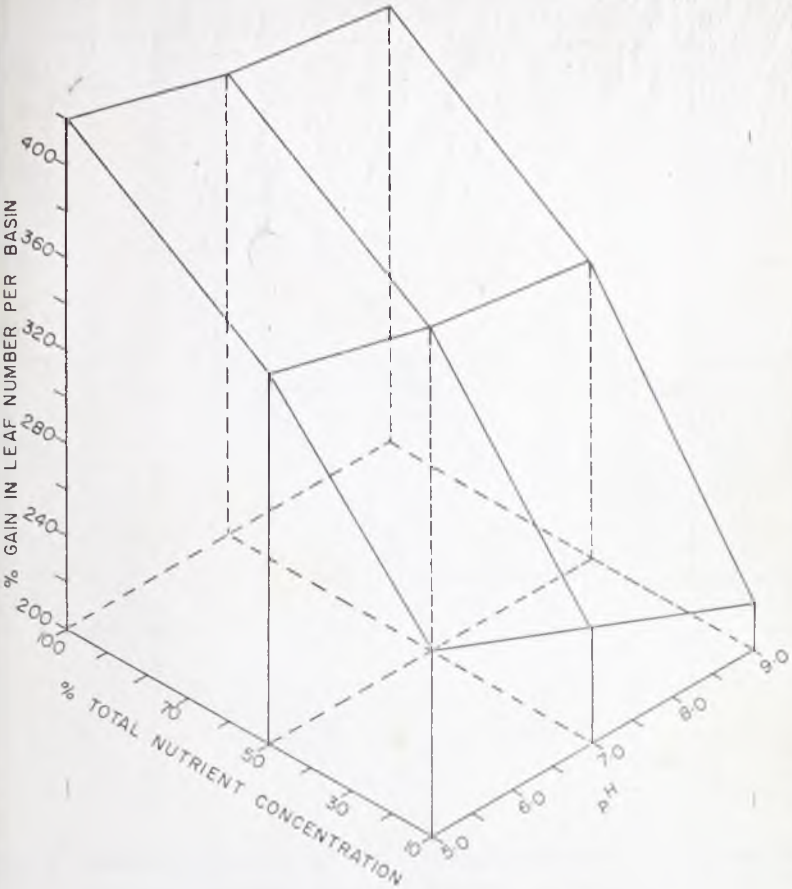


FIG. 17 : COMBINED EFFECT OF P^H - TOTAL NUTRIENT CONCENTRATION OF CULTURE SOLUTION ON GROWTH OF PISTIA (LEAF NUMBER)

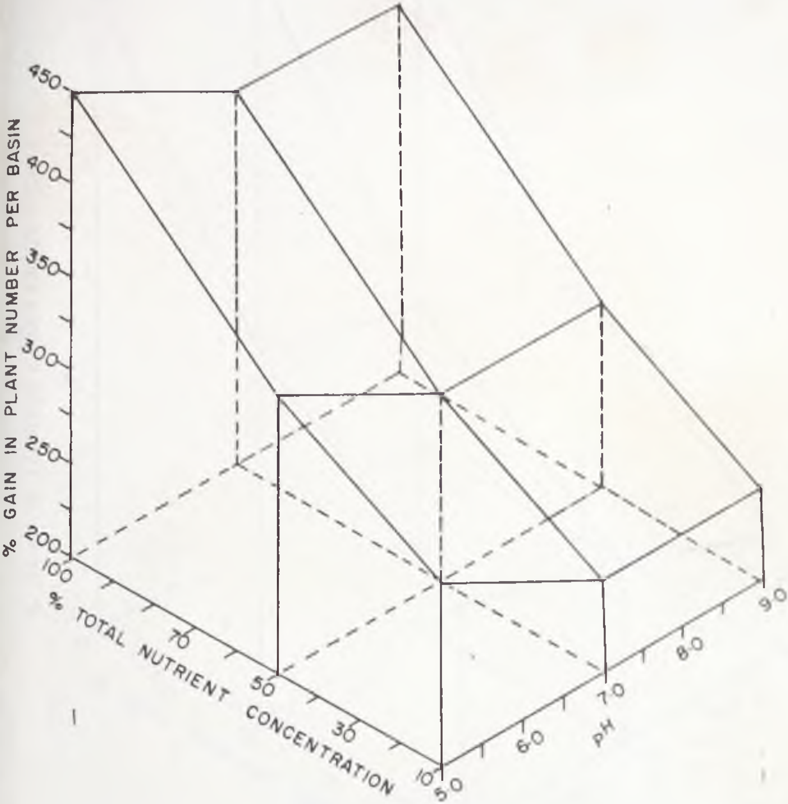


FIG. 18 COMBINED EFFECT OF P^H - TOTAL NUTRIENT CONCENTRATION OF CULTURE SOLUTION ON GROWTH OF PISTIA

(PLANT NUMBER)

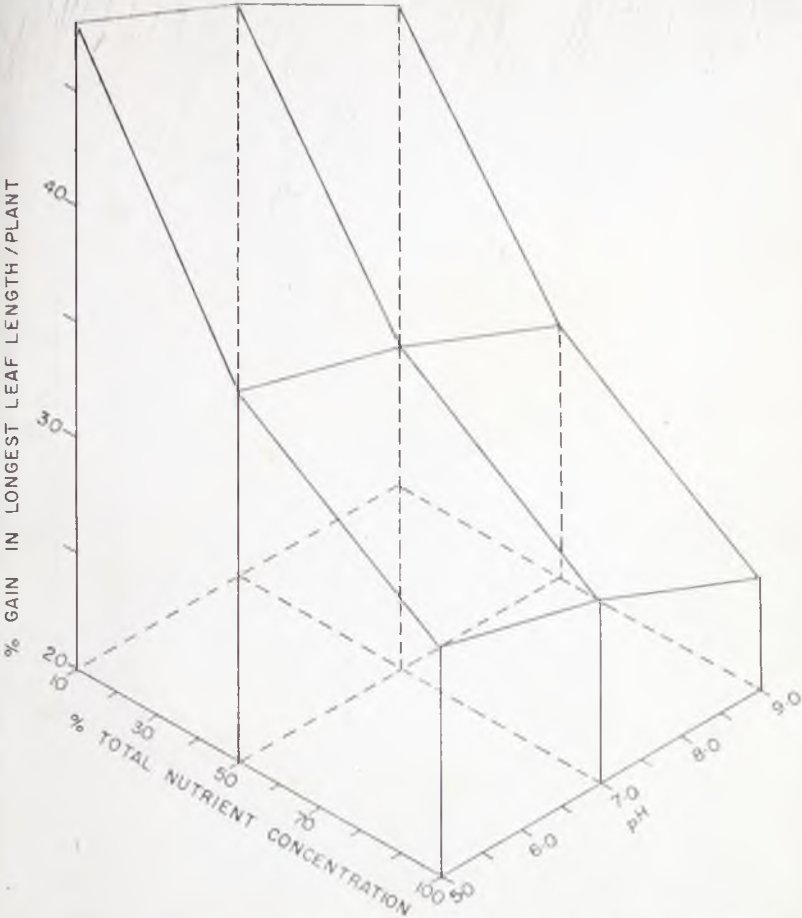


FIG. 19 COMBINED EFFECT OF P^H – TOTAL NUTRIENT CONCENTRATION OF CULTURE SOLUTION ON GROWTH OF PISTIA

(LEAF LENTH)

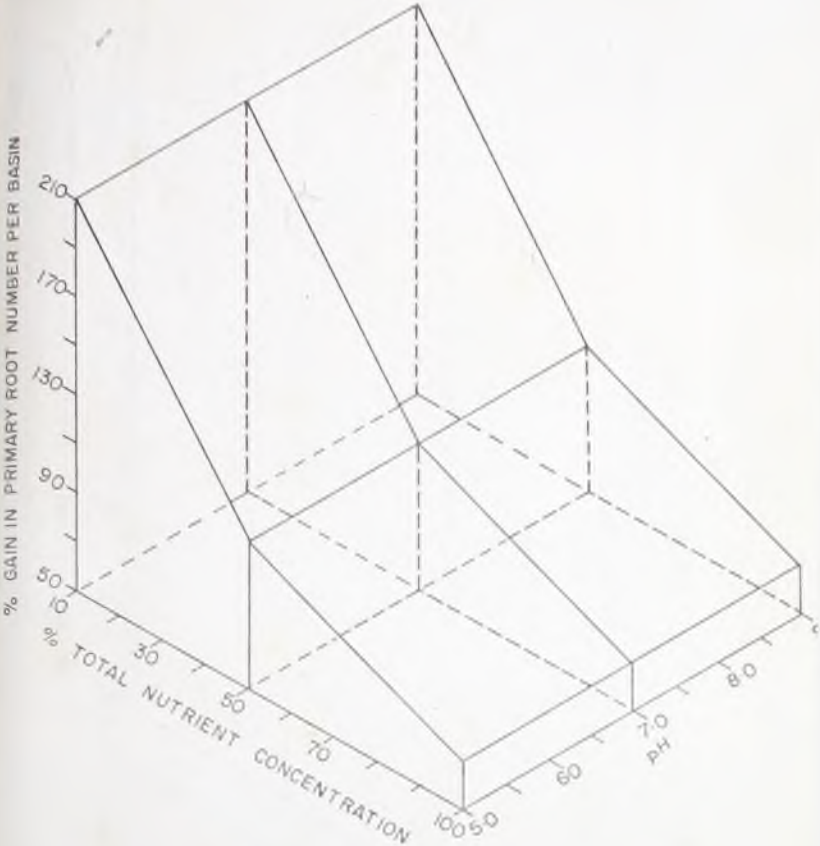


FIG. 20 : COMBINED EFFECT OF P^H – TOTAL NUTRIENT CONCENTRAT
OF CULTURE SOLUTION ON GROWTH OF PISTIA.

(ROOT NUMBER)

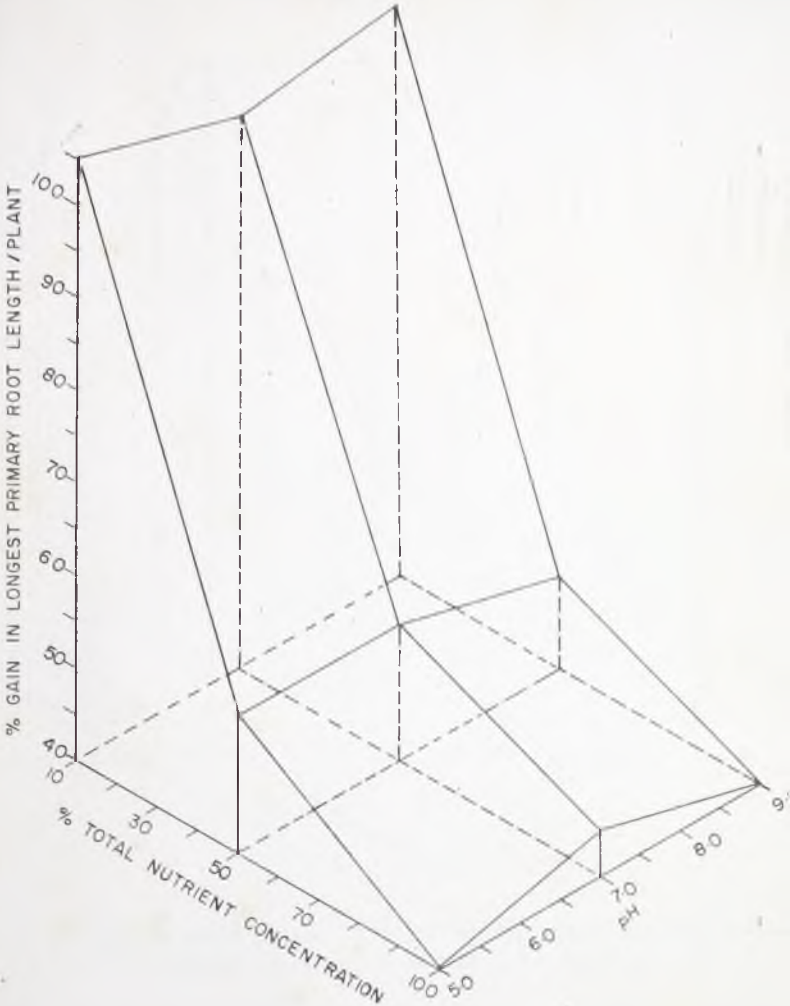


FIG. 21 : COMBINED EFFECT OF PH – TOTAL NUTRIENT CONCENTRATION OF CULTURE SOLUTION ON GROWTH OF PISTIA.

(ROOT LENGTH)

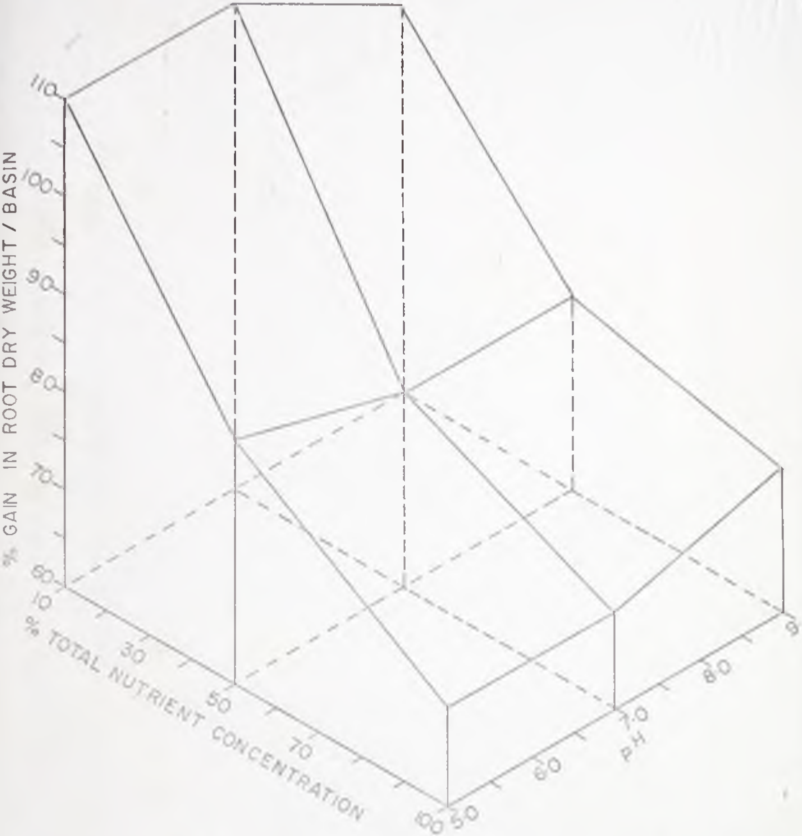


FIG. 22 COMBINED EFFECT OF P^{H} – TOTAL NUTRIENT CONCENTRATI
OF CULTURE SOLUTION ON GROWTH OF PISTIA.

(ROOT DRY WEIGHT)

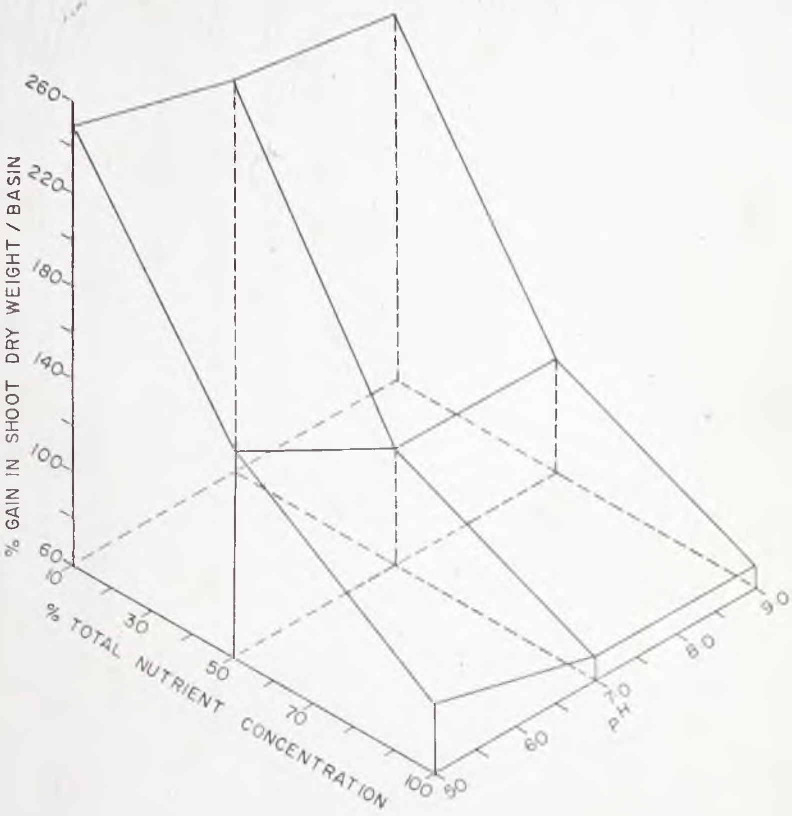


FIG. 23 : COMBINED EFFECT OF P – TOTAL NUTRIENT CONCENTRATION OF CULTURE SOLUTION ON GROWTH OF PISTIA.

(SHOOT DRY WEIGHT)

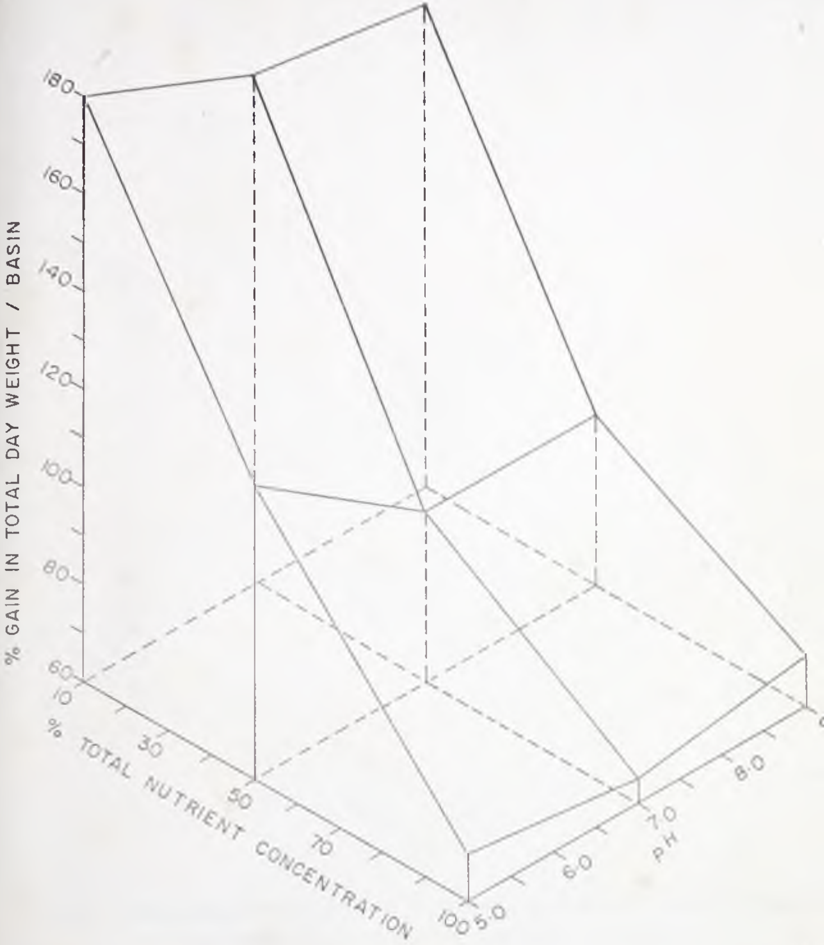


FIG. 24 : COMBINED EFFECT OF P^H – TOTAL NUTRIENT CONCENTRATIO
OF CULTURE SOLUTION ON GROWTH OF PISTIA
(TOTAL DRY WEIGHT)

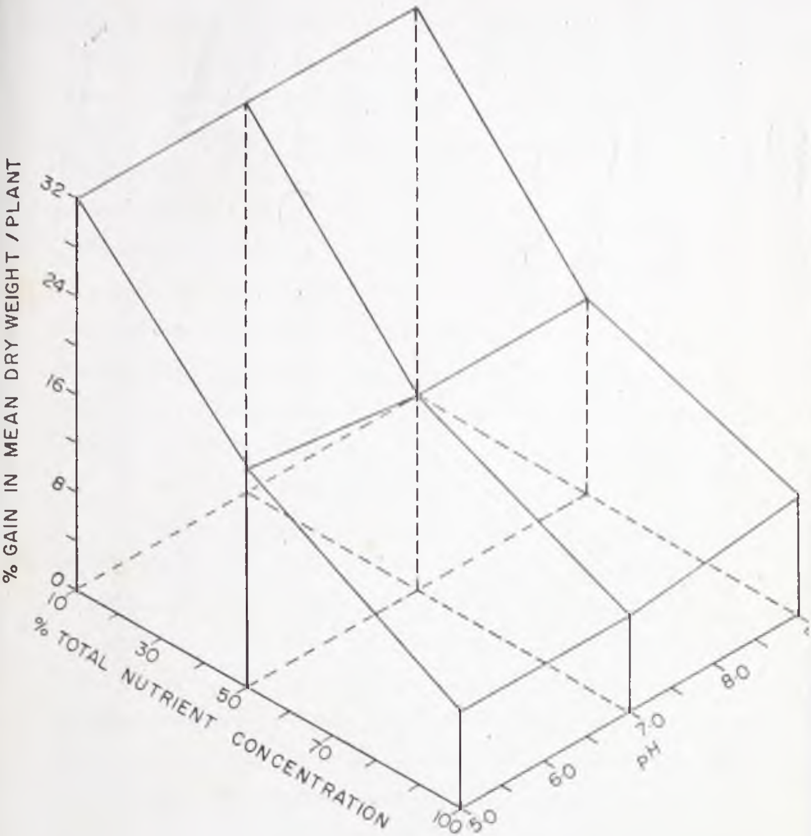


FIG.25: COMBINED EFFECT OF P^H – TOTAL NUTRIENT CONCENTRATI
OF CULTURE SOLUTION ON GROWTH OF PISTIA.

(DRY WEIGHT PER PLANT)

examination of the extent of variation in growth between the treatments indicates that growth measured as increases in leaf and plant number, leaf and root length, and root, shoot and total dry weight, appeared to have been influenced significantly by the interaction (appendix 15). Although figure 20 shows that the production of new roots was not significantly influenced by the interaction, statistical analysis shows that the variation in root number was significant (appendix 15).

Production of new leaves was highest at pH 5.0 x 100% nutrient concentration and decreased with increasing pH and decreasing level of nutrients (fig.17). The decrease with increasing pH was greatest at the lowest nutrient concentration and least at the higher nutrient content. With decreasing concentration of nutrients, the reduction in leaf production became higher the higher the pH value.

The reaction of *Pistia* to the interaction in terms of changes in plant number was largely similar to its response assessed in terms of leaf number. The largest number of rosettes was produced at 100% nutrient concentration and the smallest number at 10% concentration at all pH values (fig.18). Reduction in vegetative reproduction as a result of decreasing nutrient supply was more marked at the higher pH levels than at pH 5.0. It is interesting to note here that variation in substrate pH influenced the production of daughter rosettes only as it changed from 5.0 to 7.0 or vice versa at all nutrient concentrations; more plants were produced at pH 5.0 than at the higher pH levels.

Figure 19 shows that the highest increase in leaf length was obtained at pH 5.0 x 10% nutrient concentration. As the level of each factor increased, growth in leaf length decreased. Reduction in leaf elongation with increasing nutrient concentration tended to be comparatively high at the higher pH values. Similarly increasing pH produced relatively small increments in leaf length at all nutrient concentrations; the higher the concentration of nutrients in the culture solution was the smaller the increment.

Growth in terms of number of roots produced was optimal at 10% and minimal at 100% nutrient concentration at all levels of pH (fig.20). At each nutrient level, the highest number of roots produced was obtained at different pH values; pH 5.0 at 10%, 7.0 at 50% and pH 9.0 at 100% nutrient concentration; this trend may appear better indicated in appendix 15.

Root elongation, like the production of new roots, was best at the lowest nutrient level and poorest at the highest irrespective of the pH of culture solution (fig.21). Optimum root growth occurred at different pH levels as the concentration of nutrients was varied. It is quite apparent from figure 22 that the combined effect of pH and nutrient concentration on root growth of Pistia was such that the heaviest yields in root dry weight occurred at 10% nutrient level at all pH values and that yields decreased with increasing nutrient concentration. The pH value at which the least amount of root dry weight was produced varied with nutrient concentration.

Judged in terms of increase in shoot dry weight growth of *Pistia* was generally poorest at pH 9.0 regardless of the nutrient concentration and increased with decreasing pH (fig.23). Increasing pH produced smaller increments in shoot dry weight at 100 than at 50 and 10% nutrient levels; it did not influence shoot growth as it changed from 9.0 to 7.0 at 100% and only barely did so at 50 and 10% concentrations of nutrients. The highest yield was obtained at 10% nutrient supply and the lowest at 100% whether or not the pH was changed. Variation in nutrient supply influenced yields to a greater extent at pH 5.0 when it decreased from 100 to 50%. Changes in shoot dry weight with further decrease in nutrient supply were of the same order of magnitude at all pH values.

Growth in total dry weight per basin in relation to pH-nutrient level interaction as illustrated in figure 24, parallelled growth in shoot dry weight which has just been described. At all nutrient levels growth was optimum at pH 5.0 and decreased with increasing pH. Rosettes growing in 10% nutrient concentration grew best and those at 100% showed the poorest growth, regardless of the pH at which the culture solution was maintained.

The interaction did not seem to have influenced the size of rosettes as has been pointed out earlier (fig.25, appendix 15). Rosettes cultured in 10% nutrient concentration were largest at all pH values and as nutrient concentration increased, the size of rosettes decreased. Increasing pH did not alter plant size at any of the nutrient concentrations. The probable reason for this may be found in the contrasting effect of the interaction on plant number (fig.18) and total dry weight (fig.24).

The trends in the production of new leaves and daughter rosettes agree with the results of previous experiments which showed that a large number of leaves and rosettes was produced at higher nutrient concentrations and lower pH levels. The occurrence of optimum growth in terms of the other indices at relatively low nutrient and pH levels confirms generally the reaction of the plant as observed under experiments 1, 2 and 3. The only discrepancy is that optimum growth in leaf length and root dry weight was obtained at pH 7.0 under the present experiment instead of pH 5.0 as reported under experiment 3.

It should have become apparent by now that the response of certain growth indices to the substrate factors investigated differs from that of others. It is recalled that the probable reason assigned to the non-significance of the interaction on plant size is the contrasting responses shown by plant number and mean dry weight per plant. However in spite of this difference, all indices seemed to have shown greater sensitivity to changes in mineral nutrient content than to pH of the culture solution. Such an observation would suggest that although the two factors exhibited significant combined effect on growth, at the levels of the factors involved, nutrient concentration appeared to contribute a greater portion of this influence.

The extent to which earlier experiments elucidate the growth of Pistia in the field has been indicated. The results of the experiment just described also shed light on the performance of the plant in nature but only as far as they confirm the results of previous experiments. Full utilization of the results of this experiment which has dealt mainly with interaction awaits the availability of the appropriate data from the field.

CHAPTER 3

SOME EFFECTS OF PISTIA ON ITS HABITAT

Soulthorpe (1967) suggests that aquatic plants influence their environment to a greater extent than do terrestial plants on account of the restricted volume of waterbodies. This influence is exerted through their photosynthetic and respiratory activities on the biotic and physico-chemical conditions of the environment. Their shading effect and decay, their provision of shelter, food and substratum for other forms of aquatic life are other ways in which hydrophytes are capable of influencing their environment. Straskraba's (1965) observations in the backwaters of the River Elbe indicate that the presence of sudd produced a strong thermal and chemical stratification and that fluctuations in pH and oxygen were determined by the photosynthetic and respiratory activities of the plants.

It is not clear from the data of Straskraba how far the effects of vegetation is determined by its cover. It is my opinion that the impact of hydrophytes on their environment would depend largely, among other factors, on how closely packed and extensive the vegetation is. This would be particularly true of floating forms such as Pistia. A thick and an extensive cover of this plant would cut off light and curtail or completely prevent re-aeration of the water by wind-generated turbulence. The former condition discourages the photosynthetic activity of algae and submerged hydrophytes and a state of critical oxygen deficit may result. Where the mat is small and the plants sparsely distributed, the water can be wind-mixed, light penetrates, the roots provide a substratum for epiphytic algae and the oxygen content of the water greatly enriched by the photosynthetic activity of these algae and submerged plants.

In this chapter, the effect of *Pistia* on the more critical environmental factors - temperature, dissolved oxygen and pH - of the Volta Lake in relation to the density and extent of the vegetation is reported. The study was made possible by the occurrence of sites with varying size and packing of vegetation on the Volta Lake. Advantage was also taken of culture experiments to study the effect of *Pistia* on the total mineral content, some important individual nutrient elements and on the pH of its substrate under laboratory conditions.

Field observations

Method: Two habitats: 1) areas of water covered by rafts of *Pistia* and 2) open water, were chosen on each of the sites for this study. These habitats were about 200 metres apart along the same bank except at Aneta-Vakpo where they were sited on opposite banks. To eliminate shore-open water variation in the factors studied, samples were collected from approximately the same distance from the shore in both habitats.

Samples were collected from three points, fairly widely distributed, at the surface below the rafts and in the open water. A Ruttner or similar sampler was used. At one of the points, a sample was collected at intervals from the surface to the bottom. Donor was sampled five times (depth probe was done only on the last three sampling occasions) and Aneta-Vakpo and Kponyo were sampled twice and once respectively.

Water temperature was measured with a sampler thermometer and pH was determined as before (see p. 16). The Winkler method was used in estimating dissolved oxygen. Data on the density of the vegetation (i.e. number of plants per m^2) were obtained from the investigation reported in chapter 1 (see p. 16). Although density is a quantitative measure of abundance of vegetation, it gives little guidance as to the cover of the water by plants. In fact high density may not necessarily mean a thickly matted vegetation but could result from sparsely distributed small rosettes. Consequently estimates of the extent of the vegetation, and the size of rosettes were also recorded. Information on rosette size was collected during the investigation reported in chapter 1 (see p. 16).

Results and Discussion

Variations at the surface in water temperature, expressed in °C, dissolved oxygen, expressed preferably in % saturation (see e.g. Mackereth, 1963), and pH between open water and areas covered by vegetation at Donor, Aneta-Vakpo and Kponyo are presented in tables 8, 9 and 10 respectively. Differences between the two habitats in terms of temperature, oxygen and pH along the depth-profile at Donor, Aneta-Vekpo and Kponyo are illustrated in figures 26, 27 and 28 respectively.

At Donor where the cover of vegetation was comparatively thin and less extensive differences in thermal condition of the water at the surface and along the depth profile between that part of the lake below the vegetation and that in the open water was non-significant on all occasions. There were however significant differences in dissolved oxygen ($t^* = 7.17, 4.43, 5.89$; $p < 0.01$) and pH ($t^* = 6.92, 3.47, 3.95$; $p < 0.01$) (Table 8, fig. 26).

On account of its thinness, its small size and indeed its instability, the vegetation at Donor did not seem to have influenced solar irradiation and overturns of the lake. The result was an isothermal condition in each habitat. That the lake at this site was mixed from top to bottom is also reflected in the depth profile variation in dissolved oxygen and pH (fig. 26).

The unhindered penetration of light probably encouraged in addition to a phytoplankton community, a rich growth of epiphytic algae on the extensive substratum provided by <u>Pistia</u>'s profusely branced root system. Photosynthesis by these additional communities may account for the higher oxygen content and perhaps for the higher pH below the vegetation. As more and more carbon dioxide is withdrawn

* t valves are given for the last three sampling days; 21, 28-8 and 9-9-68 in this order.

Table 8

Effect of *Pistia* vegetation on some physico-chemical conditions of the Volta Lake at Donor in Ajena Bay.

Date of sampling	30-7-68								Description of vegetation
Habitat	Below Pistia mat				Open water				
Replicates	1	2	3	Mean	1	2	3	Mean	Sparse, 198 plants/m^2 on average 30% of plants were of small size, 58% of medium size and 11% of large size*, about 200 x 10 m in dimension
Temperature °C	30.0	29.8	30.1	30.0±0.1	29.6	30.0	29.5	29.7±0.2	
Oxygen (% sat.)	119	112	116	116±2	99	99	97	99±0	
pH	7.50	7.50	7.40	7.50±0	6.90	6.80	6.95	6.90±0	
	8-8-68								
Temperature (°C)	29.8	29.8	30.0	29.9±0.1	30.1	29.7	29.8	29.9±0.1	
Oxygen (% sat.)	99	95	94	96±2	69	65	68	67±1	"
pH	7.60	7.80	7.30	7.60±0.2	7.10	6.90	7.05	7.00±0.1	
	21-8-68								
Temperature (°C)	29.0	29.1	29.0	29.0±0	29.0	29.0	29.0	29.0±0	
Oxygen (% sat.)	140	116	132	124±7	90	83	96	90±4	"
pH	8.6	7.9	8.2	8.2±0.2	7.5	7.6	7.8	7.6±0.1	

* Shoot length ranges for size classes 1 (small), 2 (medium) and 3 (large), as used in tables 21-23, are 2.0 - 6.0 cm., 6.5 - 10.5 cm. and 11.0 - 15.0 cm. respectively.

Table 8. (continued)

Date of sampling	28-8-68								Description of vegetation
Habitat	Below Pistia mat				Open water				
Replicates	1	2	3	Mean	1	2	3	Mean	
Temperature (°C)	30.0	30.0	30.0	30.0±0	30.0	30.0	30.0	30.0±0	"
Oxygen (% sat.)	124	132	126	127±2	109	110	120	113±4	
pH	8.6	8.9	8.5	8.7±0.1	8.0	8.1	8.3	8.1±0.1	
	9-9-68								
Temperature (°C)	29.0	29.0	29.0	29.0±0	29.0	29.0	29.0	29.0±0	"
Oxygen (% sat.)	117	119	105	114±4	91	94	98	94±2	
pH	7.8	7.8	7.5	7.7±0.1	7.1	7.2	7.2	7.2±0	

Table 9

Effect of Pistia vegetation on some physico-chemical conditions of the Volta Lake at Aneta-Vakpo on River Dayi.

Date of sampling	30-10-68								Description of vegetation
Habitat	Below Pistia mat				Open water				Dense, 400 plants/m^2 40% of plants were of small size, 54% of medium size and 6% of large size; vegetation was about 40 metres wide and extended beyond sight.
Replicates	1	2	3	Mean	1	2	3	Mean	
Temperature (°C)	30.8	30.4	30.5	30.6±0.1	31.3	31.4	31.2	31.3±0	
Oxygen (% sat.)	20	23	21	21±0	40	45	42	42±1	
pH	6.0	6.2	6.0	6.1±0.1	6.9	7.1	7.0	7.0±0	
	23-1-69								Dense, 362 plants/m^2; 91% of the plants were of small size and 90% of medium size; vegetation was about 30m. wide and extended beyond sight.
Temperature (°C)	30.0	29.8	29.9	29.9±0	30.5	30.4	30.3	30.4±0	
Oxygen (% sat.)	46	49	41	45±2	86	90	74	83±5	
pH	6.5	6.3	6.3	6.4±0.1	8.1	8.5	7.9	8.2±0.2	

Table 10

Effect of *Pistia* vegetation on some physico-chemical conditions of the Volta Lake at Kponyo on River Pawmpawm.

Date of sampling	15-11-68								Description of vegetation
Habitat	Below Pistia mat				Open water				
Replicates	1	2	3	Mean	1	2	3	Mean	
Temperature (^{o}C)	28.8	28.8	28.9	28.8±0	30.0	30.0	29.9	30.0±0	Dense, 488 plants /m^2; 94% of plants were of small size and 6% of medium size; vegetation was about 200m. wide and extended beyond sight.
Oxygen (% sat.)	36	32	34	34±1	63	68	61	64±2	
pH	6.95	6.90	6.80	6.90±0	7.35	7.50	7.30	7.40±0.1	

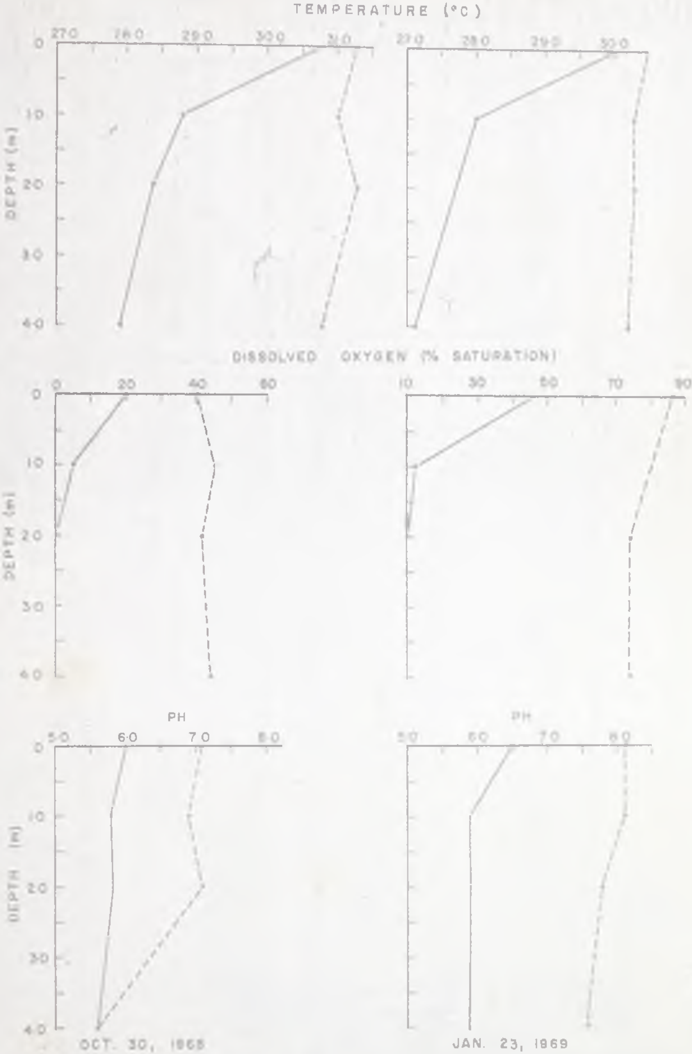


FIG. 27 DEPTH PROFILE VARIATION IN TEMPERATURE, DISSOLVED OXYGEN AND PH BELOW *PISTIA* MAT (—) AND IN OPEN WATER (---) AT ANETA – VAKPO ON R. DAYI

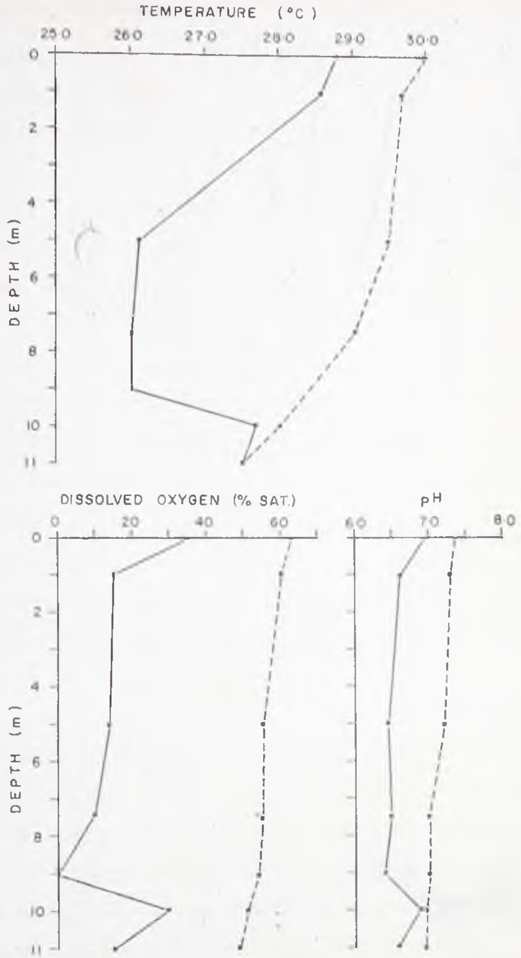


FIG. 28 DEPTH PROFILE VARIATION IN TEMPERATURE DISSOLVED OXYGEN AND pH BELOW PISTIA MAT (—) AND IN OPEN WATER (– –) AT KPONYO ON R. PAWMPAWM

from the water for photosynthesis, the water would become less and less acid if it is not well buffered.

The occurrence of floating vegetation at Aneta-Vakpo and Kponyo also influenced the environmental factors on account of the relatively dense, extensive and the resultant stable condition of the vegetation. While the thermal condition of the lake below the vegetation and in the open water were similar at Donor, temperature variation between the two habitats on the other two sites differed significantly at both the surface and along the depth profile (t values for depth profile comparison between the two habitats on 30-10-68 and 23-1-69 are respectively 3.24 and 3.32 at Aneta-Vakpo; t = 2.77 at Kponyo). The lake was on all occasions cooler below the cover of vegetation than in the open water (tables 9 and 10; figs. 27 and 28).

It is suggested that the lower temperature of the water below the mat is the direct result of shading and the restriction on mixing of the water by the floating vegetation. Absence of vegetation in the open water would, besides exposing the water to more intense and direct solar irradiation, promote wind-generated mixing of the lake. Heat from solar irradiation absorbed at the surface would be transferred to the bottom by currents so generated. That this must have happened is borne out by the isothermal condition of the open water in contrast to the strong thermal stratification below the vegetation.

Another contrasting feature is that while at Donor the lake below the vegetation was more oxygenated and perhaps therefore more alkaline than in the open water, (table 8; fig. 26) the lake below the vegetation was more poorly oxygenated and possibly therefore tended to be more acid than in the open water on the other two sites (t values for depth profile comparison in dissolved oxygen between the two habitats on 30-10-68 and 23-1-69 are respectively 3.67 and 6.33; t values in pH are respectively 3.54 and 9.00 at Aneta-Vakpo, $p < 0.05$; t values for dissolved oxygen and pH are respectively 2.17 and 4.98 at Kponyo, $p < 0.05$) (tables 9 and 10; figs. 27 and 28).

It is suggested that these effects are causally related to the cover and stability of the vegetation. The thickly matted vegetation on these sites probably reduced if it did not completely cut off the light reaching the water below it. The growth of submerged hydrophytes, epiphytic and planktonic algae would be reduced if not completely inhibited under this condition. As a result of the poor hydrophytic and algal growth, the respiratory activity of the roots, the decay of dead plants and the restriction of wind-generated mixing, the dissolved oxygen became markedly depleted and the water tended to be more and more acid.

A similar observation has been reported from Lake Victoria (East Africa) where a tangled mass of water-lilies hindered mixing and light penetration and thus produced a marked oxygen depletion at less than 2 m. depth (Carter, 1955). Several other instances of oxygen dissipation by aquatic plants have been reported from the Grand Chaco Swamps of South America (Carter and Beadle, 1931) and from the tropical rain forest of Guyana (Carter, 1934).

Variations in oxygen and pH along the depth profile in the open water were not as pronounced as under the vegetation. Dissolved oxygen became drastically reduced within the first metre of water at Aneta-Vakpo (fig.27) and between the first and fifth metre at Kponyo (fig.28). Stratification in terms of dissolved oxygen and pH coincided more or less with thermal stratification but pH stratification was not as marked as the thermo - and oxy-clines.

The sudden decline in dissolved oxygen and pH with increasing depth was most probably due to absence of mixing and to shading of the water. Large amounts of acids released during decay, and root respiration, must have tended to even up differences in pH along the depth profile under the cover of vegetation.

It is interesting to note that unlike at Aneta-Vakpo (fig.27) the drop in temperature, dissolved oxygen and pH with depth under the cover of vegetation at Kponyo stopped short of the bottom (fig.28). The contrast does not seem to be related to differences in the depth of the Lake on the two sites. In fact one would expect a further drop as depth increases. It is recalled that while samples were collected in a bay off the main channel of River Dayi at Aneta-Vakpo, samples from Kponyo were collected from over the old river channel. It is therefore suggested that increase in the factors after an initial decline is due to an under-current from the warm, well oxygenated River Pawmpawm. This would suggest that this area of the Lake was neither typically lacustrine nor riverine but represented a zone of transition.

This suggestion seemed to be reflected in the fish-fauna of the area - a mixture of current-loving forms e.g. the Mormyrids and stagnant water-loving forms e.g. the Cichlids.

It may be noted in passing that in addition to the variation between the two habitats on each site, there were also variations in the factors investigated, especially in dissolved oxygen, between sampling days at Donor (table 8; fig. 26) and Aneta-Wakpo (table 9; fig.27). The cause of these variations is not known with certainty but may be presumed to be changes in light intensity as these influence the balance between photosynthesis and respiration or, in general, changes in factors that add oxygen to or remove it from the lake water.

Laboratory observations

Method: While culture experiment 2 (see p. 59) was running, advantage was taken to study the extent to which *Pistia* influences the mineral composition and pH of its substrate. The concentration of nitrogen, phosphorus, potassium, calcium and sodium, and pH were estimated as before (see pp. 16 and 17) at the beginning of the experiment and just before the nutrient medium was renewed on the third day. Daily changes in pH and total mineral composition, measured as conductivity (see e.g. Welch, 1952), were also recorded. Culture medium without plants was used as the control.

Results and Discussion

Changes in pH and the concentration of individual elements are given as % of the original concentration in table 11 and the daily changes in total mineral content and pH are illustrated in figs. 29 and 30 respectively.

The concentrations of elements in, and the pH of, both the test and control media at the end of the experiment differed significantly (table 11). Unlike the control medium the concentrations of elements and pH at the start and end of the experiments were significantly different. These results suggest that two medium-sized rosettes growing for three days appreciably influenced the mineral composition and pH of their substrate. Potassium (95% change) was the most depleted followed by nitrogen (53%), then calcium (37%) and phosphorus (31%) and finally sodium (18%). These results strongly confirm earlier observations on the mineral composition of the plant which indicate the same order of nutrient element uptake (see pp. 22 - 24).

Daily changes in the total mineral content of the culture solution as the rosettes grew were expected (fig.29). The decline was slow at first probably as a result of the adjustment of the plants to a new substrate. It increased sharply probably after the adjustment but only to slow down presumably as a result of the scarcity of nutrients. It is interesting to note that the total mineral content of the control medium increased appreciably. As the culture solution was uncovered, dust blown into it and evaporation are likely to have cuased the observed increase.

Table 11

Changes in mineral composition and pH of 10% modified Long Ashton Solution caused by <u>Pistia</u> in 3 days.

	Initial concentration of elements (ppm)					% change in test solution					% change in control solution				
Replicates	1	2	3	4	Mean	1	2	3	4	Mean	1	2	3	4	Mean
Nitrogen	12.5	12.5	10.0	10.0	11.3	60	40	50	50	50±14	0	0	0	0	0
Phosphorus	4.8	4.8	4.8	5.0	4.8	33	29	29	36	32±2	0	4*	4*	4*	2* ± 1
Potassium	7.6	7.4	7.4	7.4	7.4	92	92	92	97	93±1	0	3*	0	3*	2* ± 1
Calcium	13.5	13.5	15.0	13.5	14.3 2.8	33	33	50	22	35±9	0	11*	0	0	3* ± 3
Sodium	2.8	2.8	2.9	2.8	2.8	21	21	21	18	20±1	0	4	0	4	2* ±
pH	5.5	5.6	5.6	5.6	5.6	6.8	6.6	6.7	6.8	6.7±0.1	5.6	5.6	5.8	5.6	5.7±0.1

* % changes are increases.

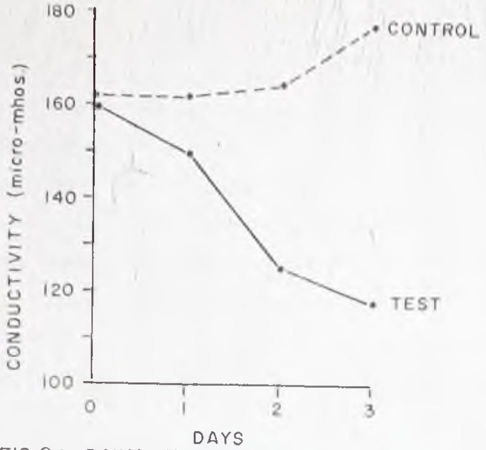


FIG. 29 DAILY CHANGES IN TOTAL MINERAL CONTENT (CONDUCTIVITY) OF 10% MODIFIED LONG ASHTON SOLUTION CAUSED BY PISTIA

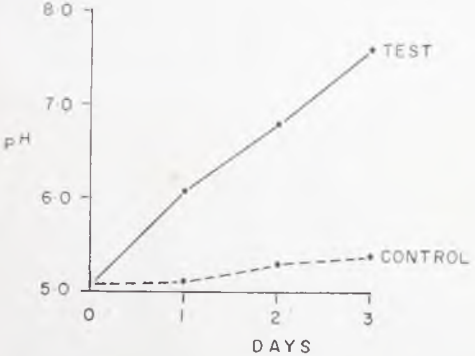


FIG. 30 DAILY CHANGES IN pH OF 10% MODIFIED LONG ASHTON SOLUTION CAUSED BY PISTIA

There were hardly any daily changes in pH in the control medium. In the test solution the pH increased steadily from acid to alkaline. One would have expected increasing acidity of the culture solution as the roots released carbon dioxide during respiration. Attempts to eliminate algae growing on the roots were visually fairly satisfactory. However it is likely that the barely visible growth on the roots was active enough to have changed the pH of the culture solution through its photosynthetic acitivity.

CHAPTER 4

SOME ASPECTS OF REGENERATION

The water level of the Volta Lake fluctuates seasonally (Volta River Authority, unpublished hydrographic curve). As the water recedes at the beginning of the dry season (December), not all the Pistia growing along the margins float away as quickly. Some become stranded on the shore into which they strike root. (see plates 4 and 5). Others are prevented, from rooting by a ground cover of twigs and other Pistia plants. In the rooted condition, vegetative reproduction appears to be strongly restricted; individual plants rather increase in size when conditions are favourable. Increase in size seems to favour flowering and setting of viable seeds which may be shed into the soil. However, when conditions are severe the leafy portion of rooted Pistia looks stunted and as wilted as that of non-rooted ones.

The level of the Volta Lake does not begin to rise until about two months after reaching its lowest limit in about May each year. Consequently, the chances of wilted plants recovering as a result of re-wetting by the rising Lake appears to be slim. However intermittent rains during the period of exposure might assist these plants in retaining viability of at least their hardier portion, the rhizome. Retention of viability in the rhizome coupled with a capacity for vegetative regeneration might enhance the chances of recolonization of open water surface when the Lake rises again. The annual oscillation of the Lake level varies yearly depending presumably on the amount of rainfall, discharge through the

Plate 4. A section of the drawdown area of the Volta Lake showing stranded *Pistia*, above pointer, more pale than still floating rosettes, below pointer, January 1969.

Plate 5. A pit dug in the soil in the drawdown area to show rooting of stranded rosettes, January 1969 (the roots coil into the form of a corkscrew as they penetrate the soil - not clearly shown in the picture).

spillways and water-loss through evaporation.

Vegetative reproduction is widespread among freshwater vascular plants and in some species, for example Salvinia auriculata (Williams, 1956), Azolla spp. (Wild, 1961), represents the only means of regeneration. Among reduced, free floating and submerged aquatics characterised by long delicate stems, any fragment of the plant's body with a bud is potentially capable of regenerating into a whole plant (Sculthorpe, 1967). Indeed in the family Podostomaceae fragments consists of only a meristem can also regenerate (Sculthorpe, loc. cit.).

Fragmentation of the body may result from violent disturbance of the medium either by strong winds or currents, from mechanical damage by foraging animals or from senescence (Sculthorpe, loc. cit.). Ease of fragmentation coupled with a remarkable ability to regenerate is perhaps one of the major factors promoting the nuisance value of aquatic plants.

Pistia has been reported to be capable of regenerating from small fragments of the rhizome bearing root and at least a bud (Laing, 1968). However the extent to which this observation applies to stranded Pistia in the drawdown area of the Volta Lake does not seem to have been previously investigated. Indeed the extent to which regeneration of stranded plants and their seeds may contribute to the re-infestation of the Volta Lake is largely unknown. Because of the potential importance of re-infestation by stranded plants in the development of control measures, it appeared profitable to investigate the following aspects of regeneration of <u>Pistia</u>:

1) regeneration of rooted and non-rooted plants in order to assess the importance of rooting,
2) regeneration of rooted plants at varying distances from the waterline in an attempt to evaluate the effect of duration of exposure on retention of viability,
3) the effect of plant size on resistance to desiccation and as this relates to the ability to regenerate,
4) ease of re-floating of rooted plants as an important consideration for the ultimate recolonisation of open water.

As mentioned earlier, stranded plants under favourable condition frequently set viable seeds which may later be shed into the soil. Germination of such seeds may provide the plants for subsequent recolonisation of the open water surface. In a preliminary observation in May 1969, soil blocks (approximately 3 cm.^{2} x 10 cm.) taken from the bank of Tokosi Swamp yielded on the average 10 seedlings per block. Similar observations were therefore undertaken on the three study sites in an attempt to assess the potential importance of buried seeds in the re-infestation of the Volta Lake by stranded plants. Although a large sample of larger soil blocks (approximately 15 cm.^{2} x 4 cm.) was taken from over a wide part of the drawdown area on each site, the soil blocks yielded no seedlings. This may have resulted from two possibilities. Either that the soil did not contain viable seeds or that the seeds it contained were still dormant even after four weeks' exposure to apparently favourable conditions. Verification of this would have entailed washing of soil and actual identification of seeds which was however not done. The former reason however appears more probable. In contrast with Pistia rooted on the margins of Tokosi Swamp, those rooted in the Volta Lake's drawdown area looked small and stunted. Samples from the three sites showed that the rosettes bore neither flowers nor fruits.

Regeneration of rooted and non-rooted plants

Material and method

Two parallel 10 metre long transects, 1 and 2 metres from the waterline were marked out in areas where appreciable quantities of stranded and apparently moribund Pistia occurred on each of the three study sites. A sample of 30 rooted plants was collected from as close as possible to each transect. Care was taken to ensure that as many roots as possible remained intact. In order to ascertain the effect of duration of exposure in the field on regeneration of rooted plants, samples were collected at known distances from the waterline. Duration of exposure was estimated from the rate of change in water level and the distance of strips from the waterline.

As it was not possible to obtain an adequate sample of non-rooted plants from each transect, samples from the two transects were bulked to obtain 30 non-rooted plants from each site.

The leaves on each plant were all removed leaving only the apical leaf bud. The roots were trimmed to standard length and the plants were rinsed in distilled water before culturing in 10% modified Long Ashton Solution in the greenhouse. There were 10 plants to 2l. of solution. The solution was renewed after 3 days. Expansion of the intact apical bud was accepted as evidence of regeneration. Percentage regeneration was scored after 6 days. The result of preliminary trials had shown that this length of time was sufficient for the production of at least one fully expanded leaf.

Results and Discussion

The % regeneration of rooted and non-rooted plants is given in table 12. Regeneration of rooted plants was significantly higher than that of non-rooted plants. This suggests that rooted plants are more capable of retaining their ability to regenerate probably because non-rooted plants wilt and die having lost contact with water. Although the leafy portion of rooted Pistia was as severely wilted as that of non-rooted plants, the rhizome with roots still in contact with water remained fresh.

Regeneration of rooted plants from the upper strip was of the same order of magnitude as that of plants from the lower strip even though the upper strip had been exposed for a much longer period - approximately 150 days as against 90 for the lower strip. Duration of

Table 12

% regeneration of rooted and non-rooted stranded <u>Pistia</u> on sites in the drawdown area of the Volta Lake

	Rooted plants									Non-rooted plants			
	Lower strip*				Upper strip*				Mean				Mean
Replicates	1	2	3	Mean	1	2	3	Mean		1	2	3	
Donor	100	100	90	97	90	80	90	87	92	10	10	0	7
Aneta-Vakpo	70	80	80	77	60	90	70	73	75	0	20	0	7
Kponyo	100	100	90	97	100	100	100	100	98	20	10	0	10

*Lower and Upper Strips were 1 and 2 metres from water line respectively.

exposure in the field did not appear to influence regeneration. The roots of rhizomes from the upper strip were probably still in contact with soil sufficiently moist as not to influence regeneration capacity. The ground cover of vegetation, among other factors, may have protected the soil against excessive desiccation.

Effect of duration of exposure and plant size on resistance to desiccation and regeneration

The observations on rooted and non-rooted plants suggested that the degree of desiccation may be an important factor in the regeneration of stranded plants. Moreover a preliminary test indicated that regeneration after exposure occurred more readily in large than in small plants. A simple experiment was therefore designed to investigate the effects of duration of exposure and plant size on the ability to regenerate under laboratory conditions.

Material and method

A sample of plants collected from Tokosi Swamp in August, 1969, was divided into lots of 27 plants each and randomly assigned to 4 desiccation treatments - desiccation for 6, 12, 24 or 48 hours. Each lot consisted of 9 plants from each of size classes I, II and III; method of classification was as described in chapter 1 (see p. 16). The plants were mopped dry with filter paper, each plant labelled and its fresh weight recorded. The plants were then spread out on a table in an air-conditioned room where the air temperature was about 23°C and the relative humidity fluctuated daily between 68 and 80%. This diurnal variation in humidity was assumed to be narrow enough as not to have influenced water-loss by plants due to the time of day they were exposed.

At the end of the exposure period, each plant was re-weighed and its % loss in weight which is here considered as a measure of resistance to disiccation was calculated. All the leaves were removed except the apical leaf bud. The roots were trimmed to a standard length and the plants cultured in 10% modified Long Ashton Solution in the greenhouse. The exposure of plants was so timed that all the treatment groups were ready for culturing at the same time. There were 3 replicates for each size class within each treatment group. Percentage regeneration was scored, as before, after 6 days.

Results and Discussion

The % loss in weight and % regeneration in relation to duration of exposure and plant size are illustrated in figs. 31 - 33.

On the assumption that % loss in weight was due mainly to water loss, other losses e.g. respiratory, being negligible, the degree of desiccation is influenced by the duration of exposure (fig.31). The longer the period is the higher the degree of desiccation. Plant size also influenced the extent of desiccation (fig.32). This observation

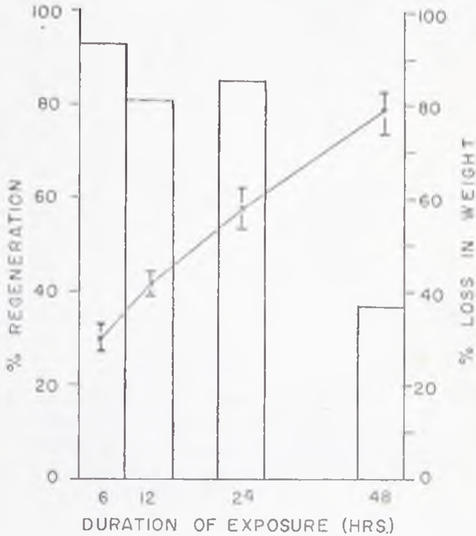


FIG. 31 EFFECT OF DURATION OF EXPOSURE ON % LOSS IN WEIGHT (GRAPH) AND REGENERATION (HISTOGRAM) OF <u>PISTIA</u>. (VERTICAL LINES INDICATE 2X SANDARD ERROR)

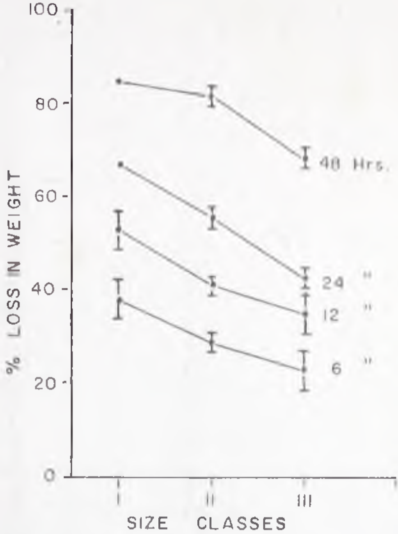


FIG.32 EFFECT OF PLANT SIZE ON REGENERATION OF PISTIA UNDER VARIOUS DURATION OF EXPOSURE (VERTICAL LINES INDICATE 2X STANDARD ERROR)

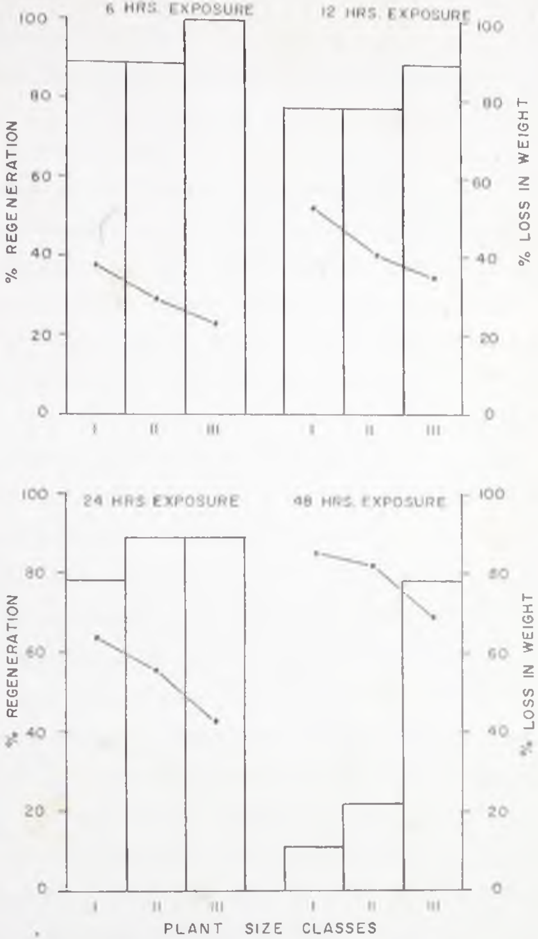


FIG.33 EFFECT OF PLANT SIZE ON % LOSS IN WEIGHT (GRAPHS) AND REGENERATION (HISTOGRAMS) OF PISTIA

suggests that large plants are more resistant to desiccation. It is pertinent here to note that in absolute terms large plants lost more weight than small ones.

The difference in % regeneration between plants exposed for 6, 12 and 24 hours on one hand and those exposed for 48 hours on the other appears significant, although this was not tested statistically. (fig.31). Even though differences within the first group are not significant (11% regeneration is equivalent to 1 out of 9 plants used regenerating), a trend which might have been significant with a larger sample size is indicated. It appears that the longer the period of exposure is the poorer the ability to regenerate. The degree of desiccation which has been shown to be time dependent appears to determine the capacity for recovery.

The different sizes when exposed for 6, 12 and 24 hours do not seem to differ significantly in the ability to regenerate although differences in extent of desiccation are significant (fig.33). Significant differences between sizes when plants are exposed for 48 hours are indicated and a trend in the effect of plant size on regeneration is also apparent. Large plants have greater power of regenerating than small plants. This power of regeneration seems causally related to the ability to resist desiccation. Absence of any causal relationship between resistance and regeneration when plants are exposed for 6, 12 and 24 hours would suggest a threshold value for degree of desiccation at and beyond which regeneration becomes influenced by the extent of desiccation.

Recolonisation of the Volta Lake by Stranded *Pistia*

It is apparent from the above results that stranded and apparently moribund *Pistia* are capable of regenerating. The ability to recover from desiccation is important but, especially for rooted plants, may not alone determine the ability to recolonise the lake surface. A simple laboratory experiment was therefore set up to investigate the ease of refloating by rooted plants.

Method

Some *Pistia* plants were placed in a glass jar containing soil, about 30 cm. deep, covered with water. The water was allowed to dry. As it dried, the plants which had been floating became rooted in the soil. Resistance to lifting was accepted as proof of rooting. The plants were then submerged in about 30 cm. deep of water, care being taken not to disturb the soil.

Result and Discussion

In about 6 hours, the plants surfaced having pulled themselves out of the soil with the force of bouyancy exerted by their leaves.

This observation demonstrates to a limited extent the ease of refloating in the field. The ability to recolonize the water surface in nature would be determined by wave action on the shore and the extent to which a plant has become established in the soil. Root development, duration of rooting and type of soil are perhaps only some of the factors that would determine the extent of establishment.

GENERAL DISCUSSION

The investigations reported in this thesis have sought to provide as widely as possible, information on the relationships between Pistia and its environment. Consequently a wide and varied approach has been used to examine the various facets of the problem. In spite of the varied nature of the approach, investigations on the different aspects have been executed in a step-wise fashion: an initial field survey followed by experimentation under controlled conditions. More often than not, only limited inferences can at best be drawn from field observations in view of the many methodological problems posed by field survey and the complexity of field situations. A better understanding of the complex plant-substrate relationships may therefore be provided by controlled experiments especially in instances where these have sufficiently reconstructed the field situation.

In carrying out these investigations on a plant that has virtually not been worked on, a considerable amount of pilot experiments became necessary. These exploratory investigations have provided useful hints on how best the plant could be handled. Some important basic information, for example the suitability of the combined parameter of leaf number X leaf length as a measure of plant size or organic matter have through these been made available. Results of the pilot experiments have also provided some reference point necessary for evaluating more fully the results of full scale experiments. It may be relevant in this connection to draw attention to the fact that paucity of information on Pistia has disallowed extensive discussion of the results which have suggested mutual influence between the plant and its habitat.

Although Pistia is widely represented along the vast stretch of the Volta Lake, extensive islands of its floating vegetation are seen only in the southerly parts. The pattern of spatial distribution of the vegetation in these parts of the Lake seems to be determined to some extent by the pH and mineral content of lake water. In general, areas with comparatively high dissolved mineral nitrogen, low total ionic content and pH tend to support vegetation of comparatively high biomass derived from increased vegetative growth of the individual rosettes. Spatial variation in the abundance of the plant does not seem to depend on any of these site factors (figs. 2 and 4).

The influence of these site factors on the temporal distribution of Pistia seems to vary from locality to locality due probably to site peculiarities. It is quite clear from figure 3 that the seasonal performance of the plant on the Dayi estuary seems to depend on the supply of nitrogen, phosphorus, potassium and sodium. Seasons characterized by low pH values of lake water are also those times of the year when the vegetation in this part of the Lake shows increased density. Variation in pH does not seem to influence vegetative growth just as changes in total mineral content of lake water appears not to limit vegetative reproduction and growth of the plant (fig.6). The growth of rosettes on the Pawmpawm arm of the Lake appears to depend on the availability of potassium, calcium and sodium (fig.3). Fluctuations in site factors seem to limit only the vegetative reproduction of the plant. Thus the vegetation is denser during the flood season when the supply of nutrients becomes richer and pH lower as illustrated in figure 7. Although attention has been focussed on the mineral nutrient supply and pH of lake water as factors determining the performance of Pistia on the Volta Lake, the possibility of other factors exerting significant effects has also been borne in mind. Indeed the inconsistent relationship or absence of correlation between the performance of Pistia and the site factors measured which have been observed at times and in certain localities may be indicative of the overriding effects of other site factors. It is recalled that the decline of the vegetation in Ajena Bay at the beginning of the rainy season (fig.5) has been suggested to have resulted possibly from lack of anchorage for the vegetation (see p. 42). This suggestion becomes more tenable against the background of the lakewide distribution of the plant. The apparent restriction of dense and extensive vegetation of the plant to the southerly reaches of the Lake, may be related more to the better shelteredness of the these reaches. Of relevance in this regard may be noted the fact that unlike the generally flat terrain in most parts of the Lake where Pistia is poorly represented, the basin of the Volta Lake in the south is flanked on either side by a range of mountains and that areas swamped by the rising waters of the Lake had been thick forests whose mostly dead but still standing vegetation provides anchorage (plates 1-3).

It has been inferred from the field observations that pH and nutrient supply may be important in determining the distribution and growth of Pistia on the Volta Lake. To obtain information on the physiological response of the plant which would elucidate its performance in the field, the effects of these factors on growth of the plant have been investigated experimentally. The results of these controlled experiments indicate that vegetative reproduction and growth are influenced markedly by these factors. Increasing concentration of nutrients in the substrate promotes the production of daughter rosettes and new leaves but discourages vegetative growth in general (figs. 9 - 11). Pistia is also sensitive to the pH of its substrate as shown in figures 13 and 14.

The optimum pH for both vegetative reproduction and growth according to the levels used is 5.0. Instant death occurs at pH 3.0. These results agree to a large extent with results of previous experiments summarized on pages 46-48 and are confirmed largely by the experiment (Experiment 4, p.75) on the combined effect of substrate pH and nutrient supply. Other factors whose influences have been studied under controlled conditions are varying degrees of aeration of culture solution, light intensity and daylength. For various reasons, results of these experiments have been considered inconclusive.

An interesting phenomenon that has emerged from the response of Pistia to its environment is the way it attains maximum yields in dry plant material. Optimum production can be achieved through increase in the production of new rosettes (Chadwick and Obeid, 1966), increase in the average size of plants (figs. 10 and 11) or both (figs. 13 and 14). Under conditions of over-crowding, production of new plant material would tend to result from average increase in the vegetative growth of rosettes. In the absence of overcrowding, attainment of high dry matter would tend to derive either from increased vegetative reproduction, or average vegetative growth or both.

Experimental evidence shows that the growth of Pistia produces marked changes in the pH and nutrient composition of its substrate which tends to be more alkaline and depleted of its nutrients. Although the upper limit of pH tolerated by Pistia is still unknown, it would appear that increasing the pH of its substrate by its growth is of greater advantage for its survival than decreasing it, since death occurs under very acid conditions. Potassium is the most depleted nutrient followed by nitrogen, calcium, phosphorus and finally sodium (table 11). This trend is reflected in the mineral composition of the shoot portion of the plant (tables 1-3).

The above data emphasize, on one hand, the potential usefulness of floating mats of Pistia on the Volta Lake. Important nutrients are prevented from being washed out to sea through absorption and subsequent storage within the plant. From here, they could be recovered by extraction or returned to the lake water when the plant dies and decays. In the latter sense, Pistia can be said to play an important role in nutrient regeneration which, according to Talling (1965), is the critical factor determining primary productivity on tropical lakes. On the other hand, uptake of nutrients by Pistia may constitute a serious competition to a generally more desirable plant community, the phytoplankton. In addition to enriching the oxygen content of lake water through photosynthesis, phytoplankton serves as food for herbivorous fish. The status of phytoplankton as fish food on the Volta Lake is however not known with certainty. The writer is unaware of any records of such utilization of Pistia either on Lake Volta or on waterbodies in other parts of the world. Pistia, besides directly consuming the oxygen content of lake water through the respiratory activity of its roots and through decay, does not appear to contribute directly to dissolved oxygen on account of its floating habit. Oxygen evolved during its photosynthesis is lost to the atmosphere. Indirect contribution to dissolved oxygen, like the other influences that Pistia exerts on its habitat, is dependent on the density and extent of its vegetation. A dense and extensive cover insulates the water below it from solar effects and may thus limit productivity of other aquatic plants (tables 9 and 10; figs. 27 and 28). The situation is reversed when the vegetation is sparse (table 8, fig. 26).

Investigations on the performance of Pistia in relation to some site factors, reported in chapter 1, have indicated that the plant is generally least luxuriant during the dry season (figs. 6 and 7). Large quantities of rosettes become stranded on the shore during this season. Studies on the regenerative behaviour of these apparently moribund rosettes have shown that not all of them wilt and die. Those that take root in the soil may survive (table 12). The size of rosettes is a critical factor determing survival. The larger the rosette, the more capable it is of resisting desiccation and therefore the more capable it is of surviving (fig. 33). Thus factors (low nutrient concentration and not so acid substrate) which promote increase in size, confer on the plant the ability to survive in the event of exposure to desiccation. Duration of exposure of rosettes to desiccation also determines the ability to survive through its effect on drought resistance as illustrated in figure 31. In the field, this factor has not proved decisive (table 12). Although the leafy portion of plants exposed to varying periods of desiccation looked differently moribund, the rhizomes appeared to be equally fresh. Evidence available so far does not show conclusively whether or not stranded plants in the Volta basin like those in the drawdown area of Tokosi Swamp produce seeds which may germinate and re-infest the lake. One fact is however clear: rooted stranded plants are capable of regenerating vegetatively and, depending on a variety of factors, may recolonize the Lake surface.

According to the results presented in chapters 1 and 3, the occurrence of Pistia on the Volta Lake is both desirable and undesirable. This observation emphasizes, in general, the need for scientific research to always precede attempts to disturb natural situations and, in particular, to control Pistia. Recommendations for controlling the plant include the primitive method of removal by hand as was and perhaps is still practised on the Nile and Niger deltas (Wild, 1961). A fairly wide range of herbicides is also in use (see e.g. Little, 1968b). In India (Ranachandran and Ramaprabhu, 1966) and Pakistan (Chokder and Begum, 1965) 2, 4-dichlorophenoxyacetic acid (2, 4-D) is known to be effective but in the U.S. diquat is the favourite (Harrison et al., 1966). Whatever the method or herbicide used, the timing of treatment is an important consideration as it may considerably reduce control costs. Like all hydrophytic vegetation, that formed by Pistia requires water for its continued existence. In view of this, the drying up of temporary waterbodies - swamps, lagoons and feeder streams - in the Volta basin and the reduction in area of the permanent ones including the Volta Lake is by itself a potent factor in controlling this weed (Lawson, 1963). In the Volta Basin the period of minimal area of water surface coincides with the season during which the vegetation declines. It is therefore to be highly recommended that programmes of controlling the plant should be undertaken during the dry season when natural destruction of the weed is also underway. Investigations on regeneration of Pistia plants stranded in the drawdown area of the Lake have revealed that the rooted ones constitute a potential source of re-infestation and should therefore not be spared during treatment.

In emphasizing the nuisance nature of Pistia as an aquatic weed, Little (1966b) notes that the plant appears to be pest-free. Observations made in Western Nigeria (Pettet and Pettet, 1970) and on a stock of the plant maintained on a pond in the Botany Department at Legon, produced evidence to the contrary. Of the several organisms known to be associated with Pistia, two appear to be potential pests. These are the moth, Tortrix sp., and the snail, Physa sp.. Tortrix sp. appears to spend the initial stages of its life cycle on the plant, beginning as oval and cream-coloured eggs. Just before hatching, the eggs seem to dissolve into the leaf tissues inside which the larvae are hatched. For about 4 to 7 days, the larvae remain within the leaf tissues on which they feed. Later the larvae emerge as dark-brown headed creamish caterpillars which continue to feed on the leaf but only during the night. During the day, the caterpillars are confined to their nests built of pieces of leaf (plate 6).

Similar observations have been made by Laing et al. (1965) who put the estimate of damage so caused at 4.5 sq. cm. of leaf area per caterpillar per day. On the macro-scale about 2 m^2 of closely packed rosettes (plate 7) were destroyed (plate 8) by an undermined population

Plate 6. A close up of 3 Pistia leaves destroyed by Tortrix sp. and Physa sp.; a nest of the moth (Tortrix) with the head of a caterpillar protruding on the right is shown near the broad distal margin of the middle leaf.

Plate 7

Pistia rosettes growing luxuriantly - before destruction by *Tortrix sp.* and *Physa sp.* on a pond at Legon.

Plate 8

Pistia rosettes showing extent of destruction by Tortrix sp. and Physa sp.

of Tortrix sp. and Physa sp. within about 14 days. The destruction was however not complete. It was limited to the softer portions, the leaves, leaving the rhizomes with roots and buds untouched. The rhizome-root-bud unit has been shown in chapter 4 to be capable of regenerating. In about 21 days after all the larvae and caterpillars appeared to have metamorphosed into Pistia - indifferent adults, the majority of the partially mutilated rosettes recovered as shown in plate 9. It would appear then that either the snails (plate 10) alone were incapable of keeping the rosettes in check or that the presence of bits of leaf in their mouth was coincidental.

Inadequacy of time has made it impossible to examine fully the different aspects of the relationships between Pistia and its environment. A number of questions still remain unanswered and call for further investigation. It would appear desirable to investigate, over a much longer period, the performance of the plant in relation to site factors on the Volta Lake. Before then, it may be necessary to develop an easily applicable random method of sampling to replace the systematic sampling method used. This might produce more conclusive results. The inferences on the effects of aeration (agitation), light intensity and photoperiod on growth and reproduction in Pistia need to be re-examined in more carefully designed experiments. It may also prove intellectually stimulating to investigate the phenomenon of intra-specific competition in Pistia.

Plate 9

Pistia. rosettes have begun to recover from the destruction.

Plate 10. A close up of a destroyed leaf of Pistia showing the snails (Physa sp.) near the broad distal margin on the abaxial surface.

Our knowledge of the effects of Pistia on its habitat is by no means complete. It is not known, for instance, whether the unhindered penetration of light into the water below thin vegetation does in fact promote growth of epiphytic algae on the roots of Pistia or whether the improved oxygen condition results purely from re-aeration. Quantitative comparison of light intensity under dense and sparse vegetation is needed to test the observational evidence that a dense mat of Pistia reduces light intensity to photosynthetically ineffective levels even near the surface of the Lake.

The evidence presented in chapter 4 on regeneration of rosettes stranded in the drawdown area of the Volta Lake only indicates that these rosettes are capable of regenerating and of recolonizing the water surface. Observations are yet to be made in the field to test these laboratory findings. It should also be intresting to find out how far type of soil, duration of stranding and root development affect the establishment of rosettes in the soil and to what extent this factor and wave action on the shore determine ease of refloating. As a further contribution to information on the importance of regeneration in the re-infestation of the Lake, soil blocks collected from areas where stranded rosettes occur should be examined for seeds and the germination behaviour of these studied.

It is too early to make recommendations on the use of Tortrix sp. and Physa sp. as biological means of controlling Pistia. Hardly anything is known about their feeding habits. Indeed the observation that Physa sp. feeds on Pistia is yet to be proved. Unleashing a large number of these organisms to control the plant may mean controlling other plants, perhaps crops. Even if it were possible to do this, one consideration which militates against their use is the incompleteness of the destruction they cause. In fact such an interference with natural situations should, as has been emphasized earlier, be preceded by adequate research.

SUMMARY

1) The relations between _Pistia stratiotes_, L. and its environment have been investigated, with special attention to the occurrence of the plant on the Volta Lake.

2) _Pistia_ is widely distributed on the Volta Lake but occurs in large quantitites only in the southerly reaches.

3) The distribution and growth of the plant in these areas are determined to some extent by the mineral content and pH of lake water. Generally, areas with comparatively high mineral nitrogen but low total mineral content and low pH are characterized by the occurrence of relatively large rosettes. The abundance of rosettes does not appear to be influenced by such site factors. Variation in biomass is more often correlated with changes in size than in abundance of rosettes.

4) The size of rosettes, and the density and biomass of the vegetation vary seasonally on the sites examined. These seasonal variations are correlated in some cases with similar variations in the pH and mineral nutrient composition of lake water.

5) Laboratory experiments show that pH and nutrient content of culture solution, singly and collectively, influence greatly growth of the plant.

6) Among pH levels of 3.0, 5.0, 7.0 and 9.0, the optimum for both vegetative reproduction and growth is 5.0. Beyond this level, both vegetative reproduction and growth decline generally. Instant death occurs at pH 3.0.

7) Increasing nutrient concentration of culture solution favours production of daughter rosettes and new leaves but impairs vegetative growth.

8) Response of the plant to substrate pH and nutrient supply elucidates to some extent growth of the plant in relation to these factors on the Volta Lake.

9) Field and laboratory observations show that growth of Pistia alters markedly the physico-chemical condition of its substrate.

10) The nature of the influence in the field depends on the cover of the vegetation. A large and dense mat insulates the water below it against solar radiation and causes stratification and poor oxygenation; the effects of a thin vegetation are the opposite of these.

11) Studies on regeneration and ease of refloating of Pistia plants stranded in the drawdown area of the Volta Lake show that these processes are important in recolonization of the Lake by such rosettes.

12) Stranded rosettes are capable of retaining viability of their rhizome only when they become rooted in moist soil.

13) Retention of viability is important for regeneration.

14) Plant size and period of exposure determine the ability to retain viability and hence the ability to regenerate.

15) Regenerated rosettes are potentially capable of recolonizing open water surface.

16) Depending on the size and packing of its vegetation, the occurrence of <u>Pistia</u> on waterbodies is either desirable or undesirable. The need for adequate research to precede attempts to interfere with natural situation is thus stressed.

17) Since the vegetation declines during the dry season, it is advisable to control the plant during this period. Control costs may be reduced by exploiting the accumulated mineral nutrients within the plant for agricultural purposes.

18) Destruction of the plant by the larvae and caterpillars of <u>Tortrix sp.</u>. and by <u>Physa sp.</u> is extensive though incomplete. Further investigation is required to assess the importance of these organisms in the biological control of the plant.

Appendix 1

Summary of analysis of variance tables (Donor, Aneta-Vakpo) and Student's "t"-test (Kponyo) for mineral composition of plant in relation to plant size

Elements	Donor in Ajena Bay	Aneta-Vakpo on R. Dayi	Kponyo on R. Pawmpawm
N	**	N.S.	N.S.
P	*	*	*
K	**	N.S.	N.S.
Ca	N.S.	N.S.	**
Na	N.S.	*	**

Appendix 2. Seasonal variation in mineral composition of Pistia and in biomass in relation to mineral composition of the Volta Lake at Donor in Ajena Bay. (values given are means with their standard errors)

Elements		End of rainy season Oct. 24-Nov.15,1968	Mid dry season (Harmattan) Jan. 23-Feb. 12, 1969	Beginning of rainy season Apr. 23-May 14,1969
N	Plant	3.25±0.29	0.73±0.1	-
	Water	0.040±0.003	0.038±0.003	0.017±0.002
P	Plant	0.44±0.01	0.25±0	-*
	Water	0.008±0	0.026±0.006	0.010±0.003
K	Plant	12.33±0.33	9.00±0.17	-*
	Water	3.1±0.2	4.0±0.2	3.0±0.1
Ca	Plant	7.17±0.05	3.45±0.02	-*
	Water	8.0±0.2	8.0±0.3	4.5±0
Na	Plant	1.22±0.02	0.62±0.01	-*
	Water	9.4±0.3	3.5±0.3	3.6±0
Biomass (gm./m^2)		190.3±17.6	296.9±4.7	0

*Plants too few for any meaningful analysis.

Appendix 3. Seasonal variation in mineral composition of Pistia and in biomass in relation to mineral composition of the Volta Lake at Aneta-Vakpo on River Dayi. (values given are means with their standard errors)

Elements		End of rainy season Oct. 24-Nov. 15, 1968	Mid dry season (Harmattan) Jan. 23-Feb. 12, 1969	Beginning of rainy season Apr. 23-May 14, 1969
N	Plant	4.42±0.25	2.40±0.42	3.00±0.15
	Water	0.060±0.006	0.042±0.004	0.046±0.008
P	Plant	0.33±0.02	0.29±0.02	0.31±0
	Water	0.012±0.004	0.018±0.007	0.026±0.003
K	Plant	7.17±0.01	4.47±0.1	4.80±0.13
	Water	1.9±0.1	2.6±0.1	2.3±0.1
Ca	Plant	5.27±0.01	3.30±0.1	2.85±0.07
	Water	2.0±0.2	3.0±0.1	5.0±0.5
Na	Plant	0.69±0.01	0.54±0.01	0.62±0.01
	Water	9.3±0.8	9.9±0.3	3.0±0
Biomass (gm./m2)		525.5±6.2	336.0±3.0	560.3±24.2

Appendix 4. Seasonal variation in mineral composition of Pistia and in biomass in relation to mineral composition of the Volta Lake at Kponyo on River Pawmpawm.
(values given are means with their standard errors)

Elements		End of rainy season Oct. 24-Nov. 15, 1968	Mid dry season (Harmattan) Jan. 23-Feb. 12, 1969	Beginning of rainy season Apr. 23-May 14 1969
N	Plant	2.58±0.29	2.23±0.08	1.30±0.05
	Water	0.059±0.006	0.026±0.001	0.021±0.002
P	Plant	0.50±0.02	0.29±0.04	0.47±0.01
	Water	0.085±0.026	0.007±0.002	0.010±0.001
K	Plant	7.50±0.12	8.00±0.27	6.60±0.11
	Water	7.7±0.5	3.5±0.1	3.0±0.1
Ca	Plant	3.23±0.16	2.00±0.25	3.80±0.24
	Water	3.1±0.4	7.7±0.1	5.6±0.2
Na	Plant	0.85±0.04	0.61±0.02	0.68±0.02
	Water	12.4±1.2	4.1±0.	4.0±0.
Biomass (gm/m^2)		403.8±3.9	213.8±8.7	300.5±14.3

Appendix 5

Summary of analysis of variance tables for between-sites ~~season~~al variation in water chemistry and biomass of vegetation

Elements	Season I	Season II	Season III
N	**	**	**
P	**	**	**
K	**	**	**
Ca	**	**	**
Na	*	**	**
Biomass	**	**	**

Appendix 6

Summary of analysis of variance table for seasonal variation in water chemistry and biomass of vegetation on individual sites

Elements	Donor in Ajena Bay	Aneta-Vakpo on R. Dayi	Kponyo on R. Pawmpawm
N	**	**	**
P	**	**	**
K	**	**	**
Ca	**	**	**
Na	**	**	**
Biomass	**	**	**

Appendix 7

Summary of analysis of variance tables for between-sites variation in mineral composition of plant

Elements	
N	N.S.
P	N.S.
K	*
Ca	N.S.
Na	N.S.

Appendix 8

Summary of analysis of variance tables for seasonal variation in mineral composition of plant on the three sites

Elements	
N	N.S.
P	N.S.
K	N.S.
Ca	N.S.
Na	N.S.

Appendix 9. Effect of site-season interaction on site factors and vegetation characters.

Site factor: pH

		Site		
		Donor	Aneta-Vakpo	Kponyo
Season	I	8.7±0	6.0±0.1	6.7±0
	II	6.8±0	6.2±0	6.8±0
	III	5.7±0	7.5±0	7.4±0

Site factor: Total mineral content (ppm) of lake water.

		Donor	Aneta-Vakpo	Kponyo
Season	I	20.6±0.4	13.3±1.0	23.3±3.1
	II	15.6±0.5	15.5±0.3	15.1±0.1
	III	11.1±0	10.4±0.3	13.4±0.2

Vegetation character: Density (no. of plants/m^2).

		Donor	Aneta-Vakpo	Kponyo
Season	I	177±26	408±40	619±56
	II	340±4	362±7	488±5
	III	0	306±12	442±75

Vegetation character: Biomass (wt.(gm.) of plants/m^2).

		Donor	Aneta-Vakpo	Kponyo
Season	I	190.3±17.6	525.5±6.2	403.8±3.9
	II	296.9±4.7	336.0±3.0	313.8±8.7
	III	0	560.3±2.4	300.5±14.3

Vegetation character: Weight (gm.)/plant.

		Donor	Aneta-Vakpo	Kponyo
Season	I	1.2±0.1	1.3±0.1	0.7±0
	II	0.9±0.1	0.9±0.1	0.5±0
	III	0	1.9±0.1	0.7±0

Appendix 10

Summary of analysis of variance tables for between-sites, variation in density, biomass, weight/plant, pH and total mineral content of lake water.

	End of Rainy Season	Mid dry Season (Harmattan)	Beginning of Rainy Season
Density	**	**	**
Biomass	**	**	**
Weight/plant	**	**	**
pH	**	*	**
Total mineral content	**	N.S.	**

Appendix 11

Summary of analysis of variance tables for seasonal variation in density, biomass, mean weight/plant, pH and total mineral content of water on individual sites

	Donor in Ajena Bay	Aneta-Vakpo on R. Dayi	Kponyo on R. Pawmpawm
Density	**	*	**
Biomass	**	**	**
Weight/plant	*	**	**
pH	**	**	**
Total mineral content	**	**	**

Appendix 12

Summary of "Student's "t-test of differences between growth of Pistia in Long Ashton Solution and in Arnon & Hoagland (1940) Solution

Growth index	Significance
leaf number	**
leaf length	N.S.
root number	N.S.
root length	N.S.
plant number	N.S.
root dry weight	*
shoot dry weight	*
dry weight per plant	N.S.

Appendix 13

Summary of analysis of variance tables

Growth index	Significance
leaf number	**
leaf length	*
root number	**
root length	**
plant number	N.S.
root dry weight	**
shoot dry weight	**
total dry weight per basin	**
dry weight per plant	**

Appendix 14

Summary of analysis of variance tables

Growth index	Significance
leaf number	**
leaf length	**
plant number	**
root dry weight	**
shoot dry weight	**
total dry weight	**
dry weight per plant	**

Appendix 15

Combined effect of pH and total nutrient concentration of modified Long Ashoton Solution on growth of Pistia. (Values given are means from 4 replicates, together with their standard errors).

Growth index: % gain in leaf number per basin.

		% total 10	Nutrient 50	concentration 100
	5.0	284±2	364±5	415±5
pH	7.0	250±4	345±4	400±4
	9.0	215±4	328±4	386±3

Growth index: % gain in longest leaf length per plant.

		% total 10	nutrient 50	concentration 100
	5.0	48±2	36±0	30±1
pH	7.0	45±2	34±2	28±1
	9.0	41±1	31±0	25±0

Growth index: % gain in primary root number per basin.

		% total 10	nutrient 50	concentration 100
	5.0	210±2	112±2	69±2
pH	7.0	205±2	114±1	70±1
	9.0	209±1	110±2	73±1

Growth index: % gain in longest primary root length per plant.

		% total 10	nutrient 50	concentration 100
	5.0	110±2	55±3	41±1
pH	7.0	100±6	55±2	45±2
	9.0	108±3	50±2	40±1

Appendix 15 (cont.)

Growth index: % gain in plant number per basin.

		% total nutrient concentration		
		10	50	100
pH	5.0	300±0	350±40	450±40
	7.0	250±40	300±0	400±0
	9.0	250±0	300±0	400±0

Growth index: % gain in root dry weight per basin.

		% total nutrient concentration		
		10	50	100
pH	5.0	120±3	86±3	69±1
	7.0	112±2	75±2	70±2
	9.0	100±5	82±3	75±2

Growth index: % gain shoot dry weight per basin.

		% total nutrient concentration		
		10	50	100
pH	5.0	260±8	150±8	85±4
	7.0	215±4	112±2	65±4
	9.0	210±1	110±1	65±6

Growth index: % gain in total dry weight per basin

		% total nutrient concentration		
		10	50	100
pH	5.0	190±4	118±3	72±1
	7.0	164±3	94±2	64±4
	9.0	155±0	96±2	70±0

Growth index: % gain in dry weight per plant

		% total nutrient concentration		
		10	50	100
pH	5.0	32±2	17±2	8±0
	7.0	31±1	16±1	8±2
	9.0	31±0	16±1	9±0

ACKNOWLEDGEMENTS

I would like to express my gratitude to Professor G.W. Lawson for suggesting the problem and for his criticism of the manuscript. I am particularly indebted to Dr. D.U.U. Okali whose patient and able supervision, assistance and criticisms facilitated the investigations. To Dr. E. Laing I render my sincere thanks for guidance in the initial stages of the studies.

My grateful thanks are due also to Doctors D.K. Acquaye of the Department of Soil Science, and N.I.C. Nwachuku for advice on plant analysis. I would also like to thank again Dr. N.I.C. Nwachuku and Professor F.E. Round of the University of Bristol for their criticism of portions of this thesis.

Very many thanks are due to Messrs. E.N. Lartey, J.S. Adomako, E.A. Thompson, T.S.K. Akoto of the Department of Zoology, J.F. Antwi of the Department of Geography and several others for various forms of technical assistance.

This investigation forms part of the U.N.D.P. - Ghana Government Volta Lake Research Project and has been carried out mainly with a studentship from the University of Ghana. For this financial assistance and the co-operation of the Project Manager, Dr. B.W. Taylor, I am very grateful.

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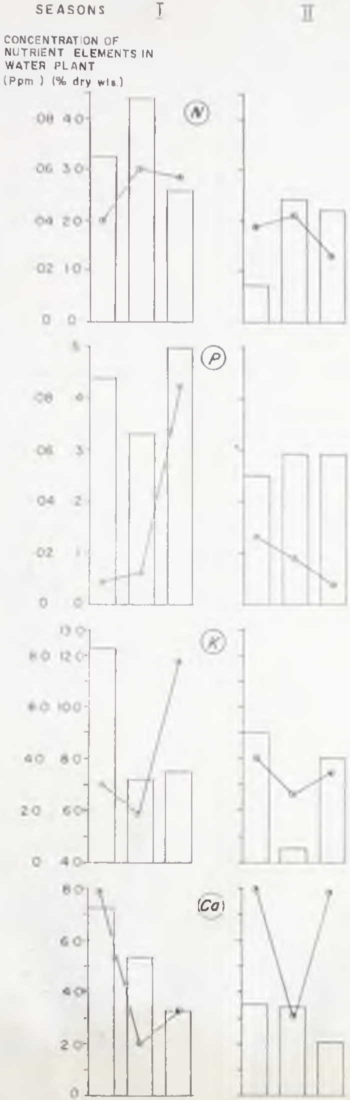
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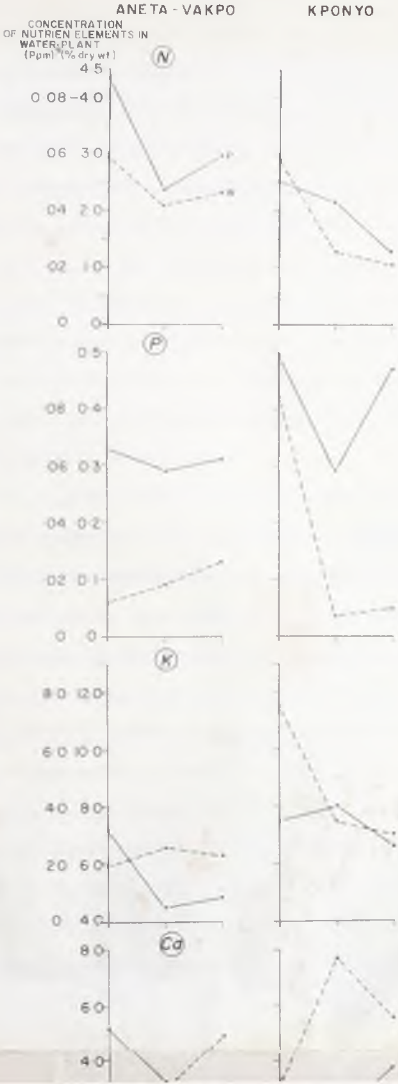
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