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NIGERIA - KAINJI LAKE PROJECT

A Limnological Description of Kainji Lake
1969-1971

A report prepared for the
Kainji Lake Project

by

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LIST OF ABBREVIATIONS

cm	=	centimetre
cal	=	calorie
g	=	gramme
kerg	=	Kiloerg
kn	=	Knot
1	=	litre
ly/d	=	light-year/day
m	=	metre
mm	=	millimetre
mg	=	milligramme
me	=	milliequivalent
me/1	=	milliequivalent per litre
m^3/see	=	cumec: cubicmetre per second
ppm	=	part per million

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1. INTRODUCTION

1.1 TERMS OF REFERENCE

The Kainji Lake Research project undertaken by the Government of Nigeria with assistance from the United Nations Special Pond and the Pood and Agriculture Organisation of the United Nations became operational on 12 August 1968. Its purpose was to assist in the comprehensive development of man Bade lake resources through research and surveys, the results of which will be made available to all regions of Nigeria. As part of the project operation, FAO assigned a Fisheries Lianologist Mr. F. Henderson from 19 July 1969 to 30 September 1971 with the following terms of reference: to aid the Government of Nigeria in the conduct of a limnological survey of Lake Kainji. The purpose of the survey was to identify and describe limnological conditions or factors which may now or in the future restrain development of the fishery.

1.2 THE LIMNOLOGICAL PROGRAMME

The limnological research programme, as suggested by the objectives of the project, was primarily aimed at providing background information pertinent to fishery research and development. Specifically, it was intended to:

(i) estimate the potential productivity of Kainji Lake with reference to the potential harvest of fish, and identify the factors which regulate this productivity;

(ii) describe the structure of the lake with respect to those factors which are thought to govern the distribution of fish in the lake, such as temperature, oxygen, depth and transparency;

(iii) describe the seasonal variations in lake structure; and

(iv) assess the changes that may be expected to develop in the above as the new lake matures.

The work set out in this report covers two years of investigation beginning in August 1969, one year after the initial filling of the lake.

1.3 PREVIOUS INVESTIGATIONS

In 1954, the Government of Nigeria engaged the Netherlands Engineering Consultants, NEDECO, to "carry out a general study and investigation of conditions obtaining in the Niger and Benue system with the object of determining how shipping conditions on these rivers can be most effectively improved,..". A report on these studies was submitted to the Government of Nigeria in 1959. This report provided the first detailed data on the hydrology of the Niger, and summarized existing information of the geology and climate of the region. Among recommendations made by NEDECO was a recommendation that a dam be constructed between Bussa and Jebba both to improve navigation and to produce electricity. While the above studies were nearing completion, the Government decided to press further on the investigation of a suitable site for a hydroelectric scheme, engaged Balfour Beatty and Company to make a detailed study of the regions suggested by NEDECO for a power dam, and asked NEDECO to work with Balfour Beatty in the study. These two firms are hereafter referred to as Joint Consultants. This later study was completed in 1961, and with acceptance of a plan for a dam at Kainji Islands, the Joint Consultants were retained until completion of the project. The reports of the Joint Consultants include extensive data on the regime of flow of the Niger, the geology and climate of the Kainji basin, and maps of the reservoir.

From July to September 1965, a biological research team, organised by the University of Ife with the assistance of the University of Liverpool and the Ministry of Overseas Development of the United Kingdom, made a brief study of the biological conditions in the proposed reservoir area. Their report (White, ed., 1965) includes data on the chemical composition of the Vigor, and on the plankton composition of the river. The University of Ife continued active work, particularly on the chemistry of the water of the river and the newly flooded lake.

Further limnological data have been provided by project fisheries personnel, and the Hydrology Section of the Niger Dams Authority, charged with operating the Kainji dam, have also continued to supply data on flow and lake level.

2. METHODS EMPLOYED

The objectives of this study emphasised a need for a general description of the limnological character of the lake and the seasonal variation in this character. The selection of characteristics to be examined was based on more or less conventional understandings of factors directly related to fisheries. Owing to limitations in time and facilities, a compromise was, however, made between the need for descriptive data used in interpreting seasonal changes in the lake structure and the need for similar data in inshore regions where most of the fishing operations occur. As data relating to the latter areas were obtained by project biologists at times and locations coinciding with the programme of experimental fishing, the limnological sampling placed emphasis on the former objective.

2.1 SURVEY CRUISES

After an initial survey of the lake in late August 1969 and discussions with the project's fishery biologists, a series of sampling stations covering the middle and lower sections of the lake were chosen. The upper arm has remained more or less riverine in character and was being regularly visited by the fishery team, hence stations were confined to the main and lower basins.

The location of the stations chosen is shown in Fig. 1. All but station 14 were located over the old river bed where maximum local depths could be obtained. In practice, these stations were located during cruises by reference to visual landmarks and echosounder, and the position was only approximately reproduced on subsequent cruises.

Cruises were planned at intervals of six weeks to occur midway between fishery surveys. Actual times were somewhat irregular and adjusted to accommodate other project needs, and the intervals between cruises actually varied from four to eight weeks. Each cruise was assigned a reference number; a list of the cruises with dates and stations occupied is given in Table 1.

The cruises usually required three days for completion, with all work accomplished during daylight hours. Stations were occupied for from one half to two hours as the full series of observations were not made at every station.

From August 1969 to July 1970 all work had to be accomplished with a 16 ft outboard boat. In July 1970 a 31 ft houseboat became available, permitting more flexible operations and allowing water samples to be analysed while the boat was underway.

Equipment and methods used in measurement and analysis were primarily dictated by the store of equipment already on hand at the project. While the results were reasonably satisfactory, some of the equipment was cumbersome for small boat use.

2.1.1 Measurement of Water Temperature

Temperature profiles were obtained at each occupied station with a bathythermograph operated from a hand winch. Considerable difficulty was experienced in maintaining calibration owing to high ambient temperatures during storage, and to uncertainties in field calibration against standard mercury thermometers. Thermal gradients near the surface were generally very steep during the day, while rapid changes during ascent and reading made such comparisons somewhat unreliable. In practice, the temperatures of the 1-metre samples were incorporated into a "quality-control" chart on which the difference between their temperature (thermometer incorporated into the sample chamber) and the temperature indicated by the bathythermograph was plotted successively for all observations for which sample temperatures were available. While there was considerable scatter in these points (Fig. 2) and the trend of drifting calibration appeared almost exponential} a fitted ourve through the tank observations was used to correct BT readings between successive cruises and maintain seasonal comparability. Unfortunately the BT was designed for temperatures to 30°C, while surface temperatures at Kainji frequently reached 32°C while surface temperatures at Kainji frequently reached 32°C and occasionally as high as 37°C. Hence temperature gradients in the first 0.5 metres could not be regularly observed.

The steep surface gradients observed led to the adoption of locally constructed sampling bottles (Meyer's type) for use by the fishery programme in obtaining water temperature at fishing stations at a standard depth of 1 metre, thus avoiding the uncertain significance of dip-sample observations at surface temperature.

2.1.2 Water Chemistry

A vertical series of water samples was taken at most of the stations. A "surface" sample was taken at a depth of one half metre. A "bottom" sample was taken at a distance of 1-2 metres above the bottom (judged from the depth recorder). One or more intermediate levels were chosen for sampling after examination of the BT profile. When a thermocline was present the intermediate sample was taken just above this thermocline, otherwise it was taken at mid-depth. On some occasions a more complicated profile was observed, in which case one or more additional samples were obtained.

These water samples were collected with three litre plastic bottles of the Van Dorn type (Gemware) with rubber-cup closing mechanism and internally mounted thermometers. As three were available, they were usually operated in series with the same winch and wire used for the BT.

Concentration of dissolved oxygen

The dissolved oxygen was determined for each sample using standard Winkler reagents (Azide modification). Thiosulphate solutions were standardised at the laboratory before and after each cruise. Prior to the arrival of the large houseboat, oxygen determinations were made with the Hach "powder pillow" reagents and FAO reagent until supplies ran out. While convenient for fishery work, this latter procedure is expensive and, owing to the small quantities titrated, of reduced precision.

Conductivity

Conductivity was determined for the samples with a Hach conductivity bridge designed for field use. Owing to initial errors in the procedure adopted in using the internal standardization procedure, and the relatively low precision of the instrument, the data obtained are suspected to include errors in the range of 5-10% (average conductivity about 55 micromhos/centimetre. While seasonal trends could be observed, these data were of little use in distinguishing between surface and bottom waters, and showed little correlation with independent determinations of total anionic concentration.

Hydrogen-ion concentration

Hydrogen-ion concentration (pH) was generally determined by colorimetry using narrow range indicators. While a battery-operated (Tokai instruments) pH metre was frequently used, corrections for temperature proved difficult to apply in the field and the colorimetric method was judged more reliable.

Total ionic concentration and alkalinity

Two one half litre sub-samples were saved from each sample and carried back to the laboratory. One set was used for the determination of alkalinity using a methyl orange endpoint, and for the determination of total anions by the method ion-exchange (method of Mackereth, 1963). As in the determination of conductivity, sensitivity was poor, and little confidence could be placed in comparisons among samples.

The other set was saved for isotope analysis and for reserve.

Turbidity

After watching the changes occurring in the lake over the first year, it became evident that the striking variation in colloidal turbidity of inorganic origin was likely to be the most sensitive variable in distinguishing between water masses in the lake, at least with the equipment at hand. Baring periods of higher turbidity, the percent transmission of blue light was measured on each water sample using the Hach portable colorimeter (No. 4445 filter). Unfortunately the length of the transmission path (approx. 2 cm) was insufficient for use during periods when the Secchi disc readings increased beyond 1 metre. An in situ transmissometer had been ordered for this work, but after a long delay, procurement was abandoned.

2.1.3 Plankton Sampling

With the recruitment of the counterpart limnologist in December 1969, a programme of plankton sampling was initiated and was developed to a semi-quantitative procedure by the following June.

Phytoplankton samples were obtained with separate casts of the water bottles used to obtain water samples, and one half litre sub-samples were returned to the laboratory for counting. Portions of these were then sedimented with Lugol's solution. Details of the methods used will be reported in conjunction with a more complete report of findings by the counterpart limnologist at a later stage in the project.

Zooplankton samples were obtained with cone nets (10 mesh) approximately 20 cm in diameter and 30 cm long, with plastic vials attached by an elastic sleeve at the apex of the net. A frame was evolved which allowed two pairs of these nets to be simultaneously drawn through the water with a one metre distance between pairs and members of a pair 25 cm between centres (i.e., nearly adjacent). These nets, attached to the weighted cable used in other sampling, were lowered to a depth of 5 metres and returned immediately to the surface. While the scheme of multiple nets provided good control of heterogeneity in the distribution of zooplankton, the uncertainties of vertical tows with such short nets leave the results some-what questionable. Again, a more detailed discussion of the sampling and counting procedures will be left to a later report on the findings of the plankton investigations of the project.

2.1.4 Other Routine Observations

In addition to the specific observations just discussed, a number of other parameters were observed or measured at each station. These included air temperature, relative humidity, wind speed and direction, cloud cover, wave height and Secchi dise transparency. The meteorological data proved to have little value in interpreting limnological events, particularly as such data could be obtained from the meteorological stations at Kainji and Yelwa. Even though the latter data were not representative of conditions over the lake itself, they had the advantage of day-by-day observations, and were less influenced by diurnal fluctuation.

Unfortunately wave heights were only “guesstimated” until November 1970, when a damped wave-pole became available (constructed at the project).

Stationary echo-sounding records for a minimum of three minutes were obtained at each station. In most oases at least ten minutes of record was obtained. These gave indications of presence or absence of fish and scattering layers. Before the arrival of the larger boat, a Mark II Furuno FG-11, a 25 kilo signal, was used with a hand-held transducer. A newer version of the Furuno Mark II, with a 200 kiloHerz signal and expanded depth scale, was permanently mounted in the larger boat soon after it became available.

2.2 LIGHT PENETRATION STUDIES

In order to examine the implications and significance of the routine observations of Secchi disc transparency, light penetration was examined on two occasions with a GM under-water photometer equipped with red, green and blue filters. As scattering by colloidal clay seemed to be the dominant factor in changes of light penetration, several attempts were made to ascertain the physical properties of the colloidal suspensions found in the lake. A much more thorough study is now underway in connexion with a project study of seasonal variation in primary production.

2.2.1 Light Transmission

Light intensity as a function of depth was measured in October 1969 and again in February 1970, when Secchi disc readings of 0.5 m and 2.2 m were obtained respectively. A more thorough study was not undertaken owing to uncertainties in the calibration of the various scales of the meter (the meter scales had to be readjusted on arrival owing, apparently, to moisture problems in the shunts). A rough adjustment was effected by adjusting serially the next more sensitive scale to the appropriate multiple (10x on most ranges) of the reading obtained on the previous scale. This procedure accumulates errors arising from the low precision of the lower part of the scale and non-linearities in the measuring circuit. In spite of these difficulties, a substantial shift in the spectrum of the transmitted light was observed and tentative attenuation coefficients for each filter were calculated. From the sensitivity and transmission curves published for the photocell and the filters respectively, the transmission coefficients were converted to relative energy units from which spectral curves could be drawn. (Vollenweider, ed., 1969).

2.2.2 Properties of the Colloidal System

Data obtained by the previous field observations were supported by similar observations on dilutions of water samples with the Hach colorimeter. The stability of these suspensions was examined by several experiments which will be described briefly in the sections where the results are discussed.

3. PHYSICAL CHARACTERISTICS OP KAINJI LAKE

3.1 THE REGIONAL SETTING

Kainji Lake lies between 9°30'N and 10°35'N latitudes and 4°25'E and 4°45'E longitudes (Fig. 1). This region is an area of Guinea savannah maintained by annual burning. The topography is of low relief lying at an altitude of 500 ft (150 m) to 1 000 ft (300 m) above sea level, with a highly dendritic pattern of drainage.

The human population density is low in the areas adjacent to the lake and generally low throughout the drainage basin. Intensive agriculture is carried out in a few places, principally in the drainage basin of the Sokoto River, tributary of the Niger and the lake. Except in a few places population density is of the order of 10-20 per square mile (Udo, 1970).

The soils are generally poor away from the river alluvium, being highly variable in physical composition, low in phosphate, very low in nitrate but fairly rich in potassium. The upland savannah soils are almost totally lacking in humus materials. The surface horizons are composed of clay, sand and stones, while silt fractions are confined to the lower layers. Data resulting from general surveys of these soils may be found in Pullen and deLeeuw, 1964.

3.2 CLIMATE

Kainji Lake lies in a transition region, dominated by dry continental trades during the winter months and moist maritime equatorial air during the summer. In West Africa the boundary region, generally called the Intertropical Discontinuity or "Front" (ITD), moves north and south seasonally through only about 12° of latitude (Fig. 3), while in East Africa the seasonal change is as much as 30° (Cloudsley-Thompson, 1969). The movement of the ITD gives marked seasonal change to the region. This, in turn, exerts a strong influence on conditions in Kainji Lake.

3.2.1 Precipitation

The annual rainfall in the area of the lake is about 1 000 mm (40 inches). This rain is almost entirely confined to a period beginning about mid-April and extending to mid-October, and much of it is associated with line squalls occurring between late afternoon and early morning. Monsoon rains, associated with low dense cloud cover, are the next most important source of rainfall (Barry and Chorley, 1968). The average seasonal distribution of rainfall for the two nearest stations with extended records is shown in Fig. 4. Yelwa is near the upper end of the north arm (see Fig. 1). Mokwa is about 40 miles to the south-east of the dam. These records show a single peak in rainfall at Yelwa, while there is a substantial mid-summer drop in rainfall (little dry season) at Mokwa. There is considerable variation among years in the amount and distribution of rainfall. In many years a little dry season may be recognized at Yelwa as well. This period corresponds to the northernmost extension of the ITD.

The local rains are of high intensity and the runoff picks up clay into colloidal suspension imparting a blue-white colour to local runoff. This material is retained in the rivers and the lake and gives the name "white flood" to this water.

About half the annual inflow to the Kainji Lake originates in runoff from the basin south of Naimey as "white flood", entering the lake beginning in mid-August and lasting until December. The balance of the inflow originates in rains at the headwaters of the Niger in the Guinea highlands. This water, having passed through the flats around Timbuktu, is much clearer and is known as the "black flood". It is considerably delayed and rises in October continuing into May.

During the dry season, the vegetation is burned to encourage new growth for cattle and to aid in hunting. This burning is virtually complete and extends well into January. The fate of the nutrients released in burning is not well known. It may be assumed, however, that much of the nitrogen is carried into the atmosphere, while phosphates and other nutrients that mineralize in burning remain in the ash; the latter is left on the soil surface at or near the site of burning. Ash is also deposited on the lake from nearby burning sites. Burning is generally done during periods of low wind, and hence the ash is rarely carried very far. "Dust devils" are very frequent during the dry season. These break up the ash and carry it, along with other debris back into the air. As the nutrient concentrations in the lake are apt to be substantially affected by the fate of nutrients released in burning, it is unfortunate that so little appears to be known about the redistribution of this ash.

3.2.2 Temperature

Air temperature is the Kainji area range from 15°C to nearly 40°C (Fig. 6). The continental air of the dry season, with little cloudiness, results in extremes of daily fluctuation in temperature, and the lowest (night) temperatures occur during the periods of domination of this air mass. As the ITD moves northward, southerly winds increase humidity and temperature, and the highest daytime temperatures occur at this time when there is still little cloud cover. With the onset of the rains, air temperatures continue to fall until August, and there is little diurnal fluctuation. In September and October, the rains diminish and air temperatures rise until the return of the continental air.

3.2.3 Humidity

As with air temperature, the humidity in this area is closely associated with the movements of the ITD, and is quite variable. A maximum occurs in August and September at the peak of the rains, but a little later than the maximum northward extension of the ITD. The minimum occurs in late January or early February (Fig. 7). There is some evidence of a local effect of the lake in the records at Kainji, where the relative humidity is less variable than at Yelwa or at Mokwa. The effect is particularly evident in higher humidity during the dry season.

3.2.4 Solar Radiation and Cloudiness

Data on solar radiation are available at Yelwa and Bida but not at Kainji or Mokwa. Fig. 8 shows means of the Yelwa and Bida figures and the two are closely correlated. Radiation maxima occur in February-March and November and minima in August and January. There is a close correlation with mean monthly air temperatures. The radiation minimum in January is probably the result of dust haze of the "harmattan", and lower solar altitude (6 percent), while the minimum in August is presumed to be the result of cloud cover which is maximum at the same time. Records of sunshine hours, converted to percent of maximum sunshine are similar, as shown in the same figure, but less regular. The "harmattan" minimum is hardly to be found in these data.

A rough conversion of Gunn-Bellani observations to absolute units can be made by assuming equivalence with comparisons with actionographs made by McComb and Iyamabo (1968) near Zaria, Nigeria. Using the Yelwa and Bida records an annual mean insolation of 502 g-cal/cm^2/day was calculated. Using Budyko's (1956) tables of maximum insolation at a latitude of 10° and the records of sunshine hours at Mokwa and Yelwa, monthly means of insolation were calculated. The agreement with the data from the Gunn-Bellani measurements was good (annual mean 494 g-cal/cm^2/day), but the latter showed less extreme values by month (see section on heat budget of Kainji Lake).

Outgoing long-wave radiation was also calculated by month from the meteorological data (based on records obtained at Faku, just below the dam). Its mean value for 1969-1970 was 94 g-cal/cm^2/day, leaving a net incoming radiation of 400.

One may also estimate the photosynthetically active component of the incoming radiation following Tailing (1960). Assuming that *6* percent is reflected from the surface and that 46 percent of the remainder lies within the 400-700 mm band (visible light), approximately 213 g-cal/om2/day is available, or about 100 kergs/cm^2/sec. Maximum values occur in February and minimum values in August. Insolation is rather lower than reported by Tailing for East African lakes.

3.2.5 Winds

The direction of the prevailing winds in the Northern Nigeria results from the major flows: the northerly trade winds which blow in the area from mid-November to mid-March, and the southerly maritime "westerlies" which dominate the flow the remainder of the year (Fig. 10). The boundary region is the Intertropical Convergence Zone or "front". These winds are light averaging about 2.5 to 3 m.p.h. (Yelwa data). Squalls are frequent at the beginning of the rains (April through June) and again in September and October. The latter, however, are much less frequent. These squall winds generally reach peak velocities of about 45 m.p.h., though 70 m.p.h. winds have been recorded. These squalls raise average wind velocities to as much as 7 m.p.h. during May (Yelwa data), and generally blow from the east.

Unfortunately records of wind velocities are not available for the lake itself. Land and sea breezes are evident at the margins of the main section of the lake, particularly in the late afternoon (sea breeze) and early morning (land breeze). the prevailing winds are most in evidence from late morning to mid-afternoon, while storms tend to occur from late afternoon to early morning. Many of the latter appear to originate near the Jos Plateau.

3.2.6 Visibility

While fog is relatively rare in the area, visibility is often much reduced during the "harmattan" season owing to dust brought into the area from the Sahara. Throughout the "harmattan" season, visibility is rarely more than 6-8 km while it is often reduced to about 0.5 km. During this season a compass is necessary for navigation in the central basin, while during the remainder of the year landmarks are visible from all parts of the lake.

3.2.7 Climatic Summary

The climate of the Kainji area is strongly seasonal. This is of considerable signifi-oance to the limnological characteristics of the lake and should impress strong seasonal characteristics to both the growth and movement of the fish fauna and the operation of the fisheries on the lake.

4. PHYSICAL CHARACTERISTICS 07 KAINJI LAKE

While the damming of the Niger produced conditions in the basin very much more lacustrine than the Niger itself, Kainji Lake retains many characteristics that are riverine. These especially include the flushing of the reservoir basin at least annually, a pronounced flood cycle, and enhanced vertical and horizontal transport of water into the deeper portions of the lake. These factors reduce storage processes in the lake and speed up responses of the lake itself to changes in larger environment. It is therefore, tempting to assume that the description of the lake presented here is that of a reservoir nearly reaching equilibrium, at least physically and chemically, with the present climatic and geographic features of the lake and its drainage basin.

4.1 MORPHOLOGY

The lake is readily divided into three major sections for the purposes of study and discussion (Fig. 1). From the dam northward, the basin is narrow and deep for a distance of about 40 km, with a substantial reduction in depth beginning at Garafini (15 km from the dam) where there had been rapids. At the site of the old Bussa Rapids, the lake widens into a large shallow basin formed by branching of the old river. This section of the lake comprises nearly 70 percent of the total area, and is the most important from the point of view of the fishery. The surrounding topography is low, in contrast to the lower arm, and the lake shore falls very gently to the depth of the former river.

At the northern tip of Foge Island the lake narrows again and becomes more and more riverine toward Yelwa. This section was given low priority in the limnological studies owing to its riverine character, distance from the base of operations and recent diminishing relative significance in the fishery.

4.1.1 Shore Development

The perimeter of Kainji Lake, including all three sections, is estimated to be about 720 km. With a surface area of 1 280 km^2, the shore development factor at high water is 5.65. This is the ratio of the actual shoreline to the shoreline of a perfectly circular lake of the sane area and hence is a measure of the amount of shoreline extension produced by bays and other indentations of the lake margin. While most natural lakes approach the idealized circular form much more closely than Kainji (values around 2.0), the values for others of the African reservoirs are much higher. In an approximate sense, the significance of the shallow littoral zone of a lake in relation to the open pelagic zone increases with the shore development factor. The lower southern arm of the lake, because of its shallow zone, contributes disproportionately to this index in Kainji.

4.1.2 Depth

The maximum depth of Kainji Lake occurs at the dam itself and is about 50.4 m at high water level. The lake is drawn down annually 9 to 10 metres. The total volume at high water is about 1.5.8 km^3 and at low water about 5.8 km^3. The corresponding areas are 1 280 km^2 and 660 km^2. The mean depths are, therefore, 12.3 m and 8.8 m respectively.

The ratio of mean depth to maximum depth is often used as an index of basin shape (Hutchinson, 1957). Calculated on the data above, a value of about 0.23 is obtained. Most lakes have values above 0.33, and in this case the low value is again accentuated by inclusion of the lower arm.

Unfortunately the reservoir basin was mapped by aerial photography prior to flooding without thorough ground survey. Contouring could only be accomplished at intervals of 40 ft. There remains, therefore, a considerable uncertainty in the above calculations.

The flooded area in the central basin, particularly over Foge Island, was quite flat. Along the western margin of the lake and throughout the lower arm, the flooded area was heavily dissected by runoff and the bottom topography is, therefore, very complex. Detailed hydrographic mapping now that the lake is formed is likely to be quite difficult, requiring careful positioning and extensive coverage.

4.1.3 Storage

A storage graph was prepared by the Joint Consultants based, presumably, on the aerial survey. This graph, converted to metric units, is reproduced in Figure 11. Volume differences for one metre depth intervals were taken from this graph and smoothed to prepare a chart of area as a function of reservoir height (Table 2). The latter has been used in obtaining weighted means of temperature, primary production and other depth-dependent variables when totals for the whole lake were desired.

4.1.4 Islands

There are three major islands in the lake, one at Garafini in the middle of the lower arm, another at Bussa, and the most significant at the point where the upper arm joins the central lake. The latter island is much extended toward the south at low water and appears to exert a substantial influence on water circulation in the main lake (see Section 4.3.4).

4.1.5 Wind Patch

Short steep waves develop quickly on most parts of the lake in response to increasing wind. The north-south directions of the prevailing winds tends to coincide with the longer axis of all of the major parts of the lake, while the middle basin and certain bays in the south arm also permit long fetches to the easterly squall winds. A maximum fetch of more than 30 km is available in the middle basin to south-southeast winds.

Possible maximum wave heights were computed by the Joint Consultants to be about 1 metre. While direct observations have not been made, experience on the lake suggests that waves of 50 to 75 cm are common and waves up to 1 m indeed occur during storms. Corresponding wavelengths are from 6 to 14 metres. A maximum setup of about 0.2 m was also predicted but has also not been directly measured.

On days of moderate windiness, striking differences are from place to place in the lower arm. One passes from windy sections to wind shadows at each major bend. On some occasions blooming algae and floating debris form large patches in the shadowed areas.

4.1.6 Drowned Trees

A significant factor in the morphology of the lake is the extensive area where trees are partially or wholly submerged. While 40 percent of the lake area was cleared of trees prior to impoundment, large areas remain. These trees reduce the effect of water and wind action on the morphology of the lake.

4.1.7 Depth of Discharge

The spillway of the reservoir lies about 15 m below the normal high water level. The intakes to the turbines have their centres at a depth of about 28 m below the high water level and are about 8 m in diameter. Deep discharge is a major factor in the stratification regime of the lake and an important difference between Kainji and natural lakes.

4.2 HYDROLOGY

Extensive hydrological studies were undertaken in preparation for construction of the dam, and are continuing in connexion with its operation. These data, provided by the Niger Dam Authority, form the basis for the following descriptions.

4.2.1 Inflow

The Niger is unusual in having two flood regimes well separated in time. The first flood, beginning in August, is derived from rains in the region south of Naimey, and carries substantial quantities of colloidal clay, chiefly kaolinitic. This water is highly turbid (Secchi disc transparency about 0.3 m) and greyish, giving the name "white flood" to this water* The rise to a highly variable peak is rapid and the flood starts to diminish in late September or early October (Fig. 5). The second flood, originating in rains of the upper Niger, is considerably delayed and spread in intensity by its passage northeastward to the interior delta near Timbuktu and thence southeastward to Nigeria. This water is relatively clear, though carrying appreciable amounts of detrital material, and is given the name "black flood". Although rising soon after the white flood, it does not reach its peak until February and does not cease until the latter part of April* The annual flow may reach about 80 000 million m^3 in a year of high flow, of which 47 000 million is obtained from the white flood and the balance, 33 000 million, in the black flood. The latter is relatively constant from year to year while the white flood may be reduced by as much as one third in dry years.

4.2.2 Discharge

While there are several lateral tributaries to the lake, these are all small (less than a few percent) relative to the Niger itself. Only the Malendo (peak discharge 500 cumecs) is included in water balance calculations.

The reservoir is operated both for power generation and flood control. This necessitates careful control of the lake level and a post-flood drawdown of almost 10 metres. Uncertainty in predicting flood levels has resulted in a substantial variability in discharge in adjusting the filling rate to design requirements during September of the last two years.

At present most of the discharge is taken from the spillway as only 400-500 cumecs are used in power generation. As capacity is increased, however, turbine discharge may be expected to triple for most of the year.

4.2.3 Evaporation

Evaporation has been estimated at about 150 to 200 cm per year or about double the local rainfall. The evaporation is a email item in the annual water balance and difficult to estimate directly.

4.2.4 Horizontal Transport within the Lake Basin

Very little information has been obtained on currents within the lake owing to the difficulties of direct measurement. During the rise and fall of the white flood, the distribution of turbidity provides some information on water movements (Henderson, 1971). Generally, the incoming turbidity spreads rather uniformly down lake, with rather more rapid dispersal along the eastern half of the central basin. Southerly winds appear to push surface water toward the northwestern bay resulting in clockwise surface currents around the northern tip of Foge Island.

4.3 THERMAL CONDITIONS

The distribution of heat in a lake is one of the most significant factors in determining the dynamic properties of the lake, as the distribution and intensity of most of the internal conditions are directly affected either by temperature or gradients in temperature.

4.3.1 Mean Temperatures

The mean temperature of the water column has been calculated for station 1, three mi above the dam, for each cruise (roughly 6-week intervals). The temperature for each 1-metre stratum was multiplied by the volume of the stratum to obtain a mean representative of the total volume of water in the lake. This calculated mean temperature is shown in Fig. 12.

Peak temperatures are reached in April and May at about 29.5°C (1970) and minima in January-February (26.2°C, 1969; 23.6, 1970). A minor peak in temperature occurs in October while the humidity is high and cloud cover has diminished.

4.3.2 Heat Budget

A heat budget analysis was made for Kainji for the period August 1969 through December 1970 in order to seek information on the sources of variability of the mean temperature from season to season and year to year. The much lower temperatures during December and January of 1971 compared to the previous season raised questions about conditions leading to thermal variability in Kainji Lake.

While the available data are of marginal significance for heat budget analysis, annual evaporation from the lake surface, estimated as a difference in the total budget, agreed rather well with other estimates made by the Joint Consultants (1961). The results of the analysis are, therefore, taken as roughly indicative of the distribution of the components of heat flow in spite of the inadequacies of the data. Conventionally, contributions to the heat budget are divided into incoming short-wave radiation less reflection, net longwave (thermal) radiation, evaporation loss, convective exchange between the water surface and the air above, advective gain or loss through inflow and outflow, and heat storage (change in lake temperature). Their sum, sign considered, is assumed to be zero. All were estimated directly except for evaporative and convective losses. The ratio of the latter (Bowen's ratio) can be estimated more satisfactorily than their absolute magnitudes, hence these are determined by difference after estimates of the other terms have been obtained.

Heat storage was estimated from the temperature records (average column temperature weighted by the volume-depth relation) at Station 1, in the lower arm. As the actual measurements did not coincide with calendar months, the observations were converted to monthly intervals by interpolation. In view of the small differences among stations and uncertainties in the meteorological observations, it did not seem worthwhile to average the storage estimates over all stations.

The radiation terms were calculated by formulae and tables given in Budyko (1956), using 10 as a reference latitude for clear-sky radiation. Cloudiness was estimated as the complement of sunshine duration (Campbell-Stokes recorder at Yelwa and Mokwa) expressed as percentage of possible sunshine. Air temperature and humidity data were obtained from records of the Niger Dam Authority Station about 1 km below the spillway (Faku). Air temperature was taken as the mean of the daily maximum and minimum, while the humidity was that of 10.00 h daily observations. Monthly means were computed from these daily observations.

Inflow and outflow were obtained from the hydrological records of the Niger Dam Authority, while their temperatures were estimated from observations of river temperature near Yelwa (inflow) and from the temperature profile at Station 1 at depths corresponding to spillway and turbine discharge (outflow).

The Bowen ratio was also calculated from the Faku records and hence must be regarded as the least satisfactory of all the estimates. The wide spacing of the lake cruises precluded use of the meteorological data obtained on the lake except to indicate that the daily air and lake temperatures followed each other closely.

The results of the analysis suggest that the monthly evaporative heat loss from the lake is almost equal to the net incoming radiation or "radiation balance" (Table 2). The latter varies over the seasons primarily in response to changing cloudiness, while evaporation in turn responds to the temperature of the lake surface and humidity. Small differences between evaporative loss and the incoming radiation are significant in determining heat storage in the lake. The overall effect of both inflow and outflow is to raise the temperature of the lake. While the effect of inflow is dominant, discharge of deep, rather than surface water through the spillway and the turbines add heat to the lake during periods of stratification. The lower temperatures of the lake in late 1970 and 1971 seem to have resulted primarily from reduced inflow during the low flood of 1970 and somewhat increased evaporation of December 1970.

While it remains difficult to separate these effects, it seems likely that the lake temperatures will continue to vary substantially from year to year, more or less as the local rain (and flood) varies.

4.3.3 Thermal Stratification

Kainji Lake stratifies each year in February (Fig. 14), and a pronounced thermocline is established and maintained to the middle of May. Drainage of the cool water below the thermocline (hypolimnion) rapidly lowers the level of the thermocline thus eventually destroying the stratification. Until November the lake is filled with warm water which shows small decreases in temperature with depth but with no evidence of stability. That vertical mixing is reduced during the period is particularly evident in October and November when there is deoxygenated water (less than 1 ppm) below 30 metres. In November and December rapid cooling occurs, apparently with cool flood water and strong differences in air temperature and radiation between day and night. Cool clear nights induce rapid cooling of the surface water which then sinks established strong vertical mixing. At this time there is complete circulation of the water mass.

While only data from Station 7 are shown, the vertical temperature distribution is very similar at all stations. Further details can be found in Henderson (1971).

During the period of local runoff, bays fed by the small streams flowing laterally into the lake show occasional stratification as reported by the fisheries officers. These conditions are presumably established by difference in temperatures of the lake itself and the inflow and appear to be localized and temporary.

4.4 LIGHT AND TURBIDITY

The transparency of the water of Kainji Lake is quite variable, primarily as a result of the colloidal turbidity brought to the lake by the white flood. The depth of disappearance of a standard white disc (the Secchi disc) is as great as 3 m in May and June and as little as 0.1 m in September at the rise of the white flood (Fig. 15).

4.4.1 Spectral Distribution of Transmitted Light

On two occasions, the transmission of natural light was measured with a photometer equipped with red, green, and blue filters. With relatively clear water (Secchi disc 2.2 m, 3 February 1970) the peak of transmission occurs in the green region of the spectrum, the more or less normal condition of natural freshwaters. During a period of turbid water (Secchi disc 0.5 m, 9 September 1969) transmission of blue and green light is greatly attenuated and the peak lies in the red region of the spectrum. Swimmers report that the underwater lighting is reddish during such periods.

A similar effect seems to occur in the illumination entering the lake during period of "harmattan" dust as observed by comparing the spectrum of low angle (30°) solar illumination with high angle (85^0) solar illumination during the "harmattan" period and under clear skies. While very rough, these results show a substantial reduction of blue and of green light by the dust.

4.4.2 The Nature of the Colloidal Particles of the White Flood

As the colloidal material might contain appreciable amounts of ferric iron, and also because of the question of the rate of clearing turbidity from the lake, an effort was made to establish the nature of the colloidal particles. It was demonstrated that the particles carry negative charge bound to the surface by placing turbid lake water in an electric field and noting accumulation and deposition of the particles of the positive electrode. Ferric colloidal particles are typically positively charged while clays are negatively charged. While chemical tests for iron were also negative, small amounts of iron are normally present in the clays washed from the soils of the area and are presumed present in the turbidity of the lake water in, however, very small amounts (clays about 1 mg/l, iron less than 0.001 mg/l). As the dominant clay in the local soils in kaolinite (Joint Consultants Report, Vol. VII), it is assumed that this is the major constituent of the colloidal particles of Kainji.

Strong acidification precipitates the colloidal particles by removing the charge stabilization. The range in the lake does not exceed 6.2 to 8.5 and is ineffective in precipitation. It should, however, be determined whether or not appreciable decomposition of the clay particles occurs under the strong reducing conditions during stratification.

The settling time of these particles is very low under laboratory conditions, less than 50 percent per month. Under the turbulent conditions of the lake it must be negligible. Nevertheless the lake loses the turbidity rapidly as evidenced by the rapid increase in transparency at the end of the white flood. It seems likely that the clearer black flood water displaces the white flood water prior to the onset of stratification in late February, and calculations suggest that the normal black flood volume is just sufficient to do so before stratification sets in in mid-February.

Isotopic analysis of the waters of the Kainji basin and the Niger (cooperative programme with the University of Ifs, the International Atomic Energy Commission and FAO) confirm that the concentration of colloidal material (as measured by colorimetric densito-meter using blue light) is directly related to the proportions of black and white flood water. The water of the black flood has been subjected to heavy evaporation and differential removal of the lighter isotopes of hydrogen and oxygen in the water molecules. Unfortunately it has not been possible to determine the concentration of the colloidal material in situ without a wide-range transmissometer.

4.4.3 Other Sources of Turbidity

The black flood appears to carry appreciable amounts of finely divided organic detritus as evidenced by accumulation on netting and anchor ropes but concentrations are low and no attempt has been made to make quantitative estimates.

The higher turbidity of the mid-lake stations April-July would appear to result both from the suspended organic materials and higher phytoplankton concentrations and later from increased stirring of the bottom sediments as the lake becomes shallow and with frequent severe wind storms. Much of the old Foge Island region lies near the surface at depths less than 10 m in June and July.

4.5 CHEMICAL COMPOSITION OF KAINJI WATER

The water of Kainji Lake is low in dissolved materials and only slightly modified from the composition of the flood water that feeds the lake. Analyses of individual components have been made by several investigators (Imevbore, 1970; White et al., 1965; NDA, data on file) and the present study has concentrated on seasonal variation in gross characteristics of the chemical composition.

4.5.1 Dissolved Oxygen

The concentration of dissolved oxygen in the surface waters (1 m in depth) at Kainji does not fall below about 70 percent of saturation. Even during the initial filling when decomposition was high, oxygen never fell below 20 percent (imevbore. unpublished manuscript). The lowest values occur in September just as the lake level begins to rise.

During much of the year the concentrations of oxygen in deep water remain above 4 mg/l. There are, however, two periods when oxygen concentrations reach values less than 1 mg/l in deep water (Pig. 14). Shortly after stratification, in early March oxygen concentrations below the thermocline drop to near aero in the entire hypolimnion. This event is clearly marked each year at the dam site by the appearance of a strong odour of sulphide owing to the escape of hydrogen sulphide by aeration at the spillway. Sulphide concentrations may reach 0.6 mg/l in the deepest water, but are generally much lower.

There is a less marked period of deoxygenation during October and November more or less coincident with a decrease in the surface concentration. This is assumed to result from increased biological activity associated with the flood and incomplete vertical mixing.

A similar effect seems to occur in the mouths of the streams tributary to the lake where local stratification occurs during flood. These floods are variable and rise much more quickly after the rains than the flood of the Niger.

4.5.2 Anion Concentration

The dominant anion in Kainji water is bicarbonate (Fig. 16). The total alkalinity (methyl orange) is quite constant at about 0.55 me/l or 28 mg/l as calcium carbonate equivalents Other anions (sulphate, nitrate and chloride) average about 0.05 or less me/l. A sample of water from the lake (October 1969) was titrated with .02 N acid and base after aeration with CO_2 free air. The results are shown in Pig. 17. Water saturated with CO_2 was also used and an approximately comparable curve is shown for the weak acid titration. Chloride concentrations are of the order of .01 me/l and sulphate even less. Total conductivity ranges between 45 and 60 micromhos/cm at 25º C and differs little from the river water before impoundment. The relation between conductivity and total anion concen-tration reported by White et al. appears to remain valid for the lake, i.e., conductivity (20°C in micromhos) equals 100 times total ionic concentration (me/l) or 2 times total alkalinity.

4.5.3 Cation Concentration

Calcium and magnesium are the dominant cations (roughly 0.2 me/l each) while sodium and potassium are an order of magnitude lower (.01 and .04 me/l respectively). Sodium and potassium appear to have decreased considerably from concentrations measured in the River Niger before impoundment while magnesium has increased (Fig. 16).

4.5.4 Total Dissolved Solids

Total dissolved solids have not been measured for Kainji waters. Estimates based on the above data suggest values between 35 and 40 mg/l. This factor is of interest in computing the morphoedaphic index of Ryder (1965) which has been used to estimate potential fish productivity of various lakes (Section 6.1.2).

4.5.5 Other Constituents

Little reliable information is yet available on the concentrations of biologically active components of the chemical system. Nitrates and phosphates are reputed to be low but quite variable while silica is very high. Iron is also variable reaching detectable levels (greater than .01 mg/l) in the lake only during stratification when ferrous iron remains in solution in the hypolimnion. Iron and manganese form dark reddish deposits on the rocks in the river below the dam where aeration of the water is high.

4.5.6 Inflow of Nutrients

The data of Imeybore (1970) suggest that the lateral tributaries to the lake may be nearly as significant as the Niger in contributing nutrients to Kainji Lake. While their combined flow is small compared to the river the concentrations of nutrients are considerably higher. Rapid deoxygenation of the mouths of these tributaries has already been mentioned and blooms of algae have frequently been noted in these bays. Nevertheless the observed variations in conductivity and total ionic concentration over the year are quite small suggesting either that the contribution of these tributaries is small or that such excess nutrients are rapidly taken up into biological storage.

4.5.7 Nutrients from Savannah Fires

It is well known that the burning of the savannah grasslands during the dry season releases bound nutrients to the air and the soil surface. Nitrates are lost to the atmosphere while phosphates remain in the ash. Much of this ash is carried short distances from the fire by convection currents and some ends up in the lake, either directly or in initial runoff at the start of the rains. There is no evidence at present from which to estimate the magnitude of this source of nutrients. In terms of long-range projections of the productivity of Kainji Lake work along this line should be encouraged.

4.6 SUMMARY OP PHYSICAL CHARACTERISTICS OF THE LAKE

Kainji Lake is rather different from the other large reservoirs of tropical Africa owing to the complete replacement of its contained volume each flood season and short period of stratification. A large annual drawdown (10 m), and other strong seasonal changes associated with the savannah climate, impart considerable variability to the lake. There is also evidence that variation among years, particularly in temperature, may be rather greater than in other lakes of the tropical region.

In contrast to the above, the chemical composition appears to be fairly uniform throughout the season and annual replacement should reduce the possibilities of gradual enrichment of the lake, while ensuring rapid response to changes in agricultural practice in the drainage basin. It is apparent that the enrichment of the water at initial flooding by decomposition of drowned vegetation was very short-lived in Kainji Lake. This was presumably also accentuated by the burning of the areas which were cleared prior to flooding.

5. BIOLOGICAL CHARACTERISTICS

While work on biological problems is well underway, it is not yet possible to detail these characteristics of the lake other than for the fishes. The latter is the subject for other reports. Current efforts are concentrated on the plankton of the lake while the organisms of the bottom and shore have been but little investigated. It is intended here to make only a few very general comments.

5.1 ECOLOGICAL COMMUNITIES OF KAINJI LAKE

The large annual fluctuation in the water level of the lake is the most significant factor in establishing community differentiation in the lake itself. Along with the change in lake level the turbidity of the white flood (September through November) reduces the depth of the photosynthetic layer to less than 2 m from about 5 m during the remaining part of the year. At high water the photic zone (assumed to be the depth to which 1 percent of the surface illumination may reach) does not reach the depth of the shoreline at low water level. Along most of the western and northern margin of the lake erosion of the shoreline dominates owing to the predominance of southerly and easterly winds, and extensive sorting of soil components takes place. Along the eastern margin, where the gradient of the draw-down area is very low (see Fig. 1) deposition predominates and seasonal growth of rooted plants is occurring.

The above conditions are not likely to permit the development of complex littoral (shallow water) communities and, as emphasized in the previous section, will tend to enhance still further the seasonality of life in the lake.

The remaining trees in the lake form another community of high seasonality owing to the changes in lake level. While these trees provide an extensive surface upon which lower plants and other organisms may find an anchor and be provided with the nutrient resources of the open water, seasonal exposure of the uppermost 10 m leads to rapid destruction of the most favourable sites both by weathering and wood-gathering by villagers. In time, it may be expected that the submerged trees will tend to support communities that are essentially benthic (bottom living) rather than littoral.

In the shallower parts of the lake, particularly around Foge Island, extensive beds of the grass Echinochloa have developed and seem to be expanding. This plant is capable of extending its leaves four metres or more above the anchored rootstock and both mats and individual stems float readily when dislodged. It would appear at this time that the Echinochloa community may become the only major source of photosynthetic production in the lake aside from the planktonic algae.

The planktonic community, apparently in contrast to the other lacustrine communities, appearsto be well developed and diverse in Kainji Lake. Well marked blooms of bluegreen algae occur in October and November. It is not yet possible to say whether the observed succession of other forms is seasonal or related to the change from river to lake. It would appear, however, that the annual exchange of water and strong seasonality will tend to maintain planktonic conditions much as they are now. Several forms of lacustrine fauna of zooplankton, incidental in earlier studies of the river, now dominate.

The bottom community of deeper parts of Kainji has not been examined. A few attempts have been made to sample transects from shore to river bed in the region near Shagunu, but only the river bed itself was successfully sampled owing to difficulties with the Ekman dredge on the stony bottom on the landward side of the channel and on the fibrous bottom of the old swamps lakeward of the channel. The river bottom samples contained a few oligichaetes. Chaoborus larvae have been frequently collected in the plankton, particularly at night, but seem not to be abundant. Emerging mayflies, presumably Povilla, are quite evident at times but appear not to have reached the levels of abundance that are reported for the Volta Lake. These burrow in the wood of the submerged trees and feed largely on algae both attached and drifting and hence are less typically benthic.

5.2 PRIMARY PRODUCTION

Some preliminary determinations of primary productivity (rate of photosynthetic production) have been made for the planktonic community using the light bottle/dark bottle technique. The results suggest a gross production of 1 to 1.5 g carbon per m^2 per day, which is consistent with the low concentrations of dissolved nutrients in the lake, although perhaps half the productivity expected was based on comparisons with other African lakes (e.g., Tailing, 1965), These studies are continuing. It seems reasonable to suppose that the total primary production of the plants in the lake itself may be perhaps twice but not more than three times the above, considering the poor development at present of plant growth in shallow water.

5.3 ULTRASONIC SCATTERING LAYER

Throughout the period of investigation echosoundings at all the sampling stations have shown a variable midwater concentration of sound scatterers. Several attempts have been made to collect the organisms responsible but with no success. Unfortunately large high speed midwater sampling devices have not been available to date. Nevertheless there are now strong reasons to believe that these scatterers are small clupeid fishes of the genera Pellomula and Sierrathrissa and that these fishes may be quite abundant in the open waters of the lake. The scattering layer shows a definite nocturnal migration to the surface. During the day the depth varies according to turbidity conditions from about 20 m when the water is clear to about 3 to 5 m when the water is turbid. This depth also tends to be greater in the deeper southern parts of the lake than in the shallower main portion. At night the layer becomes rather more diffuse but extends to at least 2 m from the surface. Just before dawn the layer concentrates near the surface and begins its downward migration as a consolidated layer to the day-depth. There is evidence of air bubbles being released as the downward migration occurs, particularly as the layer reaches the day-depth. Tows with small plankton nets failed to show, on the three occasions attempted, any zooplankton which might be concentrated in the scattering layer though the depth of tow could be monitored on the echosounder. Larval fish were sometims collected but, again, there was no evidence that these were associated with the layer. As the nets available could not be towed faster than about 1 to 15 kn, it is likely that even small fishes would readily escape.

Fishery studies, using light-attractive methods, have shown the presence of the above species and the screens protecting the intakes of the spillway often become blocked by these fishes.

5.4 SUMMARY OF THE BIOLOGICAL CHARACTERISTICS

The preceding discussion is largely speculative as the initial biological work was largely concerned with identification of the species of lower plants and animals that appear in Kainji Lake. Quantitative work is now underway and the results will be reported when appropriate. Nevertheless there is at this stage reason to believe that a drifting planktonic community may continue to be important in the total biological production of

Kainji Lake, while the shallow waters will be limited significantly to seasonal importance. This suggests that lateral migrations, particularly of the fishes, will continue to be as important as they were in the river.

6. FISHERY DEVELOPMENT

The limnological studies completed and underway have been undertaken primarily to provide a base for developing the potential of the fishery of Kainji Lake. Limnological studies of the sort so far accomplished should be regarded as sources of a tentative hypothesis in considering fishery problems rather than a firm foundation for explaining the present and future condition of the fishery. In particular it must be borne in mind that the knowledge of the physiology and behaviour of freshwater tropical fishes is generally rather more poorly known than that for temperate and marine species and it is thus difficult at present to anticipate the responses of the local fauna to such conditions as low oxygen concentration, thermal gradients and similar physical characteristics of the water. Nevertheless it seems useful to suggest some of the more salient implications of the work reported to the problems of fishery development as a guide to further work at Kainji.

6.1 POTENTIAL YIELD OF PISHES

6.1.1 Trophodynamic estimate

The potential catch or yield of fish from any body of water is fundamentally limited by the supply of food available to the fish. This is in turn limited by the quantity of inorganic nutrients in the lake and/or influx of organic and/or inorganic materials to the lake from its tributaries. While there is considerable variability both in the efficacy with which these materials are utilized in various lakes and in the components of the total fish production which are harvestable, a rough estimate of potential fish production and of fish yield is possible by using well established coefficients of transfer of food from the primary photosynthetic producers through generalized food chains to the fishes.

In order to obtain such an estimate the following assumptions were made:

(a) Tropical lakes with surface temperatures in the range 20 to 30 C have an expected gross rate of primary production in the range 2-6 g Carbon/m^2/day (Tailing, 1965); Kainji Lake has an expected value of 2-3 g Carbon/m^2/day (Section 5.2.2).

(b) Net production is about half of gross.

(c) Between 5 and 15 percent of the net primary production may be transferred to secondary production, i.e., herbivore production.

(d) Further transfers along food chains occur with a similar range of efficiency though these are expected to be of somewhat greater efficiency owing to higher utilization rates of animal food,

(e) Harvesting of the fishes of Kainji will continue to be divided more or less equally among herbivorous, microphagous (eating small animals) and predaceous species.

(f) That the Kainji fishery is reasonably efficient in harvesting a variety of fishes, cropping from 20 to 30 percent of the annual production of the fish community.

Using these assumptions[1] and standard conversion factors from carbon to dry weight (x2) and dry weight to fresh weight (x5 for fishes), the tropical lakes above should yield fish as fresh weight of from 25 to 750 kg/ha/year, while Kainji might range from 25 to perhaps 450 kg/ha/year. Comparison of these figures with catch data from other tropical lakes suggests that these figures are somewhat optimistic as they tend to fall in the lower part of the range calculated.

[1] Justification for these assumptions and a more detailed discussion was given in an appendix to the semi-annual Progress Report to the Government of Nigeria, February 1971

It is worth noting that by very approximate calculation the zooplankton standing crop in Kainji Lake may be about 10 kg/ha (Cladocera, Copepoda, Rotifera), As only the uppermost 5 m are regularly sampled, this probably underestimates the actual standing crop somewhat. As the zooplankton produce several generations per year, the production of the zooplankton may be from 10 to 20 times the standing crop (Mann, 1966) suggesting 100 to 200 kg/ha/year for the production of the zooplankton as actual weight or 20 to 40 kg/ha as dry weight. This figure is very low compared with the estimates of herbivore production as obtained from the primary production figures (400 to 2 000 for Kainji), perhaps indicating that the planktonic community is of less importance in the overall biological economy of Kainji Lake than suggested in Chapter 5.

6.1.2 Estimate of Catch from the Morphoedaphic Index

Studies by Ryder (1965), Jenkins (1967) and Regier (unpublished) suggest that the total dissolved solids and the mean depth of a lake are the most important limnological indices of potential and actual catch of fish from a freshwater lake. Data for a few lakes in Africa have been assembled by Regier, Ryder and Cordone (unpublished). Assuming that Kainji belongs to the same family of lakes as those examined, the figures for Kainji Lake (Sections 4.1.2 and 4.5.4) suggest a potential catch of around 15 to 30 kg/ha or equal to the lowest estimate from section 6.1.1. The morphoedaphic estimate, however, is based on actual catches assuming that these are close to potential.

6.1.3 Limitations of the above estimates

While the above estimates may be useful as order—of-magnitude estimates in connexion with planning, they are of very low precision and provide little guidance for evaluating management strategy. It should be noted that the shallow lakes of the interior delta of the Niger, Lakes Faguibine and Do-Niangaye, yield about 45 to 65 kg/ha (Joint Consultants' Report, Vol. 6, Part 8), While these lakes presumably are both higher in total dissolved solids and lesser in mean depth, thus presumably rather more productive than Kainji, many other factors also influencing catch are probably more similar to Kainji than Kainji is to the other lakes used for reference in the above calculations.

6.2 DISTRIBUTION OF FISHES AND FISHING EFFORT

By far the greatest area (69 percent) of the lake falls in the middle section where the Niger is split into two channels. As this portion is also shallow, has a large fraction of drowned trees and *Echinchloea* marsh, and the greatest expanse drawdown land suitable for agriculture, it seems very likely that more than 75 percent of the annual potential catch of fish will come from this central basin. While the catch survey now underway shows that already 60 percent of the canoes engaged in fishing are on this portion of the lake, it is also the area farthest from the main administrative, marketing and distribution centres at Yelwa and Kainji.

Owing to the short period of stratification and relatively little enrichment of deep water, upwelling at the downwind margins of the lake is unlikely to be significant in the distribution of production in the lake, even though such movements of the water should be appreciable.

Much greater significance is likely to follow from concentrations of nutrients in the bays of the Swashi, Kpan, and other rainy season tributaries to the lake. These are also likely to be important migratory routes for flood-spawning fishes.

Stirring of the bottom over the former Foge Island during low water when storm winds are frequent (Section 4.5.3) is another likely source of enriched food supplies, or at least, greater vulnerability of bottom organisms.

6.3 DEPTH DISTRIBUTION OF FISHES

It was noted in Section 5.2.3 that small clupeid fishes seem to be distributed throughout the lake, concentrating during daylight hours at depths to 20 metres. Numerous echoes of large fish have been noted at depths near this layer. Though these echoes have not been identified there is reason to believe that they are of adult Lates, both as they show morphological adaptation to predation at low light intensities (a reflective layer in the retina of the eye) and as they are reported to be captured most successfully at such depths in other lakes during daylight (Lake Rudolf and Lake Tanganyika). While such species are better fished at night commercially, deep trolling for Lates and and other species may become a valuable adjunct to the development of the game reserve and tourism even though rather special boats and equipment are required.

Stratification of the lake from February to May is likely to impose additional depth restrictions on fish distribution owing to the poor oxygen conditions in the layer below the thermocline. While a number of the species in the lake are adapted to low oxygen through supplementary air-breathing, these species tend to be inshore or surface-active species.

6.4 MIGRATION AND SPAWNING OP PISHES

Many of the species of the Kainji Lake appear to migrate into flooded areas for spawning. A notable feature of Kainji Lake is the wide dispersion of the flood period over time. Plow in the small lateral streams begins to rise in May and June soon after the start of the rains. It is also noted that catches of tiger fish (Hydrocynus) below the spillway of the dam increase at about this time. The main flood begins to rise in August and it is likely that the majority of the flood spawners of the river started migrations toward the latter part of August and September. The black flood of the Niger maintained high water levels in the river until April, while the local streams drop in December. The lake level is delayed relative to the river cycle by about one month. As there is little information available concerning the stimuli which initiate spawning behaviour in these species, it may be expected that several generations may be required to accomplish readjustment of the timing of spawning to the somewhat altered flood regime.

6.5 SEASONAL VARIATION *IS* GROWTH RATE OP PISHES

In comparing the seasonal characteristics of the river and of the lake, it appears that the seasonal cycle in the lake is rather more complex than in the river, particularly with respect to temperature. There appears to have been only a single short cool season in the river, beginning in mid-December when temperatures dropped rapidly from around 30°C to 22°C. The higher temperatures were reached again by February, and remain more or less at this level for the rest of the year. While the temperatures at the surface of the lake remain high except during the same period, temperatures below one metre show a double seasonal cycle (Fig. 12). Most other factors show a single seasonal cycle. The combined effects of the numerous factors affecting growth of fishes may, however, lead to a more complex pattern of growth of the fishes owing to distinct differences in phase among the annual cycles of water level, illumination, nutrients, stratification, and the several floods. Thus, while conditions in the lake have been described in this paper as highly seasonal for a tropical system, it would be well to reserve judgement regarding seasonality of fish growth until more direct information is available.

6.6 UNDERWATER VISIBILITY

It is usually assumed that the visibility of fishing gear to fishes can be an important factor in gear efficiency. The local fisherman are quite aware of this and anxiously await the onset of the turbidity of the white flood. The change in underwater visibility is quite pronounced in the lake, varying by a factor of about 10 (Section 4.4). Turbidity, which increasing scattering of light, is more effective in reducing underwater visibility than light absorption reduces the intensity of light. This is particularly the case where image resolution is necessary as in distinguishing the netting of large mesh gill nets.

Net colour is also thought to be significant although the evidence is less certain that colour plays an important role. In this case, it is necessary to match the net colour to the apparent colour of the background. The latter may depend very much on the angle of view. It is worth noting that both the intensity and the colour of the underwater light is markedly altered by the white flood, making a red net appear lighter and a blue net darker than would be the case when the turbidity is reduced.

It is also interesting to note that red seems to be a frequent "signal" colour among the fishes of Kainji. Particularly noteworthy is the similar colouration of species of Alestes, Citharinus, and Hydrocynus, all of which are more or less silvered but counter-shaded (dark above) with a patch of red along the ventral surfaces and the lower portion of the caudal fin. Apparent dominance of red pigment to dominance of red light in the Niger flood waters would appear to be connected.

6.7 AGRICULTURAL DEVELOPMENT AMD ENRICHMENT OF THE LAKE

In projecting the present productivity of Kainji Lake into the future, the most likely source of gradual change is change in the nutrient input to the lake with changes in agricultural practice in the drainage basin. With an increase in the use of nitrate and phosphate fertilizer, the most deficient nutrients in the local soils, an increase in these nutrients may be expected in the lake. These are also the nutrients that appear to be most critical to the productivity of the lake itself. Such development will almost certainly reduce the amount of dry season burning, an uncertain factor in the present productivity of the lake (Section 4.5.7). There is little doubt, however, that the overall effect will be to increase the nitrate concentrations, while phosphate will increase more slowly (phosphate tends to be more tightly bound to the soil). Owing to the low level of nutrients in Kainji Lake, such development may be expected to increase the fish production of the lake significantly though such increases may be accompanied by changes in the species composition.

It is also likely that such development may increase the amount of soil transported by runoff with the effect of increasing the turbidity of the local floods. The latter effect is difficult to evaluate, but is less likely to affect the productivity of the lake itself.

6.8 SUMMARY

The present yield of Kainji Lake is likely to be in the neighbourhood of 20 kg/ha/annum, with most of the total catch obtained from the large central basin of the lake. This estimate is preliminary and of only temporary utility. Much remains to be learned about the relation between the physical and biological character of the lake and optimal fishing strategies.

7. RECOMMENDATIONS FOR FUTURE WORK

The research programme currently underway was established to provide an understanding of the seasonal changes in Kainji Lake as well as a summary of the conditions presumed to be related to potential production of fishes in the lake. In evaluating the work up to the present, it is appropriate to suggest changes in the current research programme and to suggest new projects which appear to be important to the development of the fishery of the lake.

In the preceding chapter a number of applications of the findings of this research were suggested. These suggestions were primarily intended for use by fishery scientists in interpreting and planning their own work, and hence only indirectly provide guidance for development itself. The recommendations presented in this chapter similarly relate to the strategy of further fishery research, while recommendations for management and development of fisheries are expected to follow from the fishery rather than the limnological work.

7.1 RECOMMENDED CHANGES IN THE PRESENT PROGRAMME OF LIMNOLOGICAL RESEARCH

7.1.1 Programme of Physical Research

The general pattern of seasonal changes of the physical characteristics of the lake are now clear, at least for the open waters of the lake. With this background available, the number of sampling stations in the main parts of the lake *can* be reduced, keeping Stations 3 (lower arm), 7 (western half of the central basin), 11 and 12 (each side of Foge Island) and 15 (eastern half of the central basin).

In place of the omitted stations, stations should be added farther inshore, at the mouths of the Swashi and Kpan rivers, and over the eastern shallows near Papiri. These will provide information on inshore conditions in those areas now thought to be deficient from the conditions described for the lake as a whole.

From the analysis of the heat budget of the lake, it appears that the year-to-year variations in temperature of the lake are closely related to the amount and temperature of the inflow. More precise information on the temperature of the inflow is needed to check this finding and to provide a basis of predicting the annual differences in the thermal regime of the lake. Owing to the considerable inconvenience of taking the large research boat into the northern arm, it is suggested that the temperatures at the Rofia ferry crossing be obtained during fishing operations in that area by the fishery crew of the project. As the temperature should be obtained for at least three depths (0.5 m, mid-depth, 1 m from bottom) it would be desirable to obtain an electronic thermometer with a long (30-m) cable for the fishery programme. Such a unit would considerably simplify the present temperature measurements made by the fishery programme.

Limnological studies have shown that turbidity is the most reliable, easily measured characteristic identifying the several kinds of water masses (white and black floods, lateral inflow) which mix in the lake determining local chemical characteristics of the water. At present it is only possible to measure turbidity readily during periods of high turbidity. While a transmissometer was ordered early in the programme, the order had to be abandoned owing to difficulty with the supplier. It is recommended that another attempt be made to obtain a wide-range remote transmissometer (electric), equipped with tri-colour filters, in order to provide more complete information on changing water conditions.

7.1.2 Cooperative Programmes in Physical Research

The project has been cooperating with the University of Ife on both chemical studies and studies of isotopic composition of the lake water. As both programmes are of considerable significance, but are beyond the technical and logistic capabilities of the project, both should be encouraged.

The gross chemical characteristics of the lake can be followed more readily by project personnel than by personnel of the University of Ife. Occasional detailed chemical analyses, (especially of phosphate, nitrate and silica) needed to interpret the changes observed in productivity and plankton composition are best obtained by the Ife group. While a few such analyses have already been made by the University of Ife, both before and after impoundment, anticipated joint expeditions have not been possible to date. Further effort should be made to arrange such joint trips.

Samples for isotopic analysis have been collected by the project and sent to the International Atomic Energy Commission (University of Heidelberg) for analysis. The interpretation of these results is the responsibility of the University of Ife and the International Atomic Energy Commission. The results to date have been of great significance in verifying the sources of water to the lake, and may be expected to provide checks on water balance within the lake. While no changes are needed in the programme, the number and location of samples obtained could well be changed to fit the suggested changes in the stations visited during the regular limnological cruises.

7.1.3 Programme of Biological Research

The initial phase of the biological programme was largely concerned with identification of the various organisms inhabiting the lake. Quantitative work on their abundance and productivity, the second phase of the research, has only begun. These studies should be continued through at least one full year, while a second year would provide a valuable check on the reality of seasonal changes. It is suggested that priority be shifted from the present studies of plankton organisms to studies of the inshore and bottom organisms after a full year's study of the former, while maintaining a check on the plankton work completed.

7.1.4 Meteorological and Climatic Studies

It is now clear that the meteorological information obtained on the regular cruises of the lake is not very meaningful in relation to the effects of weather on the lake. The present meteorological stations are either poorly located for limnological purposes or incomplete. Plans are underway to improve the stations at Shagunu, Yelwa, and Kainji, and to add one at Papiri in connexion with the project's programme of irrigation.

Within one year of the completion of these improvements, that is, with a full year of records, a further analysis of wind and radiation balance for the lake would be desirable, as the present data do not permit reasonable assessment of the effect of change from river to lake on local conditions of wind, humidity, temperature and evaporation. While the effects of the lake are expected to be significant only within a few miles of the lake, agricultural, fishery and transport developments on or near the lake are somewhat hampered by the lack of reliable data on these conditions. If possible, the analysis should include a study of wave conditions on the lake in relation to the local winds to provide a basis for advice to fisherman on lake hazards in the central basin. While a pole for measuring wave heights was constructed for the project to be used on the routine cruises, systematic measurements of wave heights were postponed until such time as valid wind data were available.

7.2 NEW STUDIES

While several of the studies suggested here are basically limnological, others are suggested to assist in bridging the relation between environmental characteristics and fishery implications and hence involve other research programmes. Several are essential to the utilization of data given in this report for guiding the management of the fisheries of the lake.

7.2.1 Meteorological and Climatic Studies

7.2.2 Total Dissolved Solids and Predictions of Catch

As discussed in Section 6.1.2, a hypothesis has been advanced relating expected catch of fishes to the morphoedaphic index. To date, the value of total dissolved solids used in calculating the index for Kainji has been calculated from other data. The necessary equipment for measuring the value directly is now available at the project, A careful study of the relations among total dissolved solids, turbidity, total ionic concentration and conductivity should be undertaken and can readily be accommodated in the present limnological programme. This should provide a basis for re-evaluating the predictions made on catch and their relation with the results of the catch surveys now underway at the project.

7.2.3 Variability of Limnological Factors

While the general features of the physical limnology of the lake have now been described, there remains some uncertainty about short-term and local variation. In addition to the recommendations made, the following new studies seem both desirable and feasible within the present resources of the project.

(a) Temperature Variation

The present measurements of temperature at selected stations have given some indication of differences from place to place on the lake which are not easily interpreted. It is recommended that a surface temperature recorder be installed in the research boat so that the changes in temperature from station to station can be interpreted in terms of data obtained between stations1/.

(b) Changes in Chemical Composition with the Floods

While the present data suggest little variation in conductivity and other measures of chemical composition over the year, data from White *et al.* (1965) suggest that substantial changes in the composition of the inflow occur during a period of about three weeks when the local and white floods are rising. An intensive study of this period could be readily undertaken from the station at Shagunu. The field work could be handled by the Limnological Technician using a small boat.

7.2.4 The Distribution and Feeding Habits of the Small Pelagic Fishes of the Lake

In Section 5.2.3 it was suggested that the scattering layer observed with the echosounder throughout the lake was produced by small fishes, probably the clupeids *Sierrathrissa* and *Pellonula.* If these prove to be as abundant as the echosoundings suggest, they will necessarily comprise a very significant element either of the developing fishery directly, or as food for the predators which are now being fished. It has been proposed that the counterpart limnologist should use part of his time in examining the relationship between the zooplankton of the lake, which he is currently studying, and these clupeids which presumably obtain a significant portion of their food from the zooplankton. This work should be encouraged while, in addition, it is recommended that someone with experience in interpreting echosoundings, preferably with experience with pelagic shoaling species, be invited to Kainji for several weeks to train project personnel in the use of the echosounder and to assist in interpreting the records that are now being obtained.

7.2.5 Physiological and Behavioural Studies of the Species of Fishes of Kainji Lake

The application of limnological knowledge to practical fishery management is largely dependent upon an understanding of the physiological requirements and behavioural preferences of the species which comprise a fishery. Unfortunately this latter understanding is much poorer for the species inhabiting tropical waters than for those of the temperate regions. The following recommendations are made to help bridge the gap between the limnological studies and practical fishery management:

(a) A thorough review of the literature pertaining to ecological life histories of tropical freshwater species should be undertaken, perhaps by FAO, emphasizing the environmental requirements of those species which are commercially important in the tropics.

(b) Universities throughout Africa should be encouraged to undertake such studies which are rather too specialized and time-consuming to be made a part of such projects as the Kainji Lake Research Project, While these studies are a direct contribution to the development of a fishing technology, they remain clearly in the category often regarded as "basic" research.

1/ A suitable recorder (Rustrak) is available at the project, but requires the addition of a thermistor bridge and cable. Inquiries concerning the latter may be directed to the Rustrak Company.

7.2.6 Long-range Changes in the Productivity of the Lake

It has been noted that gradual changes in the productivity of Kainji were most likely to follow indirectly from changes in land use in that part of Nigeria and West Africa which supplies water to Kainji Lake. The Kainji Lake Research Project is in a favoured position to integrate the findings of several kinds of disciplines as they relate to changes in fertilization, burning of grasslands, grazing lands and distribution of human populations. All these are pertinent to the future productivity of the lake, for better or for worse.

7.3 SUMMARY OP RECOMMMDATIONS

While some significant study programmes in fishery limnology are limited by available knowledge, time and equipment, the present capability of the project for limnological research seems adequate for immediate needs. It may prove advisable to engage a consultant in echosounding for a short period of time.

In relation to new limnological programmes, further emphasis should be given to cooperation with Nigerian universities. The project should retain responsibility for integrating the work of such institutions with the specific demands of fishery development.

<u>Appendix 1</u>

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Table 1

SUMMARY OP SURVEY CRUISES (LIMNOLOGICAL PROGRAMME)

Cruise Number	Date	Boat	Bathythermograph Stations	BT Slide Numbers	Complete Stations	Staff	Remarks	
K-4-69	27-28 Aug	16 ft	1(2),2,3,4,5,6,	10-16	2,5,7	Henderson	Extra station	
		Aluminum	7,9	18-19			between 6 and 7	BT17
K-6-69	7-10 Oct	"	1 through 14	20-25	1,3,6,8,10,	Henderson	"	BT26
				27-35	11,13,14			
K-8-69	20-22 Nov	"	1,3,5,6,7(2),9,	37-47	1,6,7,9,12	Henderson	-	
			11,12,13,14					
K-1-70	14-16 Jan	16 ft	1.3,5,6,7,9,13	53-59	3,6,9,13	Henderson	Engine break-down prevented completion	
		Whaler				Adeniji		
K-3-70	14-17 Feb	“	1,3,5,6,7(4),8,	60-61	1,3,5,6,7(2),	Henderson	Includes special stations for co-operative programme with Imevbore, Univ. of Ife	BT62
			9,11,12,13,14,	64-66	8,9,11,12,13,			63
			15	68-79	14			65
								67
K-4-70	16-17 March	“	1,3,5,6,7(2),8,	80-91	1,6,9,11,12,	Henderson		
			9,11,12,13,14		13,14	Adeniji	-	
K-6-70	21-22 April	„	1,3,5,6,7(2),	94-100	1,6,7,9,11,	Henderson		
			9,11,12,13,14	105	12,13,14	Adeniji	-	
K-7-70	3-11 June	“	1,3,7,9,11,12,	106-113	1,3,7,11,12,	Adeniji		

			13,14		13,14			-
K-8-70	22-24 July	31 ft	1(2),3,5,6(2),7,	114-125	1,3,6,7,9,11,	Henderson		
		Houseboat	9,11,12,13,15		12,13	Adeniji		-
K-10-70	13-15 Oct	31 ft	1(2),3(2),5,6,	138-147	1,3,6,7,9,11,	Henderson	No BT148	
		Houseboat	7(3),9,11,12,13,	149-153	12,13,14,15	Adeniji		
			14,15			Karlman		
K-12-70	1-3 Dec	"	1(2),3(2),6,7(2),	153-163	1(2),3,6,7,9,	Adeniji	No BT164	
			8,9,11,12,13,14	165-166	11,12,13,14	Karlman		
K-1-71	14-15 Jan	31 ft	1,3,6,7(3),9,11,	167-178	1,3,6,7,9,11,	Henderson		
		Houseboat	12,13,14,15		12,13,14,15	Adeniji		-
K-2-71	3-5 Mar	"	1,3,6,7(3),9,11,	179-189	1.3,6,7,9,11,	Adeniji		-
			12,13,14		12,13,14			
K-3-71	15-16 Apr	"	1,3,6,7,9,11,12,	192-199	1,3,6,7,9,11,	Adeniji		-
			13		12,13			

<u>Table 2</u>

HYPSOGRAPHIC CHART FOR KAINJI LAKE

Height of Upper Surface (m above M/S/L)	Lake Volume (m^3 x 10^9)	Area of 1-m Stratum (m^2 x 10^9)
142	15.6	1.30
141	14.4	1.24
140	13.2	1.17
139	12.0	1.11
138	10.9	1.05
137	9.9	,99
136	8.85	.92
135	7.95	.86
134	7.10	.78
133	6.30	.73
132	5.60	.67
131	4.90	.63
130	4.3	.58
129	3.7	.53
128	3.25	.48
127	2.75	.43
126	2.3	.39
125	1.9	.35
124	1.55	.31
123	1.25	.26
122	1.0	.22
121	.85	.18
120	.7	.14
119	.6	.09
118	.5	.07
117	.4	.05
116	.35	.04
115	.30	.03
114	.25	.02
113	.2	.01
112	.1	.005
111	.05	-
110	-	-

Table 3

ANALYTICAL HEAT BUDGET FOR KAINJI LAKE 1970

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Units
					RADIATION								
Net Solar	444	447	523	454	493	519	410	388	429	483	459	469	ly/da
Outgoing Longwave	102	87	78	44	86	105	77	77	84	105	130	144	ly/da
Radiation "Balance"	342	360	445	410	407	414	333	311	345	378	329	325	ly/da
						ADVECTION							
Inflow	-24	-6	16	6	2	1	0	-1	0	-2	-9	-24	ly/da
Turbines	2	8	76	9	8	3	0	4	4	+ 1	+2	0	ly/da
Spillway	8	15	37	11	1	-1	-2	6	2	+ 1	0	-1	ly/da
Total Advective Gain	-14	17	60	26	11	3	-2	9	6	0	-7	-25	ly/da
						EVAPORATION AND CONVECTION							
Bowen Ratio	-0.077	-0.021	-0.044	-0.097	-0.032	0.070	0.064	0.075	0.090	0.058	0.056	0.007	
Convection Loss	-30	-8	-20	-43	13	29	22	22	28	21	19	3	ly/da
Evaporative Loss	387	366	453	444	401	414	340	299	313	357	331	389	ly/da
Evaporation Calc.	20.6	17.6	24.3	23.0	21.5	21.4	18.2	16.0	16.2	19.1	17.2	20.7	cm/mo
Total Loss at Surface	357	358	433	401	414	443	362	321	341	378	350	392	
						STORAGE							
Storage	-29	19	72	35	4	-26	-31	-19	10	0	-28	-92	ly/da
Mean Temperature of Lake	26.7	26.5	27.8	29.0	29.6	29.3	28.6	27.9	27.7	27.8	27.4	25.9	°C

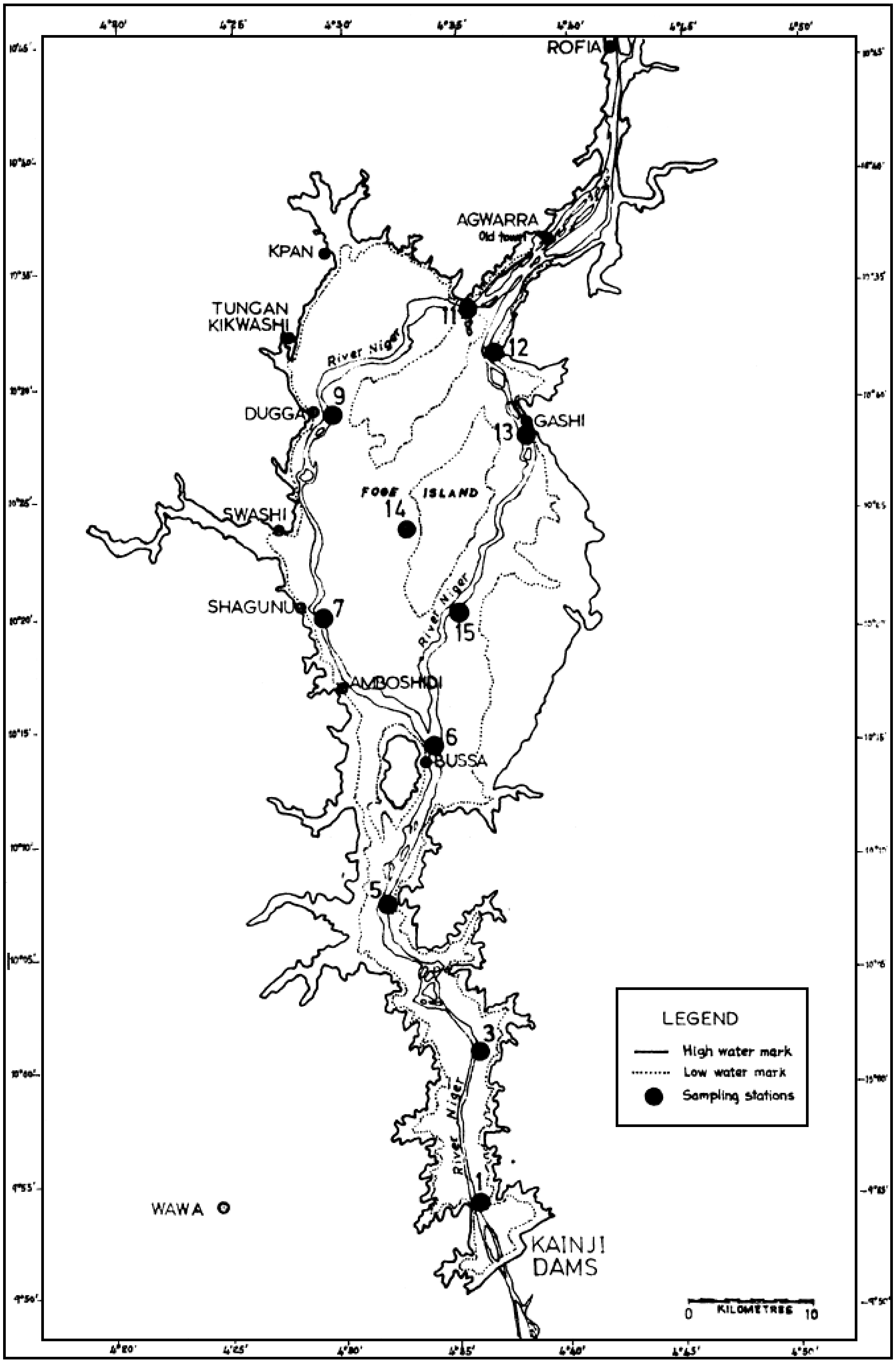

Fig. 1 -Map of Kainji Lake, redrawn from White (1965), with limnological sampling stations indicated.

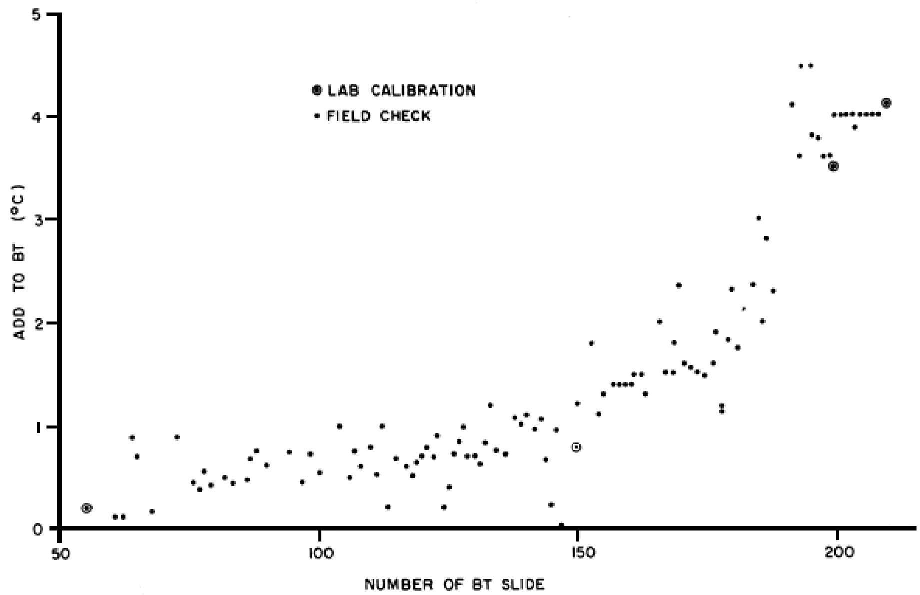

Fig. 2 - Control chart for bathythermograph calibration. The ordinate is the difference between the temperature measured with a mercury thermometer in a water sample taken from 1 metre and the temperature indicated by the bathythermograph for the same depth. Circled points are differences measured by mercury thermometer and bathythermograph in a water tank at the laboratory.

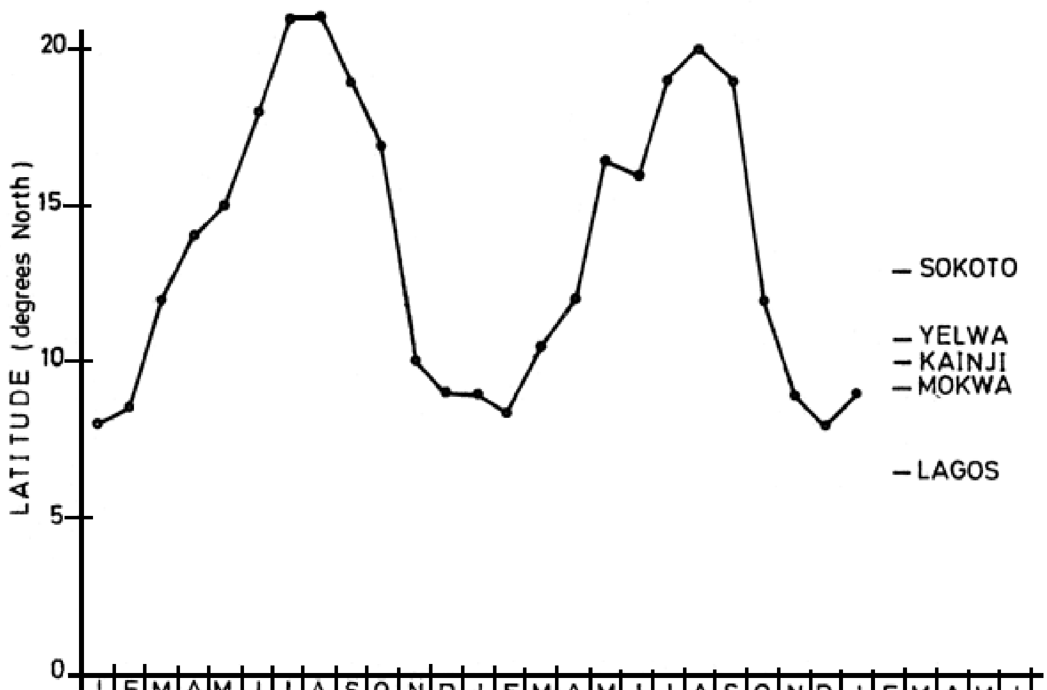

Fig. 3 - Approximate latitudinal position of the Intertropical Front (ITF) as taken from the Agrometeorological Bulletin of the Nigerian Meteorological Service. The latitudes of reference towns are shown at the right.

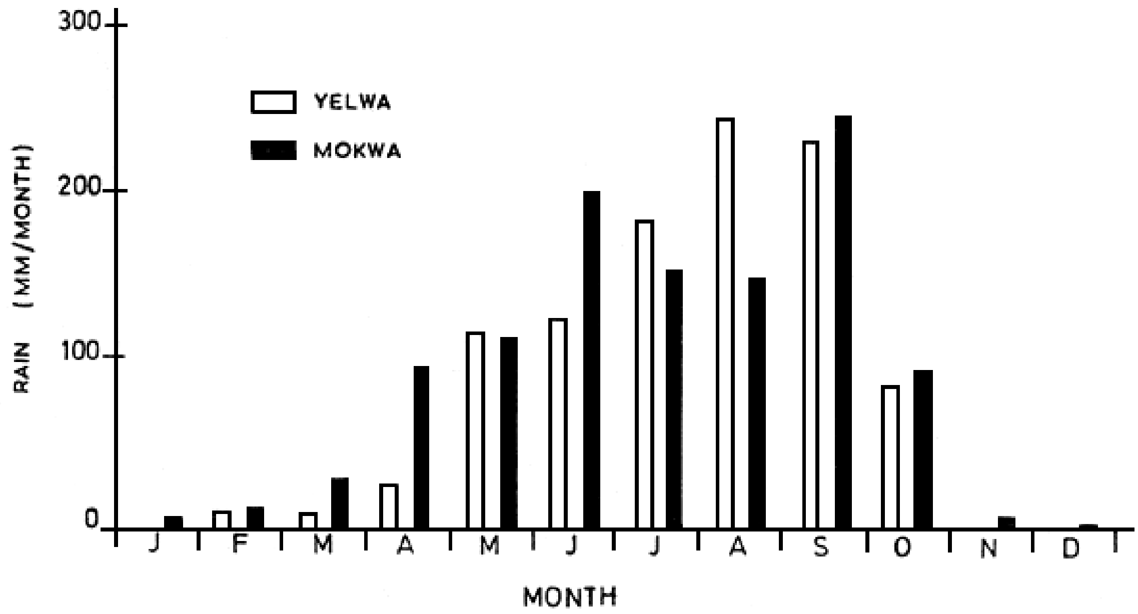

Fig. 4 - Average rain per month at two stations near Kainji Lake from the Agrometeorological Bulletin of the Nigerian Meteorological Service.

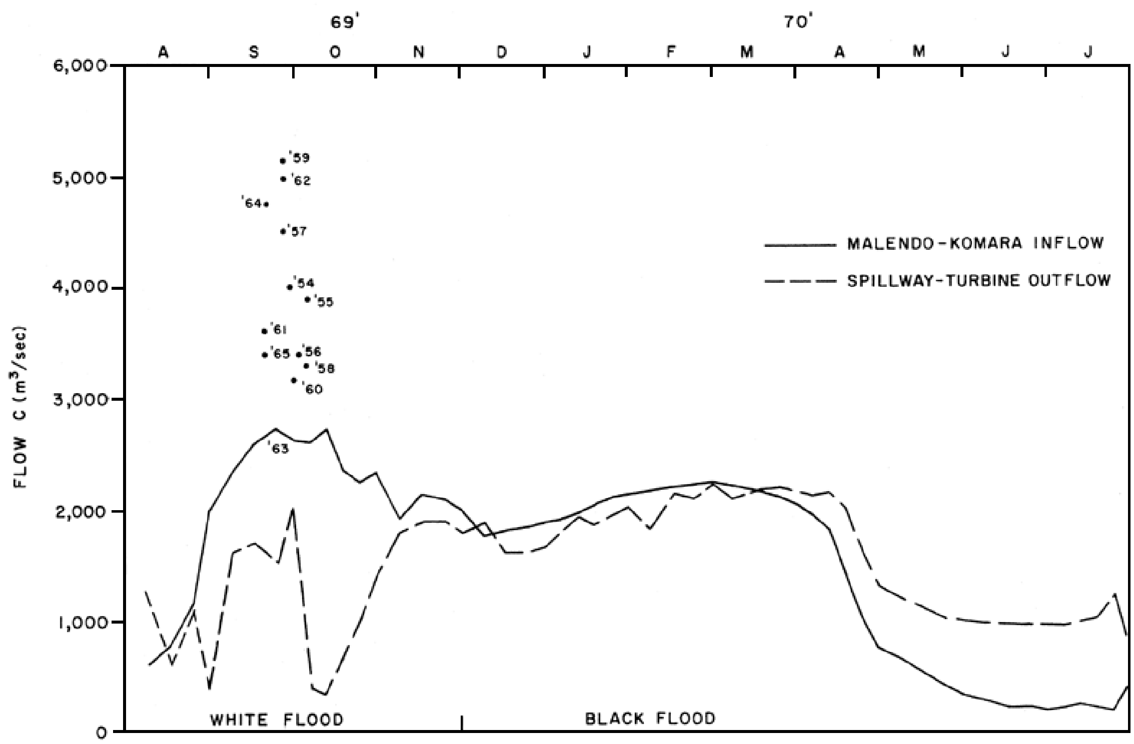

Fig. 5 - Inflow and outflow at Kainji during a year of low flood (1967-70). Dated points are the peaks of the white flood for the stated years.

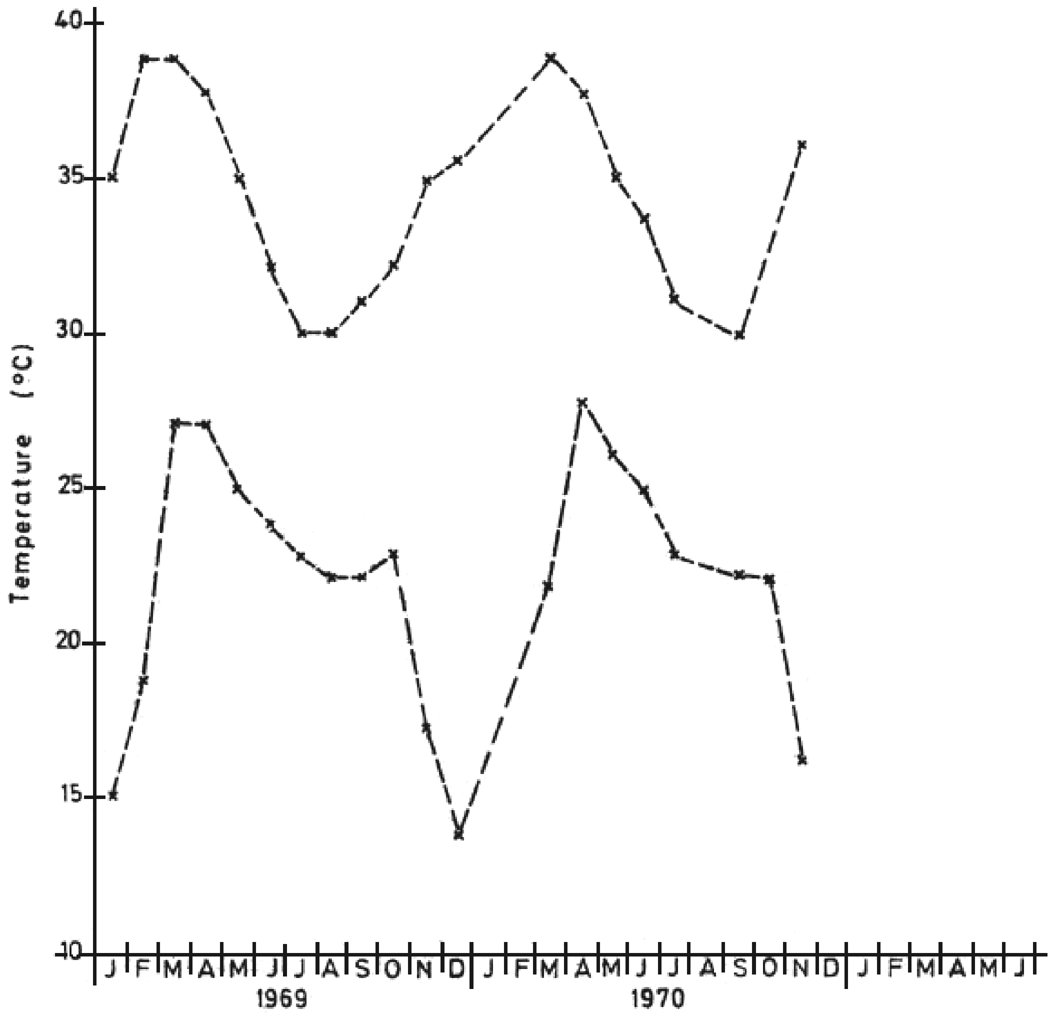

Fig. *6* - Maximum and minimum air temperature by month. Data shown are averages of Yelwa and Mokwa taken from the records of the Nigerian Meteorological Service (Agrometeorological Bulletin).

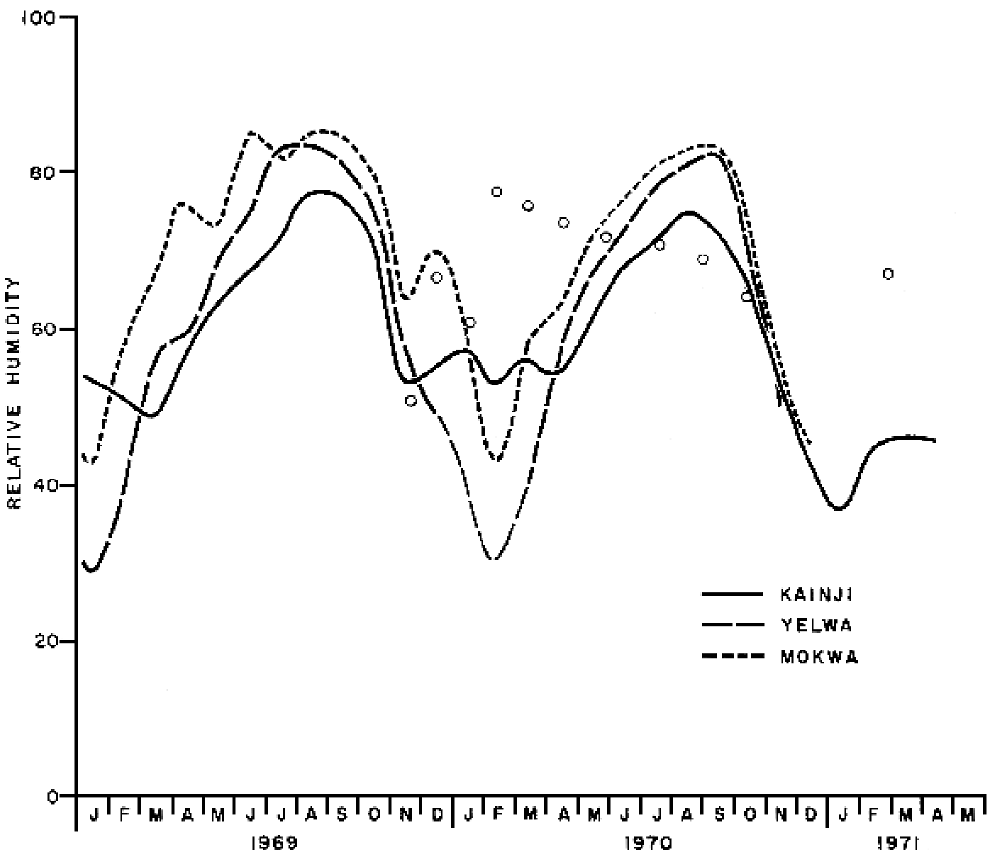

Fig. 7 - Relative humidity by month (mean of daily measurements at 10.00 h). Yelwa and Mokwa data from Agrometeorological Bulletin and Kainji data from NDA meteorological records near the dam site.

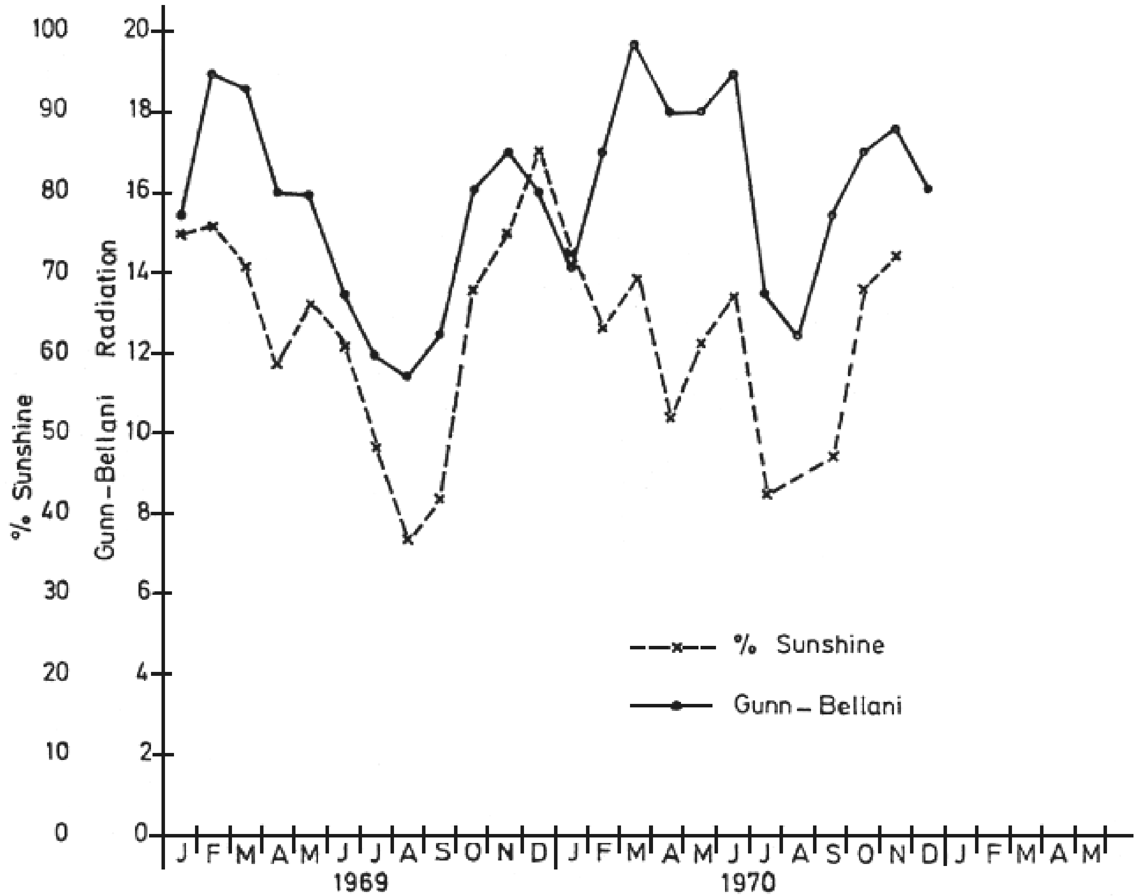

Fig. 8 - Radiation climate at Kainji. Data were obtained from Agrometeorological Bulletin and averaged for the Yelwa and Mokwa stations.

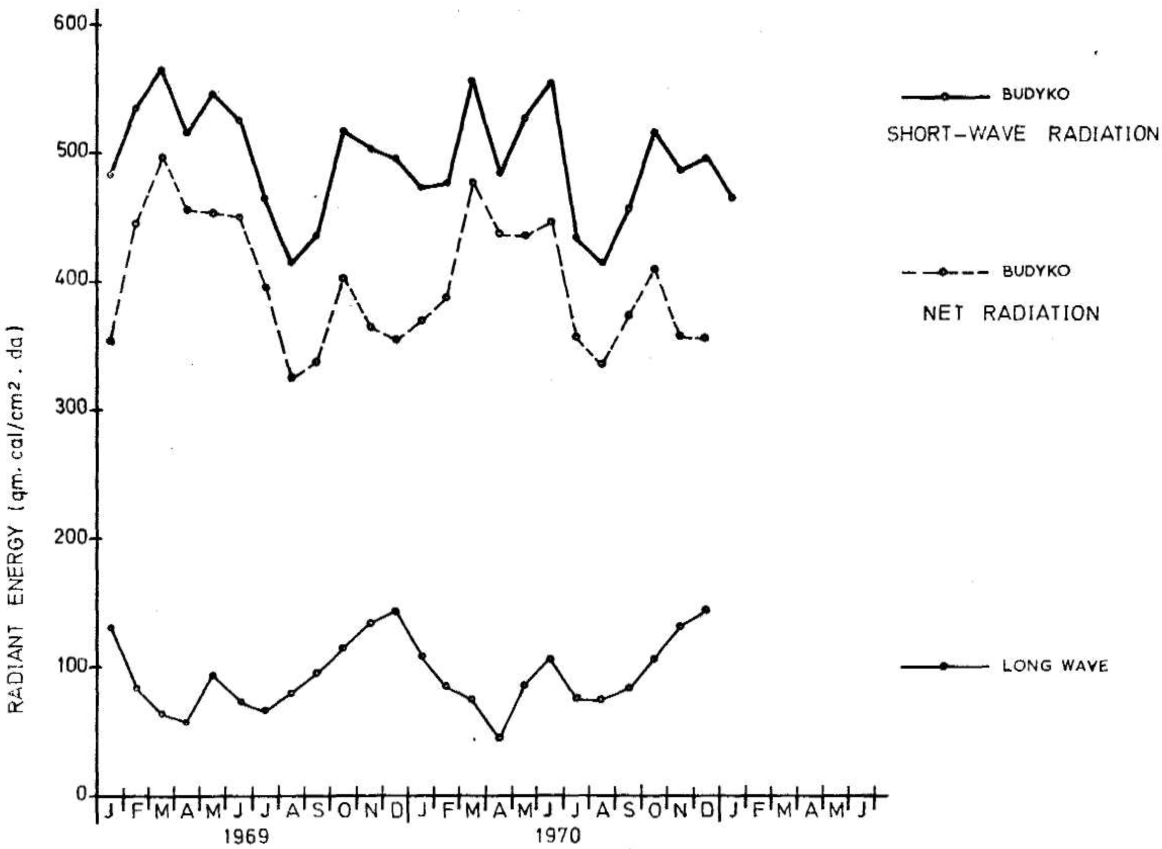

Fig. 9 - Radiation balance calculated for Kainji region using the formulae of Budyko (see text).

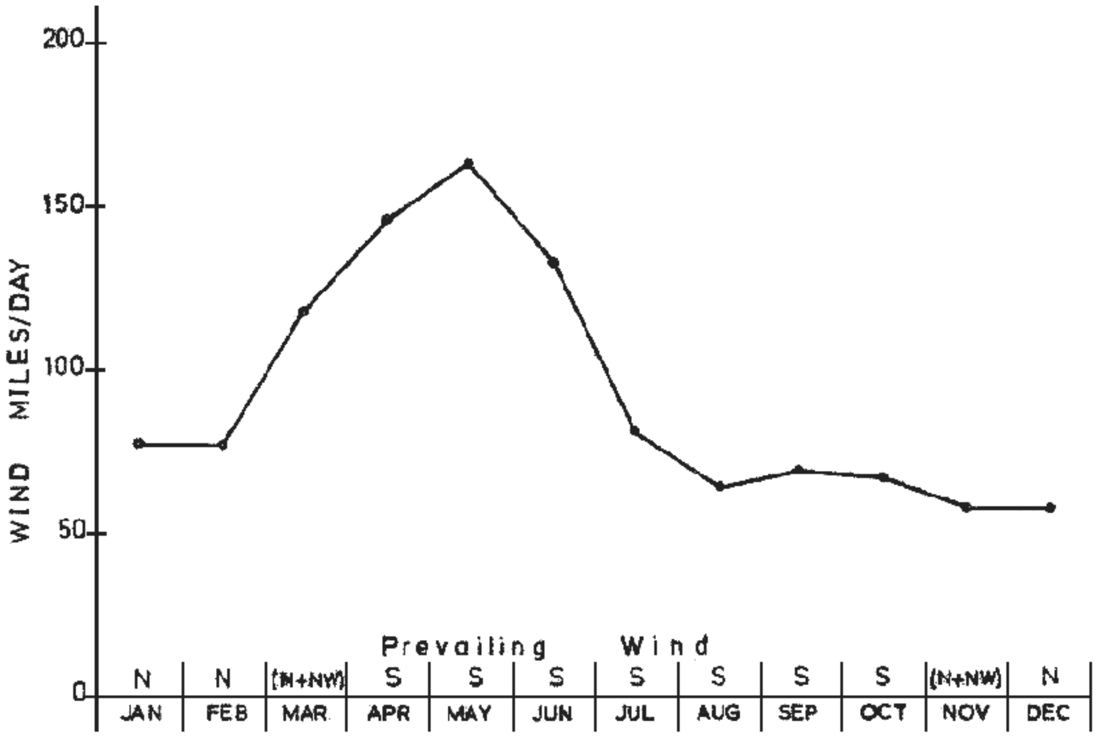

Fig. 10 - Wind run (monthly average) for the Yelwa station (Agrometeorological Bulletin 1969), and prevailing winds for Yelwa from data assembled by J. R. Charter, unpublished.

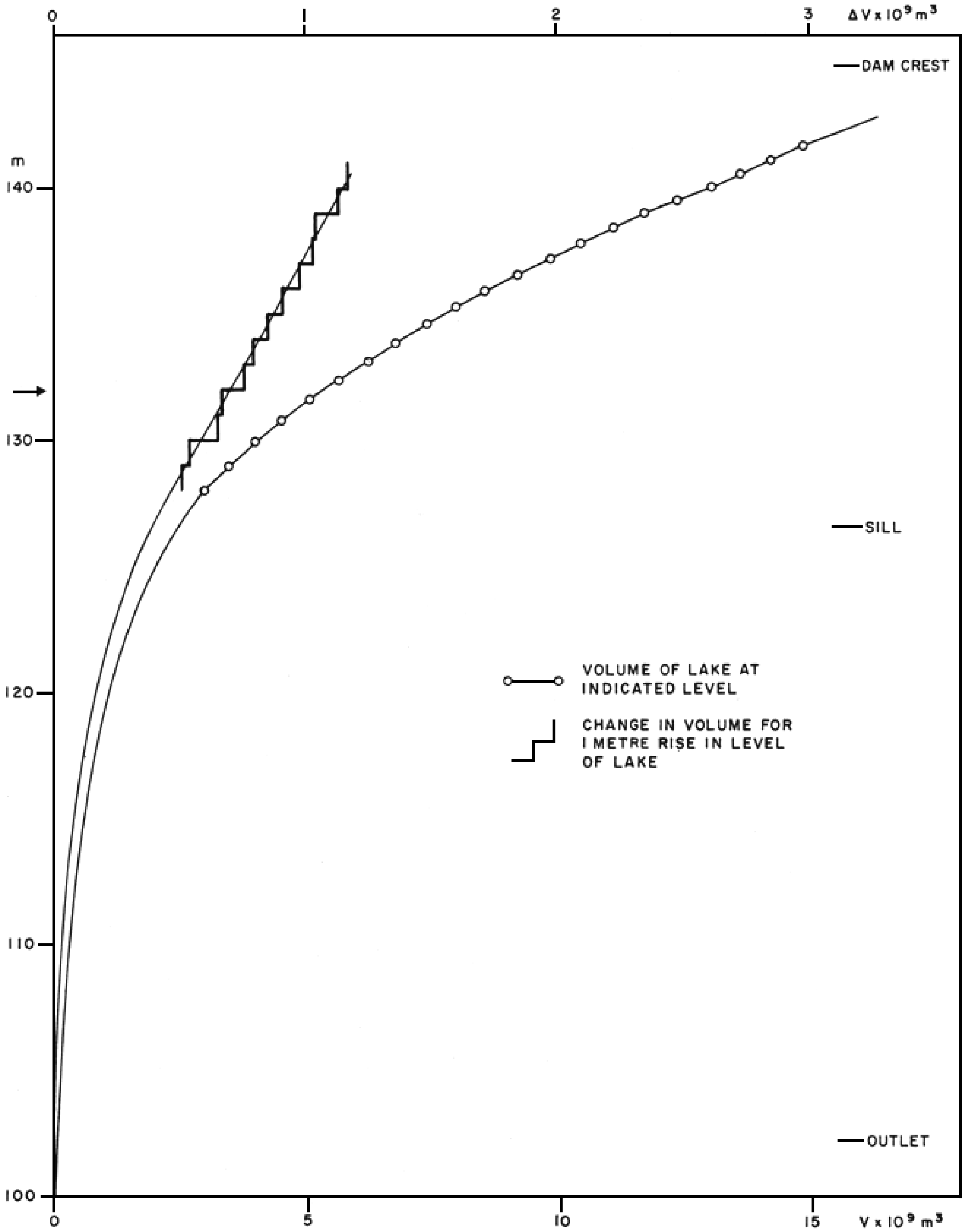

Fig. 11 - Hypsometric chart for Kainji from volume data provided by the Niger Dam authority.

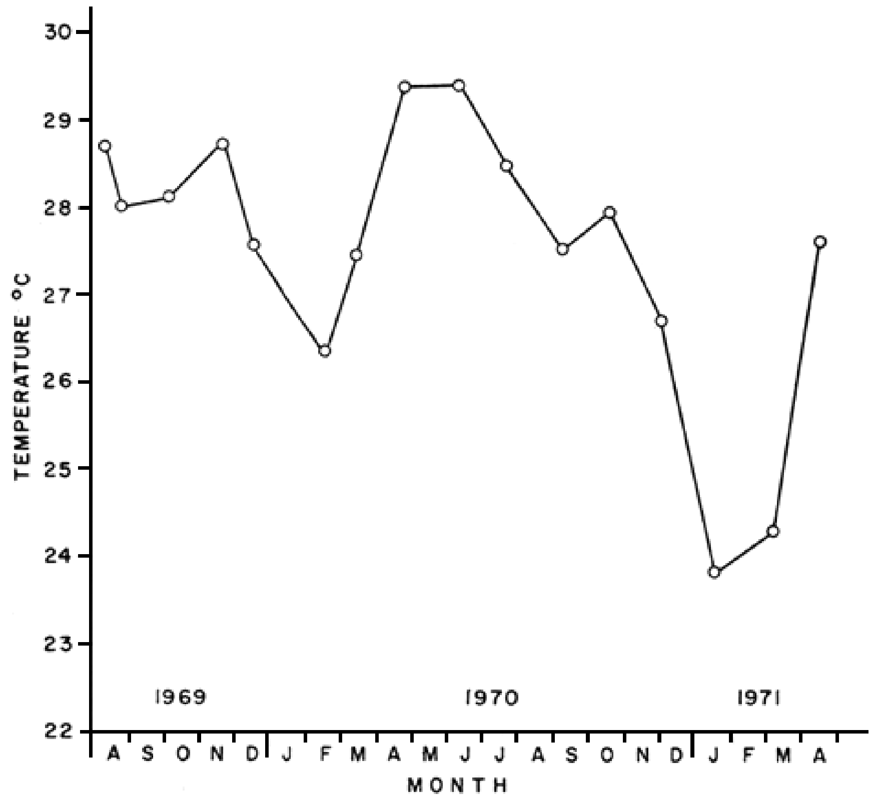

Fig. 12 - Mean temperature of the water column at Station 1 calculated from hypsometric data and bathythermograph observations (1969-71).

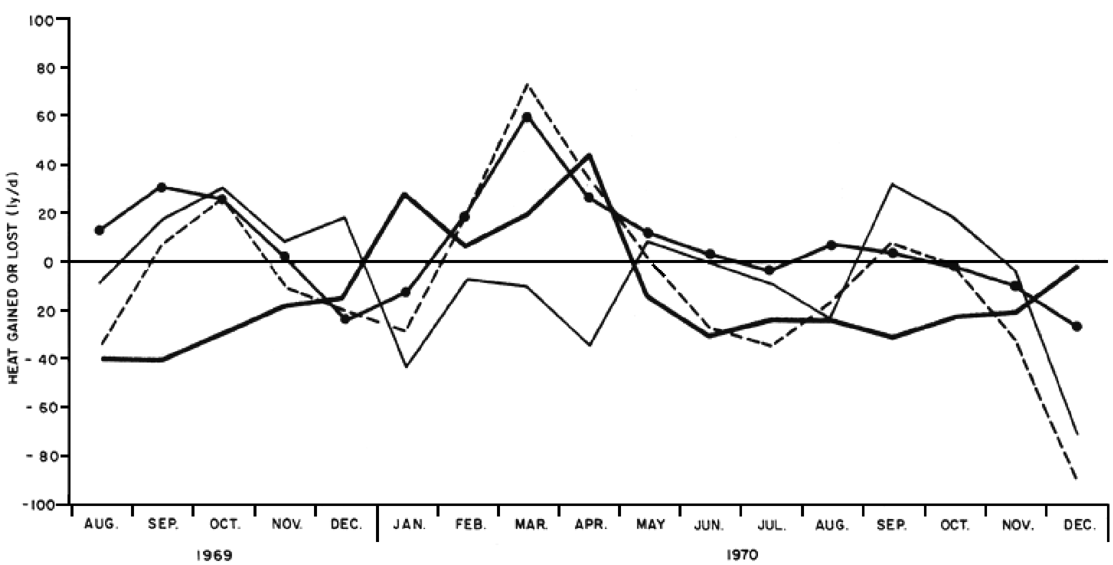

Fig. 13 - Components of the heat budget;

- Net radiation minus evaporation

--- Storage (change in water temperature)

•-• Advection (inflow heat minus outflow heat)

— Convection

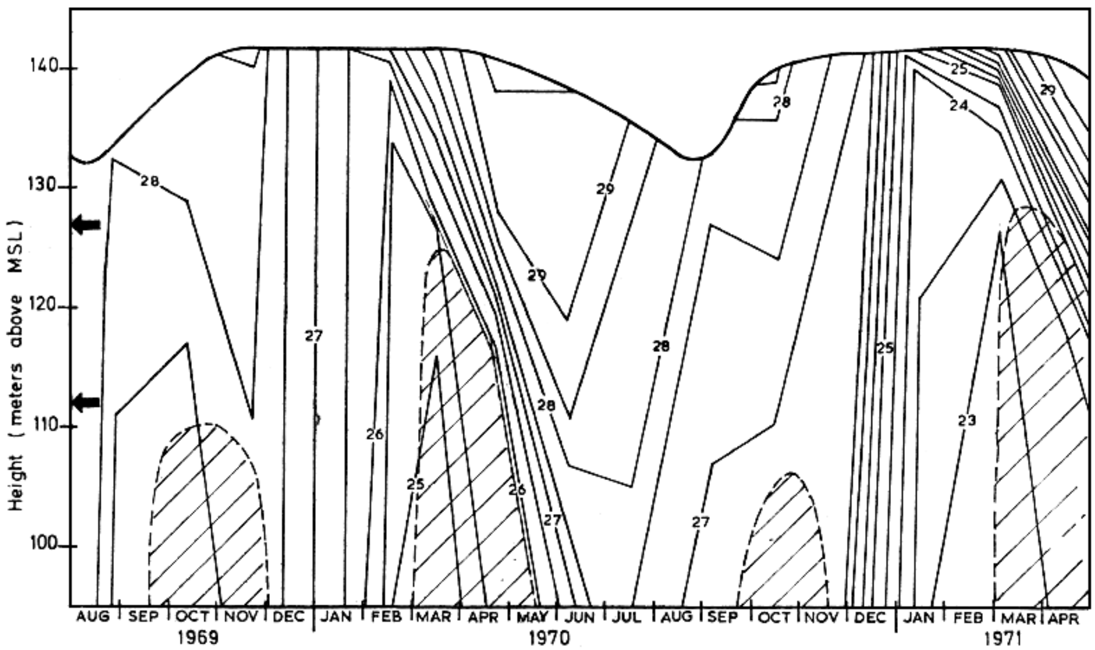

Fig. 14 - Thermal structure of the lake through the period of study. Upper boundary shows the changes in lake level. The numbered lines are isotherms drawn for internal of 0.5°c. Closely spaced lines indicate rapid change in time or depth. Shaded zones indicate depths and times of oxygen depletion (< 1 ppm of O_2). Heavy arrows indicate depth of spillway (upper) and discharge through the turbines (lower).

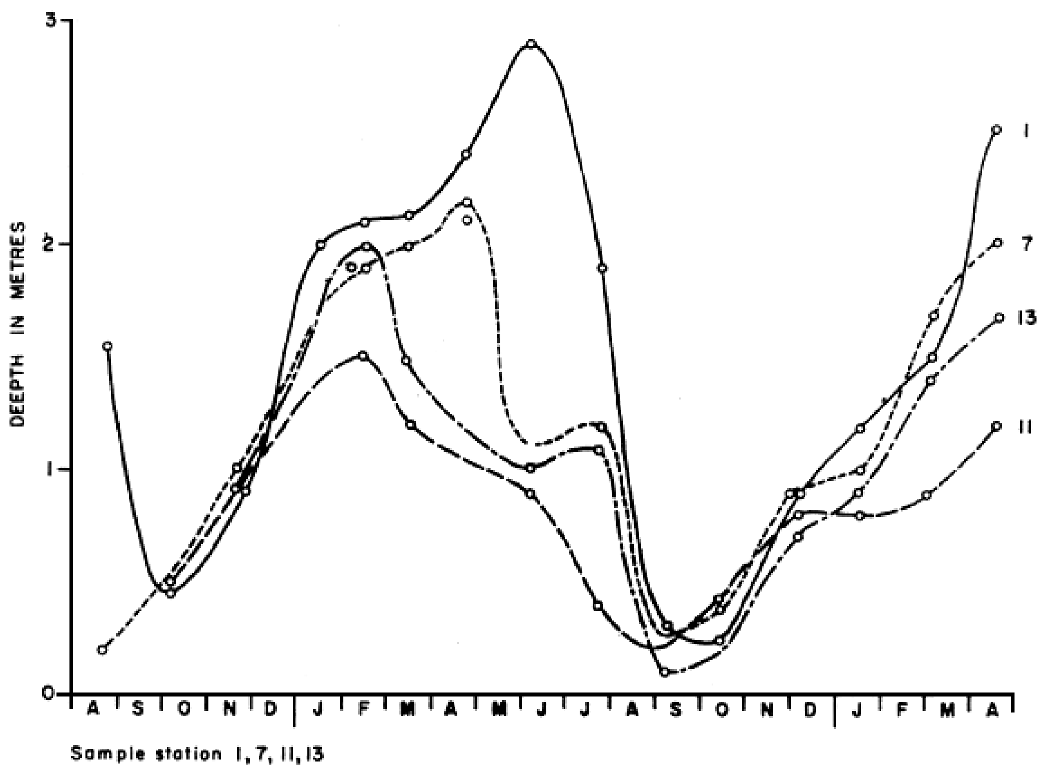

Fig. 15 - Seasonal change in water transparency (Secchi depth - depth of disappearance

of standard white discs) at three stations: Station 1, near the dam, Station 7, western part of the mid-late region, Station 11, west side of Poge Island, Station 13, eastern part of mid-lake region.

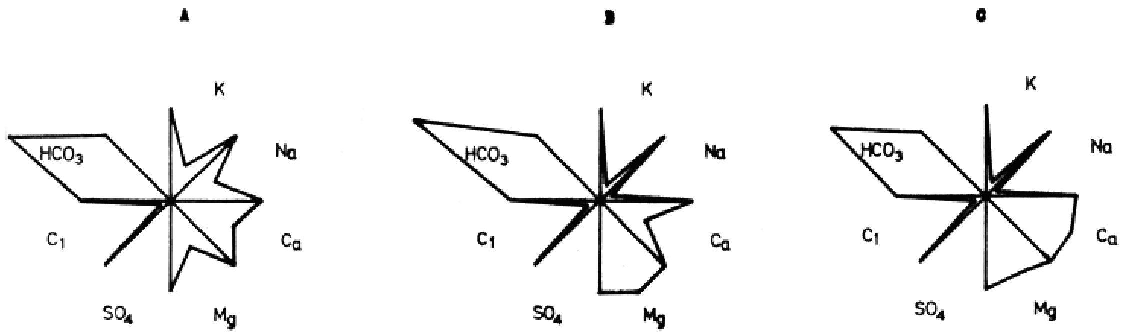

Fig. 16 - Chemical composition of Kainjl water by major ions: A - Rinen (White report, 1965); B -Open lake, 1969; C-Shagumu Bay, 1969

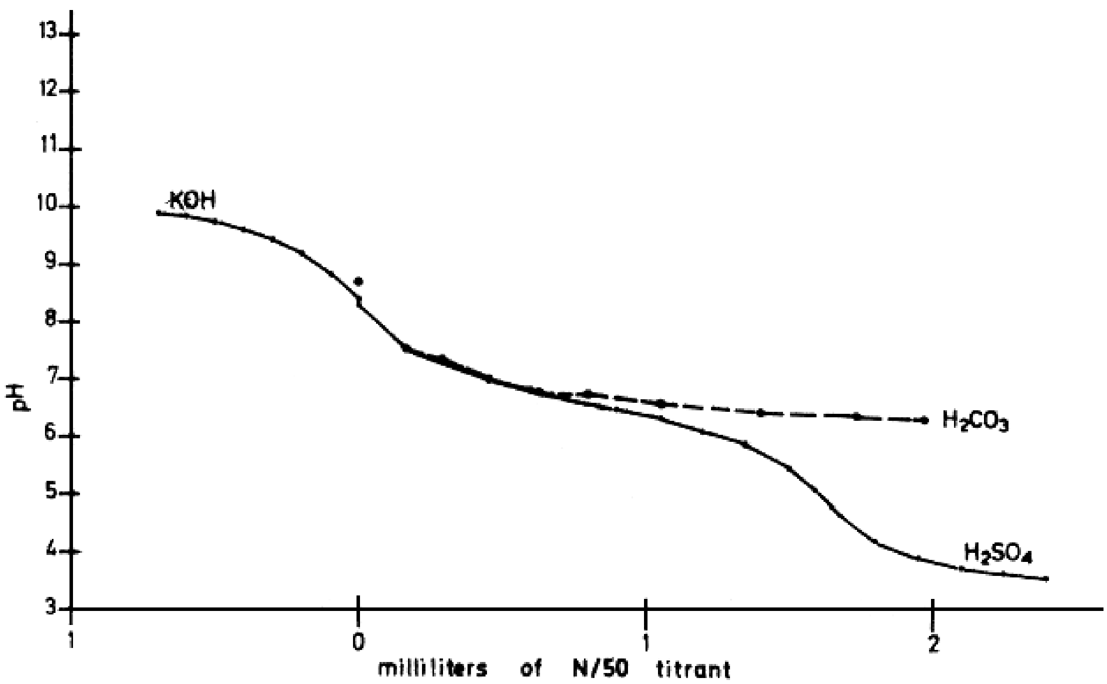

Fig. 17 - Titration curve for Kainji Lake water (South arm, October 1969). Strength of the carbonic acid calculated from assumed strength of CO_2 saturated water. Sample volume - 62 ml, temp. 28°C.