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AN EVALUATION OF THE PELAGIC PRIMARY PRODUCTIVITY AND POTENTIAL FISH YIELD OF KAINJI LAKE, NIGERIA.

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1.0 INTRODUCTION

The trophic status of natural waters is measured mostly by the photosynthetic activities of its phytoplankton - a process commonly called photosynthesis. Primary production estimates are derived from this photosynthetic process. According to Vollenweider (1969), primary production estimation is concerned with "evaluation of the capacity of an ecosystem to build up, at the expense of external energy (radiant and chemical), primary organic compounds for transformation and flow to a higher level trophic system". It measures the trophic status and changes in trophic characteristics, over time, of open water systems.

The fundamental process involved in primary production is usually expressed by the following equation:

$$6CO_2 + 6H_2O + \text{Light energy} = C_6H_{12}O_6 + 6O_2$$

Based on this equation, carbon uptake (from CO_2 using radioactive carbon technique) or dissolved oxygen production (O_2 evolution of the light and dark bottle technique), are the two principal methods for measuring primary productivity. While the former method is known to be much more accurate, its requirement for sophisticated equipment, in addition to a high level of safety and expertise in handling radioactive materials (Vollenweider, 1969; Wetzel, 1983), makes the latter method the most commonly used.

Primary production studies in the tropics is not new, although most of the investigations were carried out in East Africa are old, dating back to the 1950s & 60s. The work of Talling (1957), on the Nile and Lake Victoria, perhaps represents the earliest and most comprehensive report of primary production in Africa. Other studies include those of Elster and Vollenweider (1961) on the Nile, Hydrodome, Mariut and Quarum in Egypt; Vollenweider (1965) on Lakes Victoria, Albert, Edward, George, Bunyoni and Mulehe; Lemoalle (1969) on Lake Chad; Vinner (1970) on Volta Lake; Gant (1972) on Lake George; Allanson and Hart (1975) on Lake Sibaya; Biswas (1978) on Lake Volta and Melack (1979) on four Kenyan Lakes. Outside Africa, within the tropics, Ganapati - Sreenivasan (1970), studied primary production in some fish ponds and reservoirs in India. These studies are the major ones known in freshwater ecosystems in the tropics.

Little documented information is available on the subject of primary production in Nigeria. The few available are those of Imevbore *et al* (1972), Karlman (1973) and Adeniji (1979,1980, 1990). Perhaps, the most comprehensive and earliest literature on the pelagic primary production in Nigeria Inland waters is that of Karlman (1973), on Lake Kainji, based on sampling carried out in 1971/72. This study revealed that pelagic primary production in Kainji Lake is generally low (2.193 g $O_2m^{-2}d^{-1}$ or 0.822 g $Cm^{-2}d^{-1}$).

Interests in primary production studies, essentially stem from attempts to relate it to potential and actual fish production in reservoirs. The potential or theoretical amount of fish that can be expected from a fishery has often been assessed using empirical limnological formula such as those derived from morphoedaphic index (MEI) and primary production covariate. The MEI of Ryder (1965), based on conductivity and mean depth and the regression equation of Melack (1976), which utilized pelagic primary production data, are two principal methods for estimating potential fish yields in aquatic systems. The first method is by far the most commonly used. The concept of MEI is based on the importance of dissolved materials (nutrient index) in controlling the yield of fish (Jenkins, 1967). Henderson (1971) described the index as 'the simplest efficient predictor of yield of standing crop per unit area of a lake' , while Kerr (1982) stressed its robustness in system theory analysis, because of its capacity to combine complex ecological factors in yield determinations.

On the other hand, the primary production covariate has been used by very few workers as an alternative to MEI in the development of predictive models of fish yield. Henderson (1973) found only a fair relationship between primary production and fish yield but indicated that because of the enhanced energy transfer efficiency of more productive systems, fish yield could be 'a power function of primary production'. Oglesby (1977) and Melack (1976), working with a combined set of North American, European and African lakes, indicated that measurements of gross primary productivity can improve assessment of fish yields from tropical lakes. The MEI has been most widely used and tested in several North American, East and Central African lakes (Jenkins,1967; Melack,1976).

1.1 Terms of Reference

Based on the above rationale, the following specific terms of reference are addressed in this report.

- A general overview of primary production in freshwaters and in particular, it's previous status in Kainji Lake .
- Evaluation of the present level of primary production in the lake, using data for 1995 to 1997 and comparing with previous records.
- Evaluation of the potential fish yield of the lake using the data on pelagic primary production and the Morpho–Edaphic Index (MEI) and comparing with actual catch from the Kainji Lake Fisheries Promotion Project (KLFPP) catch assessment survey.
- Discussion of possible factors for the results obtained.

2.0 RATIONALE OF THE STUDY

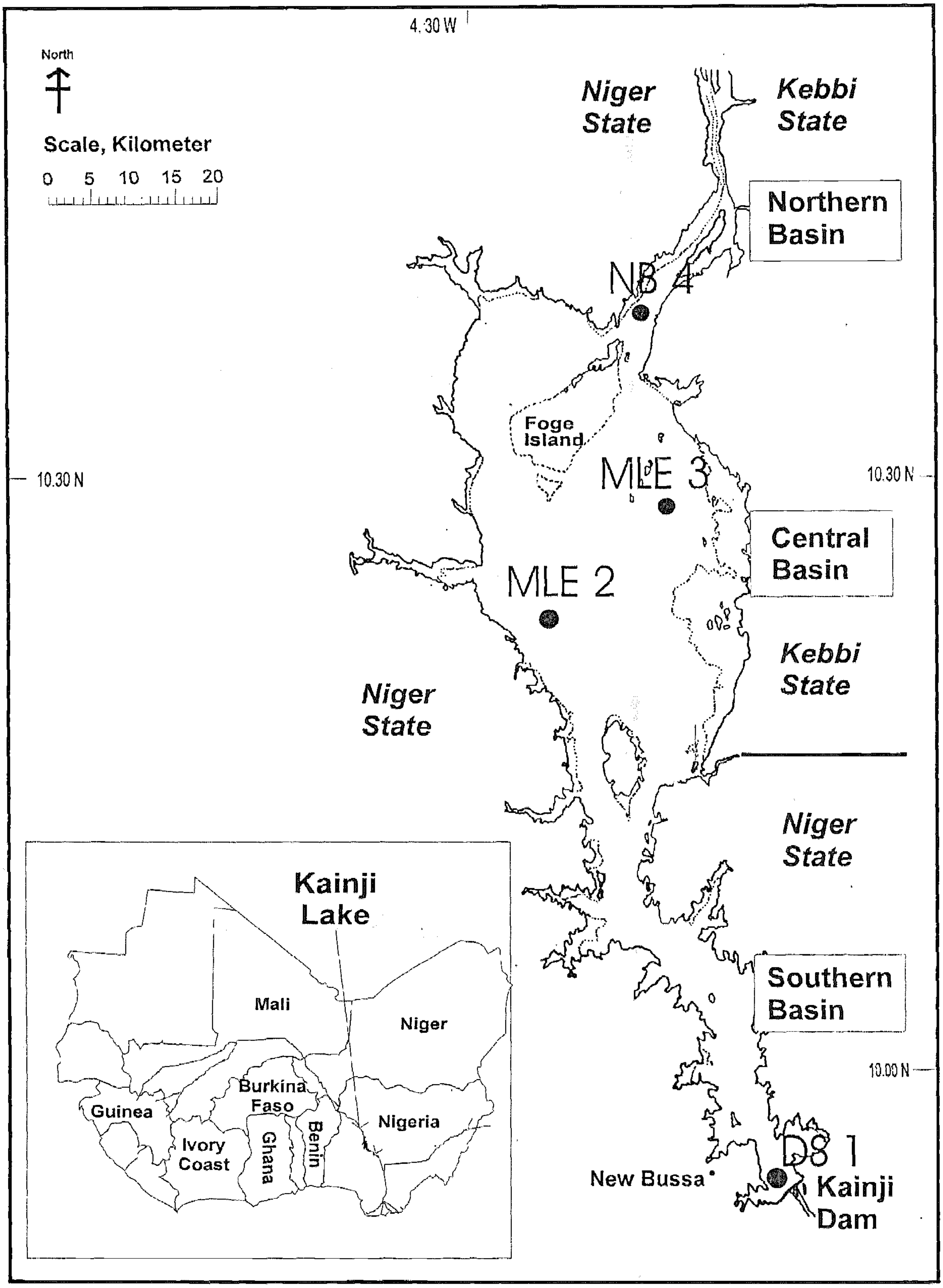
For sometime, there has been concern about the dwindling catches from Kainji Lake as production was estimated to have plummeted from about 28,638 t yr^{-1} in 1970/71 (Bazigos,1972) to less than 10,000 t yr^{-1} in the 80's (Ita,1993). This notion of an overfished lake was however, reversed by recent catch estimates from Catch Assessment Surveys (CAS) of the Nigerian-German (GTZ) Kainji Lake Fisheries Promotion Project (KLFPP) which estimated production at 32,474 t yr^{-1} in 1995. One factor that could account for this observed increase, it was thought, was improvement in the nutrient status and consequently, primary productivity of the lake. This scenario informed the major objective of this study, which is an attempt to evaluate the present level of primary production in the lake and relate this to previous records and to present levels of fish yield from CAS and other empirical yield estimates like the MEI and the pelagic primary production covariate.

3.0 MATERIALS AND METHODS

3.1 The Study Area

The Kainji Lake (Fig. 1) was impounded in 1968 in the Guinea Savannah Vegetation Zone of north-western Nigeria. It is located between longitudes 9°50' and 10°55' East and latitudes 4°20' and 4°45' North. Detailed information, on the lake's characteristics, is available in Adeniji (1975), El-Zarka (1973), Karlman (1973) and Imevbore (1971). The three major basins of this lake i.e. the Northern, Middle and South Basins were described, in detail, by Mbagwu and Adeniji (1994) and were recognised in the determination of sampling stations for this study.

Fig. 1 A Map of Kainji Lake showing Sampling Stations 1-4



3.1.1 Sampling Stations and Frequency

Four stations (Fig. 1) were established and sampled for this study. Station 1 is located in the Southern basin, at the Dam site (DS), about 0.5 km from the dam wall. This station was sampled monthly from March 1995 to February 1997. Stations 2 and 3 were located in the Western and Eastern section of the middle basin of the lake and are designated MLW and MLE, respectively. Station 4 (NB), was located in the northern basin. These three stations were sampled at quarterly intervals between March 1995 and February 1997. The term 'other stations' wherever it appears in this text refers to these three latter stations i.e. MLW, MLE and NB.

3.2 Parameters Studied

Limnological factors investigated in the course of this study included water temperature, hydrogen ion concentration (pH), conductivity, water transparency, dissolved oxygen content, pelagic primary production and potential fish yield.

3.2.1 Water Temperature

A two-litre transparent Van-Dorn water sampler with a mercury thermometer hung on its inner side was used to collect water samples from various depths and the water temperature measurements were read to a precision of 0.05°C.

3.2.2 Hydrogen ion Concentration (pH)

This was estimated on the lake with a lovibond comparator and later cross-checked with a pH meter in the laboratory.

3.2.3 Conductivity

The conductivity of water samples was measured with a conductivity meter with temperature compensation and recorded in μmhos cm^{-1}

3.2.4 Water Transparency

The transparency of the lake's water was measured by using a 20 cm-diameter all-white Secchi-disc and expressed as Secchi-disc transparency in metres.

3.2.5 Dissolved Oxygen Concentration

This was measured by using the azide modification of the Winkler's method as described by America Public Health Association *et al.* (1980). Detail information on the preparation of the reagents, titration and calculation of the dissolved oxygen are similar to those of Wetzel and Likens (1979) and Adeniji (1990).

3.2.6 Pelagic Primary Production

This was measured *in situ* using the oxygen light and dark bottle technique. The water samples were obtained from different depths (0.1, 0.3, 0.5, 0.7, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 5.0 m) with a Van Dorn water sampler equipped with a mercury thermometer. The incubation bottles, (250 ml reagent bottles) were filled with water and suspended in the water column at the depths from which the water samples had been taken. One light and one dark bottle, covered with black plastic, were tied at opposite ends at each of the above depths to a steel hanger attached to a line hanging from a metal bar. The bar was supported by one small buoy to minimize shading and sinking.

The incubation time was four hours, starting from two hours before noon as described by Karlman (1973). Immediately after the incubation period the bottles were brought into a shady area of the boat for the application of the Winkler's reagents to stop photosynthetic process and the oxygen titrations were carried out without delay by using standard thiosulphate solution (0.025 N) and starch solution as indicator. The titrations were carried out in the field with a precision of 0.4 mgO_2^{-1}. The oxygen production was measured as the difference in oxygen concentration between the light and dark bottles (gross production). The gross production was used as more reliance is placed on estimates of gross than on net production (Talling, 1969). The calculation of the dissolved oxygen concentrations is similar to those in Wetzel and Likens (1979) and Adeniji (1990).

The total gross pelagic primary production per unit area was calculated by using Rhode's (1965) formula based on Talling's (1957) model as described by Karlman (1973).

This formula is given as:

$$\sum a = z_{0\cdot1}\, jmpc \times a_{max}$$

where $\sum a$ = total photosynthesis per unit area.

$z_{0\cdot1}$ = the depth, in meters, of the 10% light transmission level

jmpc= penetrating component.

a_{max} = the maximum photosynthetic rate measured in the water column.

The total gross pelagic primary production was also calculated by using the depth strata technique whereby production at every 0.1 meter depth was calculated from field data from the water surface to the depth where photosynthesis seized at each sampling station. These data were summed as daily total gross pelagic primary production and expressed in $mgO_2\, m^{-2}\, d^{-1}$.

4.0 POTENTIAL FISH YIELD

The potential fish yield of the lake was estimated by two methods.

4.1 The Morpho-Edaphic Index (MEI) Technique

The MEI technique of Ryder (1965) and Henderson and Welcome(1974), is based on conductivity which is a measure of total dissolved solids divided by mean depth. *The formula is expressed as:*

$$Y = 12.5078X^{0.4861} \quad \text{or} \quad \log_{10}Y = 0.9421 + 0.3813\log_{10}X$$

where Y = *potential fish yield (kg ha^{-1})*

X = *MEI = Conductivity/mean depth in meters*

4.2 Pelagic Primary Production Technique

The second method uses Melack's (1976) regression equation based on pelagic primary production. *The equation is given as;*

$$\text{Log10 } Y = 0.91 + 0.113\,PG$$

Where Y = *fish yield (kg ha^{-1})*

PG = *pelagic primary production (g O_2 m^{-2} d^{-1})*

5.0 STATISTICAL ANALYSIS

Analysis of variance (ANOVA) and correlation coefficients of environmental factors and production estimates were done using SPSS statistical package. Comparison was made between results obtained for the two recent sampling years (1995/96 and 1996/97) and the results of Karlman(1973) who did a similar work on the lake in 1971/72. Analysis of variance for temperature, pH, conductivity and dissolved oxygen for the three study periods were restricted to the damsite station since data are not available for these parameters at the other stations (i.e. MLW, MLE and NB) in 1971/72. Correlation analysis was also restricted to the Dam site to enable inclusion of fish yields (12 data sets) in the matrix.

6.0 RESULTS

6.1 Surface Temperature

Seasonal variation in surface water temperatures (Fig. 2) followed prevailing weather conditions in the lake's basin with high temperatures before the rains, dropping slightly during raining season, with the coolest period during the harmattan around November to February. The ranges and means of temperatures were: 1995/96 (25.4° - 29.5°mean=27.78°); 1996/97 (24.25° –29.4° mean=27.78°. Although, 1971/72 was generally warmer, there was no significant difference ($p>0.05$) between the three sampling periods (1971/72,1995/96 and 1996/97) at the dam site and between 1995/96 and 1996/97 for the entire lake.

6.2 Hydrogen Ion Concentration (pH)

Seasonal variation in pH (Fig. 3), showed no distinct pattern but was generally similar for the three sampling periods. No significant difference ($p>0.05$) was therefore, observed between the three sampling periods at the dam site and between 1995/96 and 1996/97 for the entire lake. The range of pH was 6.3 to 7.6.

6.3 Conductivity

Seasonal variation in the conductivity of the photic zone of the lake is shown in Fig. 4. Values were significantly higher ($p<0.05$) at the damsite station in 1995/96 (range 60-600 µhmos cm^{-1}) compared to 1971/72 (range 50-62 µhmos cm^{-1}) and 1996/97 (range 40-100 µhmos cm^{-1}). Similar significant difference ($p<0.05$) was also found between 1995/96 and 1996/97 when the entire lake (i.e. damsite + other stations) was considered. The year, 1995/96, could therefore, be considered an exceptional year of high conductivity, especially in January 1996 at the damsite and in October 1995 at the North Basin. The very high flood recorded for that period, which has the capacity to bring in agricultural chemicals and other nutrients as runoff into the lake, may account for this observation.

6.4 Transparency

The seasonal variation in water transparency (Fig. 5) indicates clearer water between March and July (low water period) and low transparency there after with the onset of the white flood which brings clay materials into the lake, through runoffs, from the lake's basin. Water transparency started improving again from November at the onset of the black flood that is characterized by lower silt load compared to the white flood. In general, the pattern of water transparency for the three sampling years was similar. However, analysis of variance indicated a significantly higher water transparency ($p<0.05$) in 1971/72 (range 0.2-3.2m) compared to 1995/96 and 1996/97 (range 0.1-2.0 m).

Fig. 2 Mean surface temperature for Kainji Lake in 1971/72, 1995/96 and 1996/97

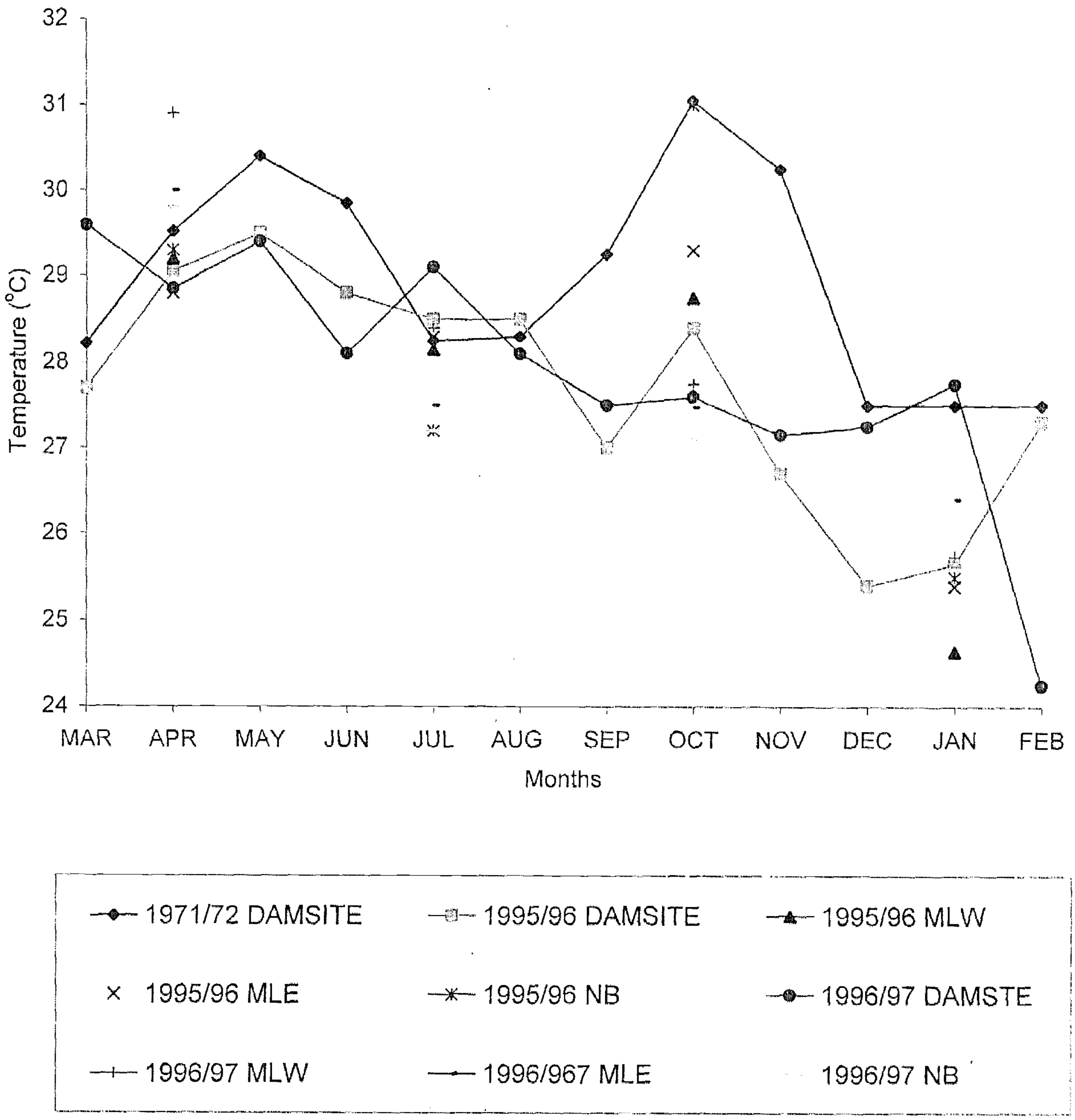


Figure 3 pH units (mean) for Kainji Lake in 1971/72, 995/96 and 1996/97

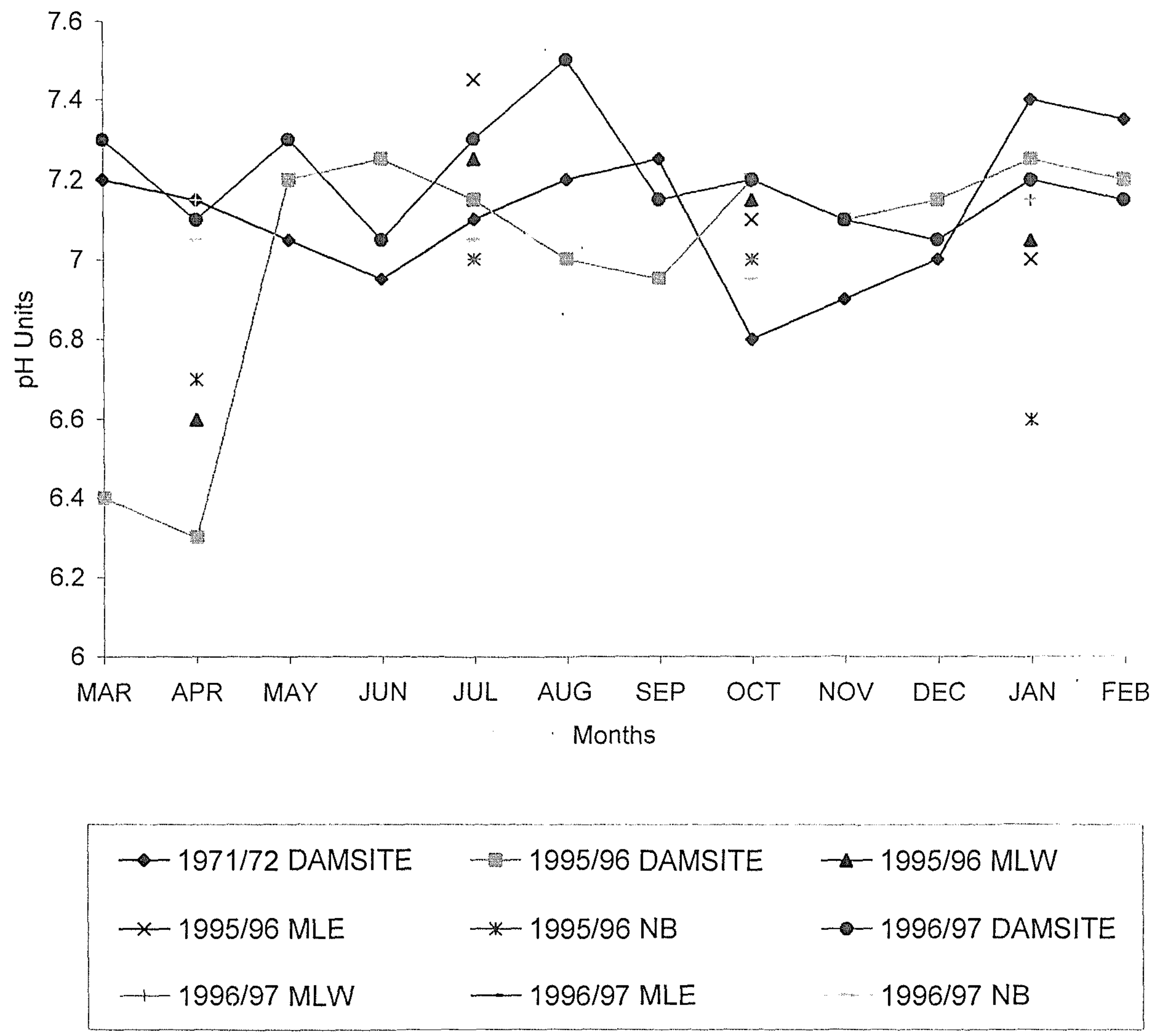


Figure 4 **Mean conductivity (µmhos/cm) on Kainji Lake in 1971/72, 1995/96 and 1996/97.**

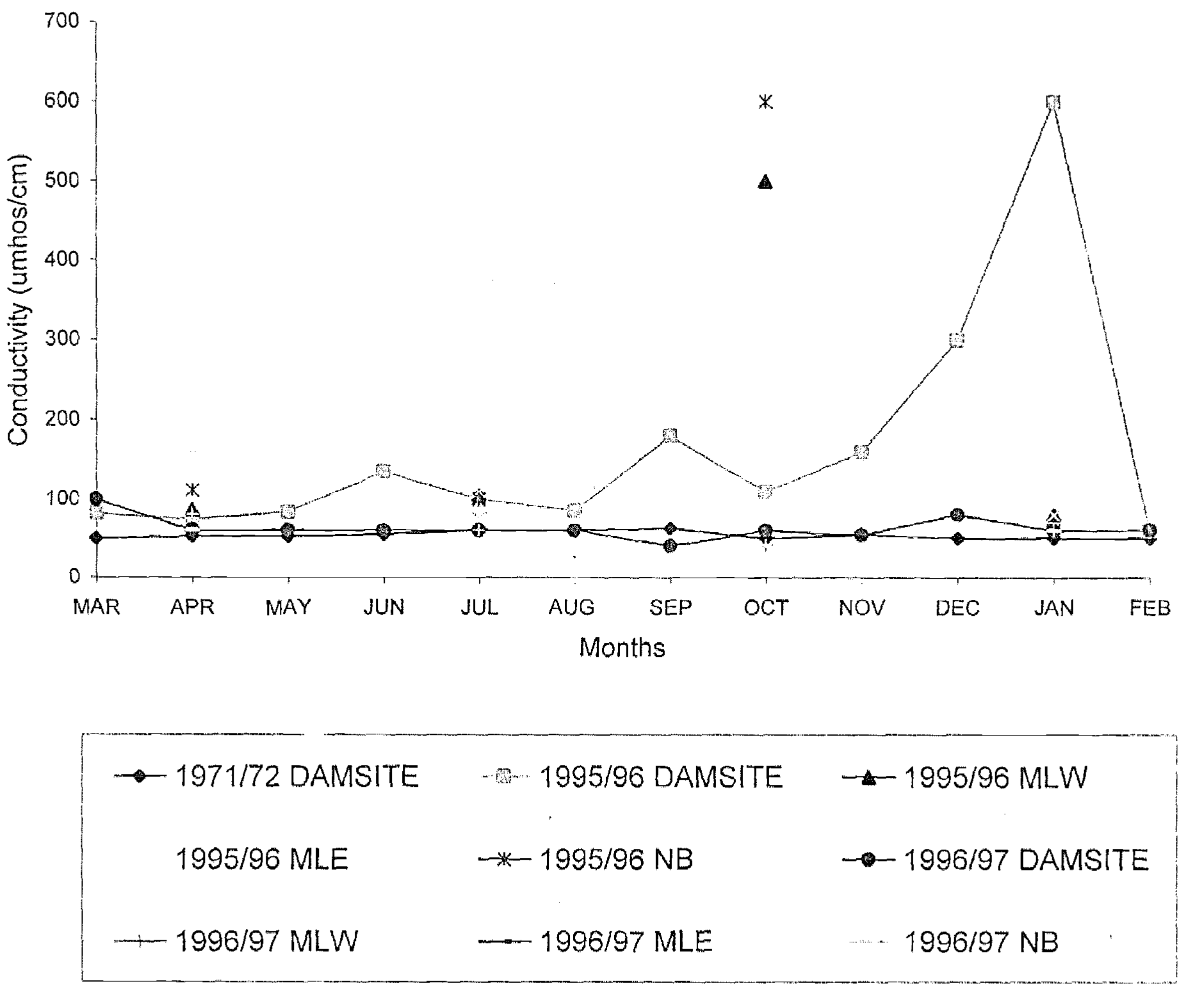
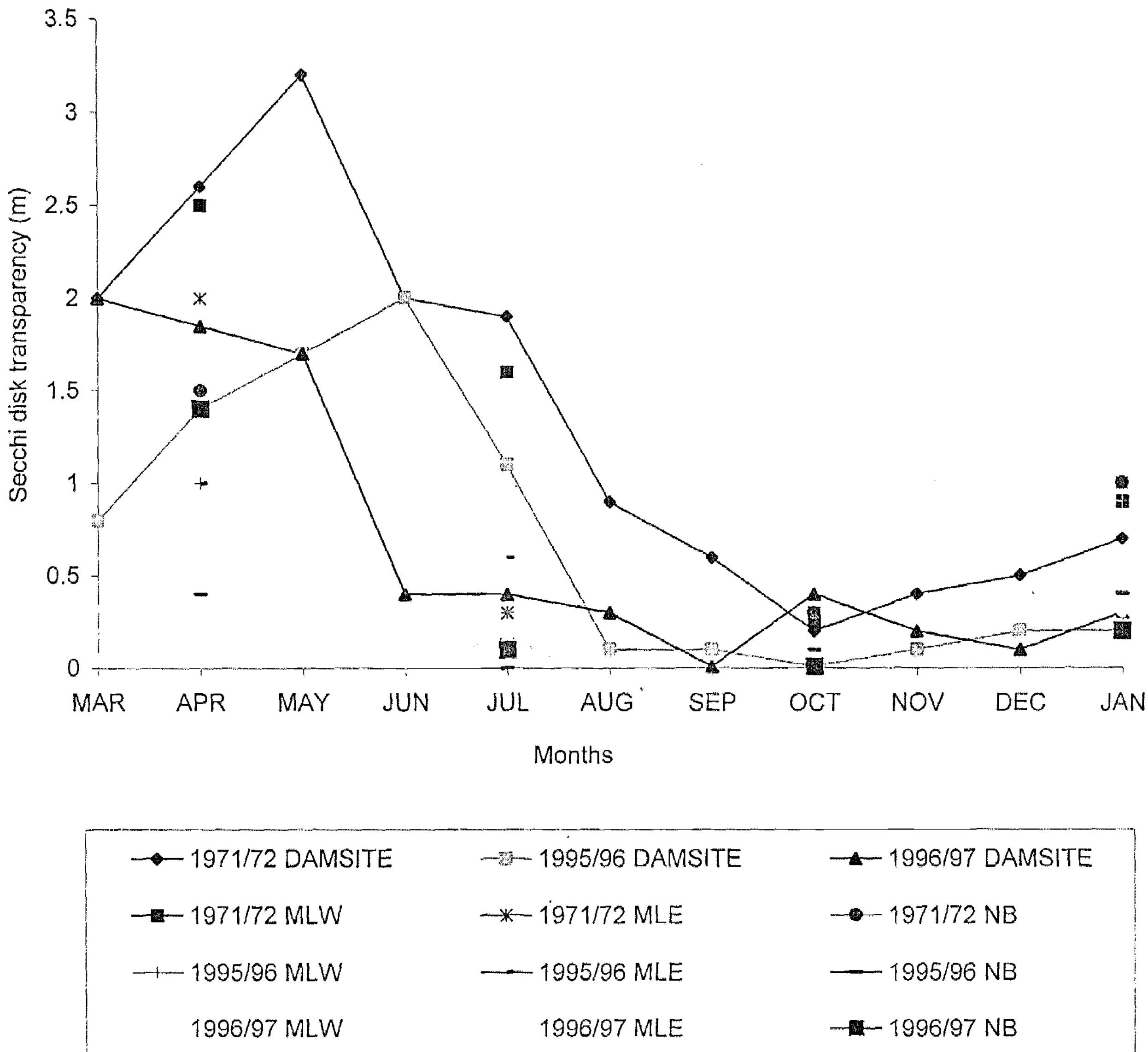


FIGURE 5 Secchi disk transparency (m) on Kainji Lake in 1971/72, 1995/95 and 1996/97 (dam site data are linked).



6.5 Dissolved Oxygen

The seasonal variation in dissolved oxygen is shown in Fig. 6. Concentrations at the damsite ranged from 3.0 to 5.8 mg l^{-1} and 4.4 to 6.0 mg l^{-1} in 1995/96 and 1996/97, respectively. With a range of 5.5-9.0 mg l^{-1}; concentrations were significantly higher ($p<0.05$) in 1971/72 compared to the other two sampling years at the damsite station. When the entire lake was compared, concentrations were found to be significantly higher ($p<0.05$) in 1996/97 than in 1995/96.

7.0 PRIMARY PRODUCTION

The seasonal variations in daily gross pelagic primary production, for the two sampling periods (1995/96 and 1996/97), in comparison with 1971/72 records of Karlman (Karlman,1973), based on Rhode's and the depth strata methods (Melack, 1979), are shown in Figs. 7 and 8, respectively. As shown in Fig. 7, a maximum production of 4.6 g $O_2m^{-2}d^{-1}$ was recorded in July of 1971/72, while corresponding peak production of 4.80 g $O_2m^{-2}d^{-1}$ and 3.375 g $O_2m^{-2}d^{-1}$ occurred in June and March in 1995/1996 and 1996/1997, respectively, all at the damsite station.

Using the depth strata method (Fig. 8), maximum production (4.02 g O_2m^{-2} d^{-1}) in 1971/72 was recorded at the North Basin (NB) in July, while corresponding maximum values for 1995/96 and 1996/97 were 4.65 $gO_2m^{-2}d^{-1}$ (MLE, July) and 3.36 $gO_2m^{-2}d^{-1}$ (Damsite, March), respectively.

In general, peak production coincided with periods of high water transparency as production dropped as from July with the onset of the white flood.

FIGURE 6 **Dissolved oxygen concentration (mg l^{-1}) at depth of 0.1 m on Kainji Lake in 1971/72, 1995/96 and 1996/97.**

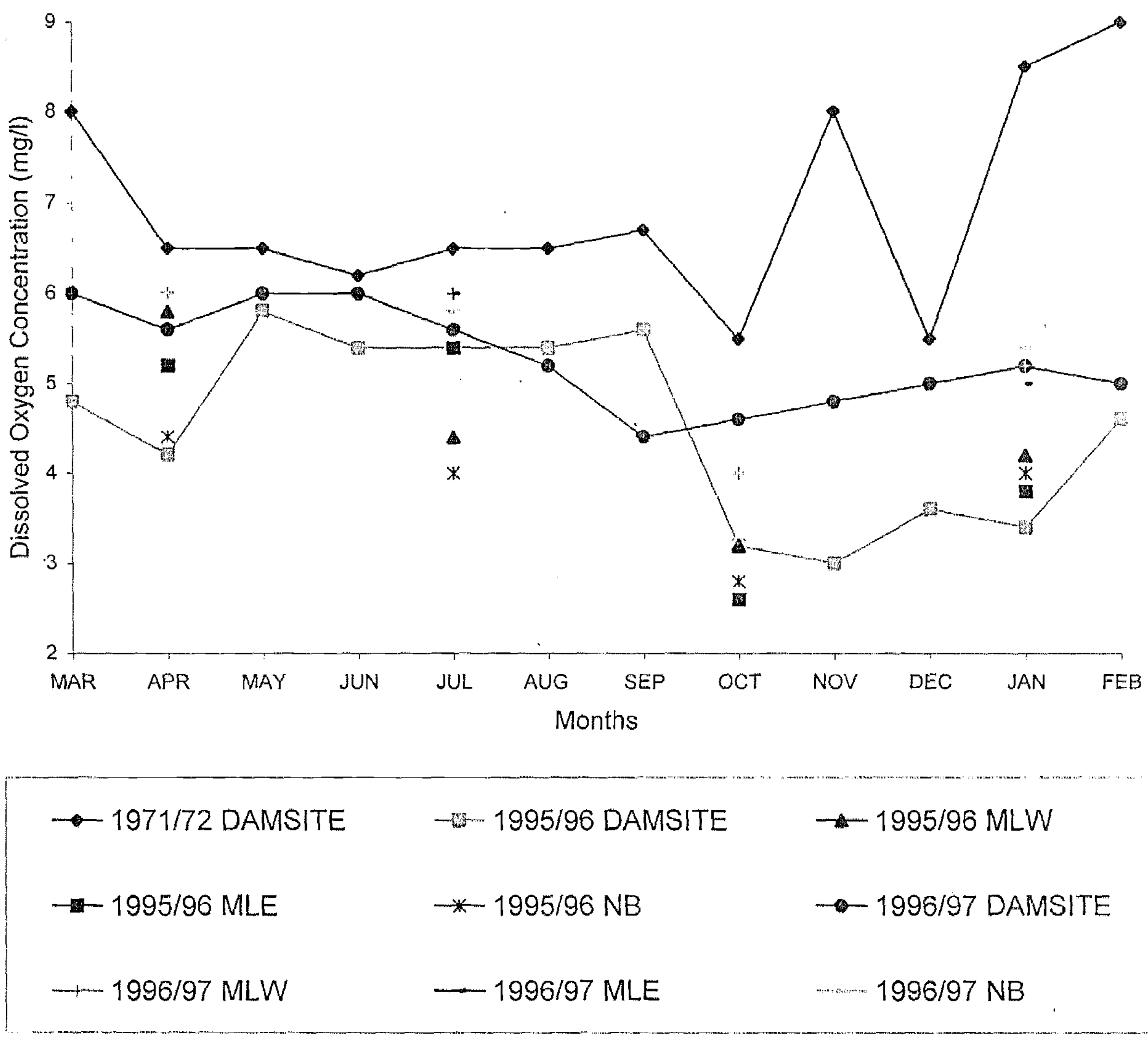


FIGURE 7 Daily gross primary production ($gO_2m^{-2}\ d^{-1}$) on Kainji Lake in 1971/72, 1995/96 and 1996/97 (using Rhode's formula), Damsite data are linked

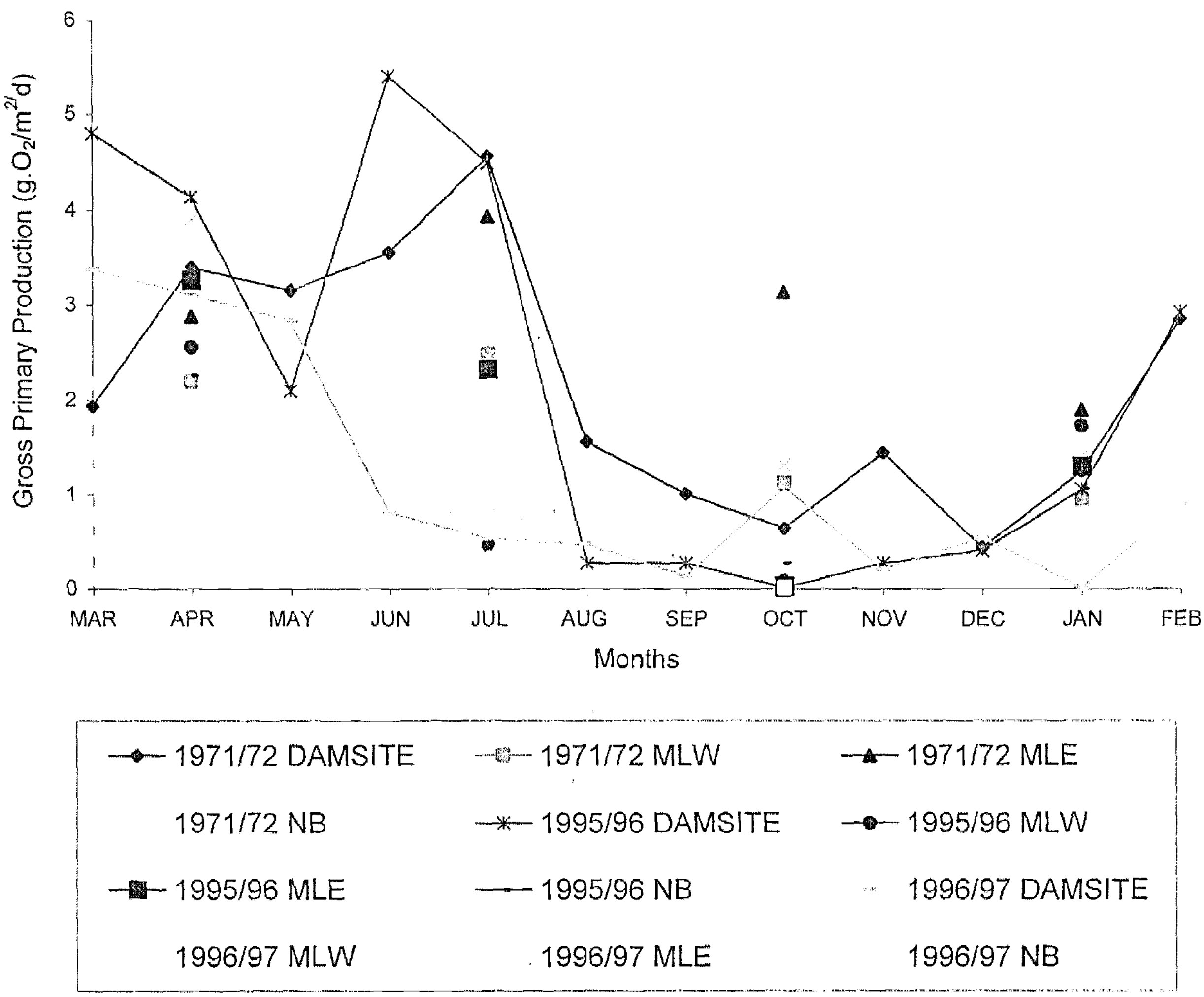
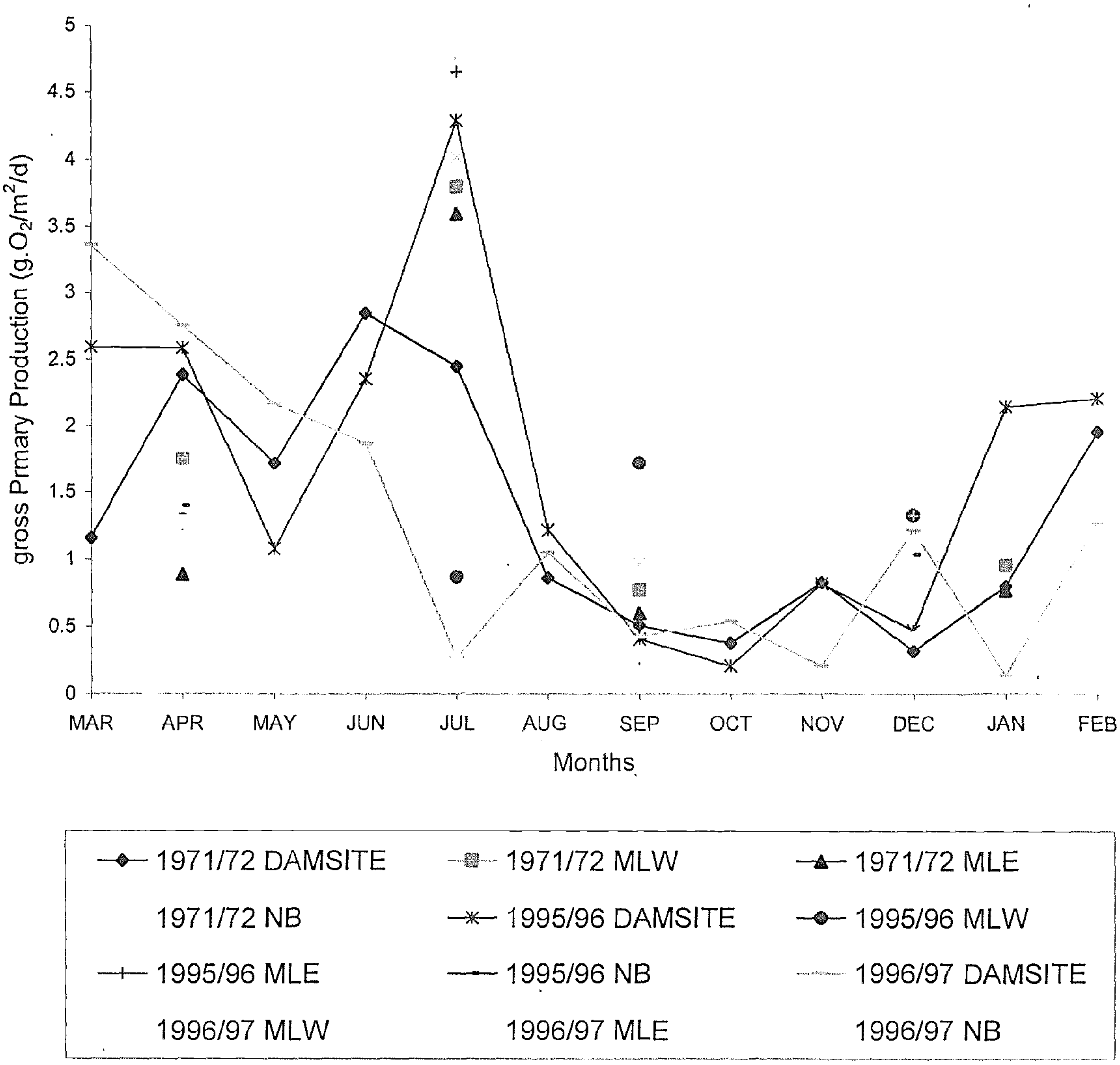


FIGURE 8 Daily gross primary production ($gO_2m^{-2}\ d^{-1}$) on Kainji Lake in 1971/72, 1995/96 and 1996/97 (using Depth Strata Data), Damsite data are linked.



Analysis of variance revealed a significantly higher mean ($p<0.05$) in 1971/72 compared to 1995/96 and 1996/97 with the Rhode's method. No significant difference was, however, observed with the depth strata method for the three sampling periods.

8.0 POTENTIAL FISH YIELD ESTIMATES

Figures 9 and 10 show the seasonal variations in the potential fish yield estimates for the lake in 1995/96 and 1996/97, respectively, using the MEI and the pelagic primary production technique, in comparison with actual fish catch from catch assessment survey by the KLFPP. In both years, estimates from the MEI and the KLFPP were fairly similar and higher than yields obtained from pelagic primary production estimates. In 1995/96, mean monthly production estimates from MEI and the KLFPP were 3900 tons yr^{-1} and 2,426 tons yr^{-1}, respectively. Comparative values from pelagic primary production estimates were 1,499 tons yr^{-1} (Rhode's method) and 1,256 tons yr^{-1} (depth strata method). In 1996/97, mean monthly estimates in metric tons per year were as follows: MEI=2,999.7; KLFPP= 3,172.8; Rhode's method=1,153; depth strata=1,139. In terms of total annual production, the MEI yielded about 47,000 and 36,000 t in 1995/96 and 1996/97, respectively, while corresponding values by the KLFPP were approximately 29,000 and 38,000 t per year. Yields from the pelagic primary production techniques were considerably lower, ranging from approximately 14,000 to 20,000 t per year for both years. The Rhode's method, however, gave higher values than the depth strata method for both years.

FIG. 9 Potential fish catch (t/month) for Lake Kainji in 1995/96 estimated by the Morpho-Edaphic (MEI) and Melach's Method plotted against fish catch data for 1995/96.

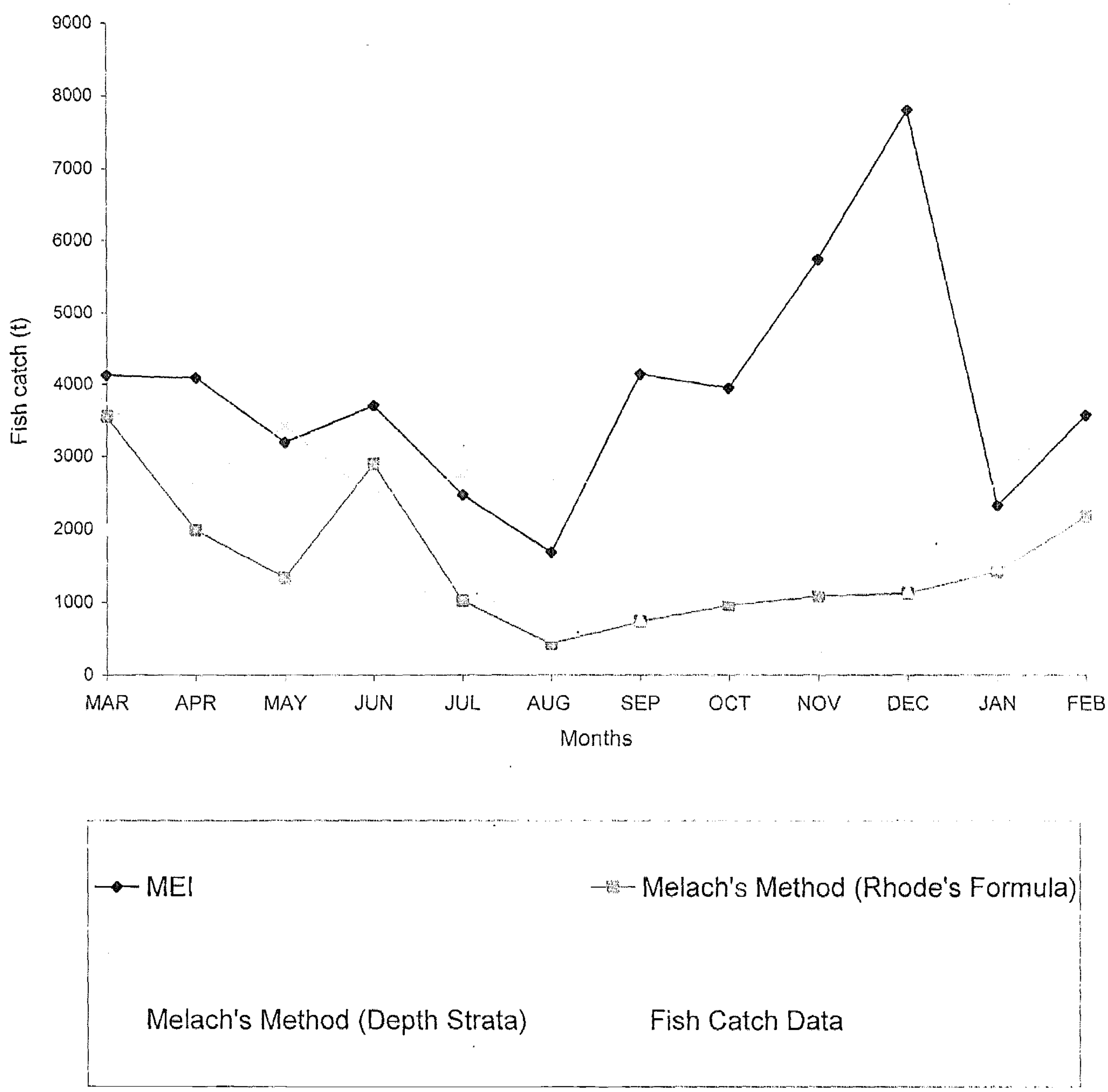
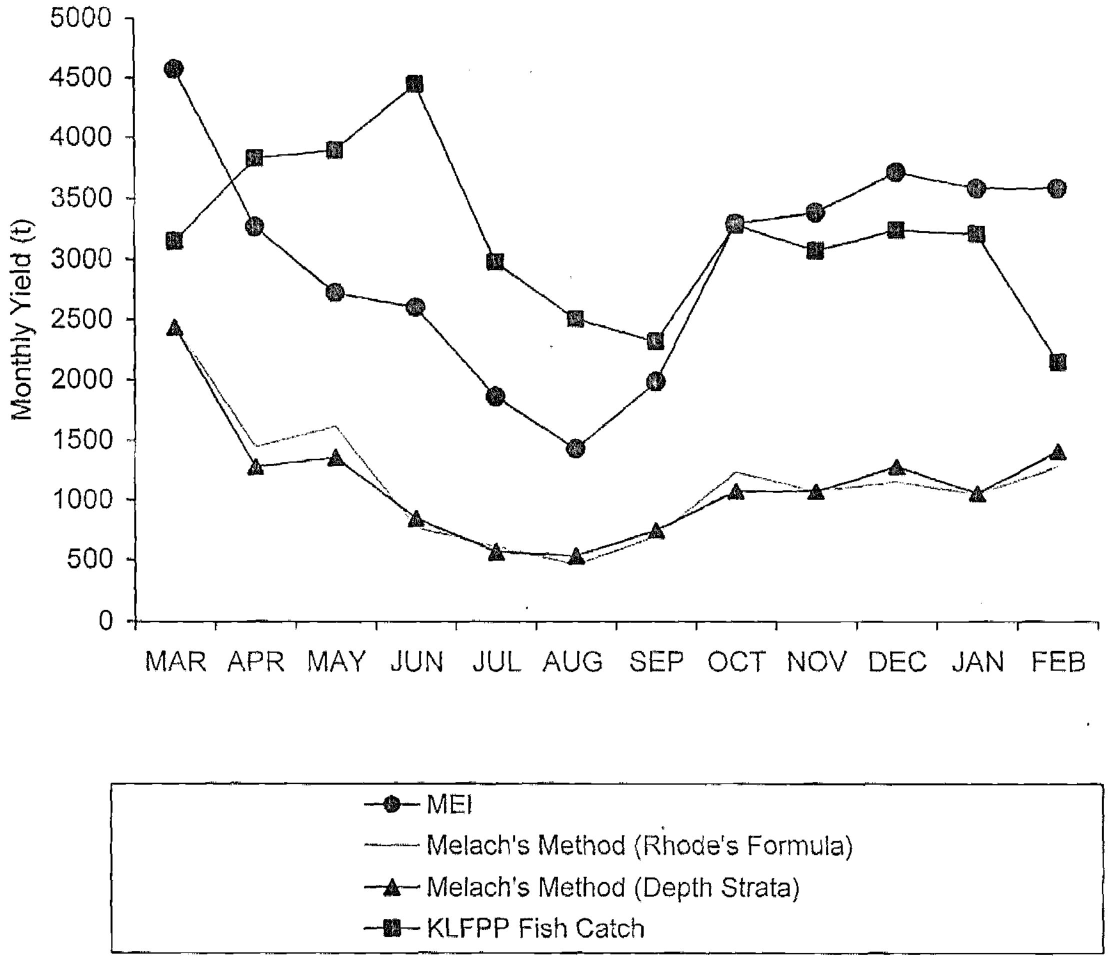


FIGURE 10 Potential fish catch (t/month) for Kainji Lake in 1996/1997 estimated by the Morphoedaphic Index (MEI) and Melack's method respectively and compared to fish catch data for 1996/1997



Analysis of variance (ANOVA) indicated that potential fish yield estimates from the MEI, in 1995/96, was significantly higher ($p<0.05$) than estimates obtained from the other methods. Also, estimates from the KLFPP was significantly higher ($P<0.05$) than yields obtained from the depth-strata method. In 1996/97, similar levels of differences were obtained but yield estimates from the MEI method and actual catch from the KLFPP indicated no significant difference.

8.1 Correlation of Environmental Factors and Production Estimates

Correlation coefficient (r) matrices for environmental factors and production estimates for the three sampling periods are shown in Tables 1-3. A total of 8, 12 and 21 significant correlation was obtained in 1971/72, 1995/96 and 1996/97, respectively. Significant correlation coefficients are marked with different number of asterisks depending on the levels of significance. Relevant significant correlation coefficients are discussed later, suffice it to say now that percent transmittance and water transparency, two important factors controlling photosynthesis, correlated significantly with primary production.

9.0 DISCUSSION

9.1 Comparison of Current Primary Production Levels in Kainji Lake with Past Records

A comparison of ranges and means of daily gross pelagic primary production ($g\ O_2m^{-2}d^{-1}$) in Kainji Lake in 1971/72 and 1995 -1997 (Table 4), indicates that the current mean level of production, at the damsite in 1995/96 (2.18 $g\ O_2m^{-2}d^{-1}$, Rhode's method), is very similar to the 2.25 $g\ O_2m^{-2}d^{-1}$ obtained in 1971 /72 by Karlman (1973), at the same station . There is, however, an approximately two - fold decrease in mean production at the same station in 1996/97 as only a mean value of 1.16 $g\ O_2m^{-2}\ d^{-1}$ was obtained. At the other stations (MLW, MLE and NB), production in 1971/72 (2.3 $g\ O_2m^{-2}d^{-1}$) is much higher than current mean levels of 1.4 $g\ O_2m^{-2}\ d^{-1}$ in 1995/96 and 0.54 $g\ O_2m^{-2}\ d^{-1}$ in 1996/97.

Table 1: Correlation Matrix for Environmental Factors and Production Estimates in Kainji Lake in 1972/72

	Temp	PH	Cond.	S. Disc	10% Transmitt	D.O	PP®	PP (DST)
Temp.								
PH	** 0.730							
Cond	0.088	0.058						
Transparency	0.105	0.065	-0.156					
10% Transmitt	0.098	0.029	-0.203	*** 0.995				
D.O	-0.419	* 0.649	-0.223	0.006	0.006			
PP ®	0.017	0.031	0.068	*** 0.820	*** 0.832	0.079		
PP (DST)	0.036	0.016	0.009	** 0.789	*** 0.801	0.72	*** 0.959	

Sig. Level

* Significant (P < 0.05)
** Highly significant (P < 0.01)
*** Very highly significant (P < 0.001)
DF = 10

PP (R) - Primary Production (Rhodes method)
PP (DSt) - Primary Production (depth strata method)

Table 2: Correlation Matrix for Environmental Factors and Production Estimates in Kainji Lake in 1995/96

	Temp	PH	Cond	S. Disc	10% Transmitt	D.O	PP®	PP (DSt)	PFY(NEI)	PFY(PPR)	PFY(PP DSt)
Temp.											
PH	-0.51										
Cond	* 0.703	0.325									
Transparency	* 0.593	-0.068	-0.334								
10% Transmitt	0.521	-0.074	-0.285	*** 0.994							
D.O	0.544	-0.058	-0.453	* 0.509	0.515						
PP ®	0.429	0.369	-0.353	*** 0.817	*** 0.822	0.407					
PP (DST)	-0.150	-0.063	0.032	-0.293	-0.263	0.332	-0.296				
PFY (MEI)	-0.481	-0.029	0.061	-0.239	-0.216	-0.481	-0.219	0.044			
PFY (PPR)	0.076	-0.421	-0.169	* 0.594	0.608	0.103	** 0.784	-0.278	0.055		
PFY (PPDSt)	-0.229	-0.293	0.045	0.359	0.380	-0.259	* 0.587	-0.384	0.117	** 0.816	
FY (KLFPP)	0.183	-0.440	-0.138	0.506	0.534	0.539	* 0.567	-0.100	-0.415	* 0.625	0.481

Sig. Level:
* Significant ($P < 0.05$)
** Highly significant ($P < 0.01$)
*** Very highly significant ($P < 0.001$)
Df = 10

PFY (MEI) – Potential fish yield (MEI)
PFY (PPR) – Potential fish yield (Primary Production – Rhodes method)
PFY (PP DST) – Potential fish yield (Primary production – Depth strata method)
FY (KLFPP) – Fish yield (Kainji Lake Fisheries Promotion Project)

Table 3: Correlation Matrix for Environmental Factors and Production Estimates in Kainji Lake in 1996/97

	Temp	PH	Cond	S. Disc	10% Transmitt	D.O	PP®	PP (DSt)	PFY(NEI)	PFY (PPR)	PFY(PP DSt)
Temp.											
	-0.197										
Cond	* 0.617	0.201									
Transparency	* 0.607	-0.369	-0.380								
10% Transmitt	* 596	-0.350	-0.341	*** 0.995							
D.O	* 0.636	0.053	-0.426	0.538	0.537						
PP ®	* 0.588	-0.521	-0.388	*** 0.918	*** 0.925	0.512					
PP (DST)	0.471	-0.478	-0.287	*** 0.833	*** 060	0.550	*** 0.954				
PFY (MEI)	0.184	-0.477	-0.376	0.118	0.114	-0.300	0.180	0.109			
PFY (PPR)	0.426	* -.593	0.053	0.445	0.425	-0.007	0.454	0.353	***0.874		
PFY (PPDST)	0.344	* -.621	0.122	0.362	0.51	-0.017	0.413	0.337	*** 0.898	** 0.984	
FY (KLFPP)	* 0.575	*0.575	0.147	0.289	0.277	0.133	0.270	0.161	** 0.709	* 0.578	* 0.565

Sig Level:

* Significant ($P < 0.05$)

** Highly significant ($P < 0.01$)

*** Very highly significant ($P < 0.001$)

DF = 10

The depth strata method generally gave lower values of production compared to the Rhode's method. The reason for this discrepancy is not well known but may be related to the usual difficulty of integrating production with depth. The Rhode's method is most widely described and used (Talling, 1957; Rhode's, 1965; Karlman, 1973).

Karlman (1973), classified primary production levels into low (<1.49g O_2 m^{-2} d^{-1}), medium (1.5 - 2.9 g $O_2m^{-2}d^{-1}$) and high (> 3.0 g $O_2m^{-2}d^{-1}$). Based on this classification, and using the computed means on Table 4, production levels between 1995 to 1997 ranged from low to medium (0.5-2.2 $gO_2m^{-2}d^{-1}$) but stood at medium level (2.2-2.3 $gO_2m^{-2}d^{-1}$) in 1971/72. Primary production in the latter period is therefore, slightly higher than in the former.

For several months, especially between March and July (Figs 7 & 8), medium to high level of production predominated in the lake. These production levels, which represent the upper limit of the ranges shown in Table 4, occurred at periods of high water transparency in the lake. This finding is in agreement with earlier reports, which established a positive relationship between primary production and water transparency (Talling, 1957; Vollenweider, 1965; Karlman, 1973; Melack, 1979; Adeniji, 1990).

With a mean daily gross pelagic primary production of 5.43 $gO_2m^{-2}d^{-1}$, (Adeniji, 1990), Jebba lake, which lies immediate downstream of Kainji lake, could be considered more productive than the latter. This is understandable considering the fact that Jebba is a much younger lake than Kainji and consequently more nutrient-rich.

9.2 Comparison of Primary Production in Kainji Lake with other Tropical Systems

In comparison to other tropical lakes and reservoirs in Africa and India, pelagic primary production in Kainji lake could be considered very low for a tropical ecosystem (Table 5, Fig. 11). The magnitude of mean production levels in these reservoirs is two to ten times higher than in Kainji. Furthermore, the ranges of production for Kainji, which are similar between 1971/72 and 1995-1997, extend only into the lower ends of lakes Albert, Volta, Victoria (offshore), the White Nile at Jabel Aulia, Amaravathi and Stanley (Fig. 11). For the rest of the ecosystems, it is evident that these are much more productive than Kainji as the upper limits of production in Kainji did not even extend to the lower limit of their production range.

9.3 Possible Factors Controlling Production in Kainji Lake

Several factors, which include solar radiation, nutrient content, water transparency, high seasonal rate of fluctuation in water level, high flushing rate *etc* are known to influence the rate of primary production in fresh waters (Talling, 1957; Vollenweider, 1969; Karlman,1973; Adeniji,1990; Priscu *et.al, 1982)*. Of these, the first three factors have been identified by Karlman (1973), as the major factors limiting or controlling primary productivity in Kainji lake.

Table 4. Comparison of daily total ranges and means of gross pelagic primary production (g $O_2m^{-2}d^{-1}$) in Kainji Lake in 1971/72, 1995/96 and 1996/97.

Stations/Years	Year	Rhodes Methods		Depth strata Method	
		Range	Mean	Range	Mean
Damsite	1971/72	0.432-4.563	2.249	0.32-2.85	1.430
Other Stations (MLW, MLE, NB)	1971/72	0.948-3.938	2.308	0.60-3.85	1.714
Damsite	1995/96	0.013-4.8	2.178	0.21-4.29	1.700
Other Stations (MLW, MLE, NB)	1995/96	0.027-3.262	1.394	0.26-4.65	1.294
Damsite	1996/97	0.013-3.375	1.163	0.21-3.36	1.27
Other Stations (MLW, MLE, NB)	1996/97	0.013-2.025	0.542	0.07-1.28	0.554

In the tropics, temperature, which is an index of solar radiation is abundant all year round and consequently, has little influence on production except on cloudy days. The higher transparency in 1971/72 may have accounted for the significant high production (Rhode's method), recorded for that year compared to the other two sampling periods. Furthermore, the significant positive correlation between percent transmittance and Secchi disc water transparency on one hand and pelagic primary production on the other hand (Tables 1-3), are indicative of and indeed, confirm the influence of the later parameters on primary production.

TABLE 5. Comparison of means and ranges of primary production levels (g $O_2m^{-2}d^{-1}$ in some tropical lakes in comparison to Kainji Lake

LAKE	PRIMARY PRODUCTION Average	Range	No. of Measurement	Sources
Albert	7.10	2.7 – 12.2	3	1
Amaravathi	5.54	1.29 – 19.17	9	2
Bunyoni	4.80	Not given	1	1
Chad	7.10	Not given	10	3
K.C. Kulam (India)	23.81	8.33 – 30.18	9	2
Stanley Reservoir (India)	2.88	1.07 – 5.99	9	2
Tamaria Kulam (India)	13.07	5.98 – 20.02	5	2
Victoria (offshore)	7.30	4.9 – 11.4	14	1
Victoria (pilking ton bay)	10.60	10.2 – 11.0	2	1
Victoria Grant bay	8.50	6.3 – 10.7	2	1
Volta	6.80	2.1 – 14.0	6	5
White Nile Lagon	4.00	Not given	1	4
White Nile Jebel Aulia	4.30	2.1 – 6.2	2	4
Naivasha	4.89	3.7 – 6.2	11	7
Oloidien	8.14	4.2 – 12.1	10	7
Crescent Island Crater	8.38	3.0 – 8.4	5	7
Winab Gulf	5.93	4.3 – 9.8	9	7
Kainji Dam site station 1971/72	2.25	0.43 – 4.56	12	6
Kainji (other stations 1991/72	2.30	0.95 – 3.94	12	6
Kainji ((Dam site, this rep) 1995/96	2.18	0.013 – 4.80	12	This study
Kainji (Other stations) 1995/96	1.39	0.027 – 3.26	11	This study
Kainji (Dam site, this rep) 1999/67	1.16	0.013 – 3.38	12	This study
Kainji (Other stations) 1996/97	0.54	0.013 – 2.03	12	This study

1. Talling, 1995
2. Ganapati - Sreenivasan, 1970
3. Lemoalle
4. Talling, 1957
5. Viner, 1970
6. Kariman, 1973
7. Melack, 1979

Other Stations = MLW = Mid – Lake West
MLE = Mid-Lake East
NB = North Basin.

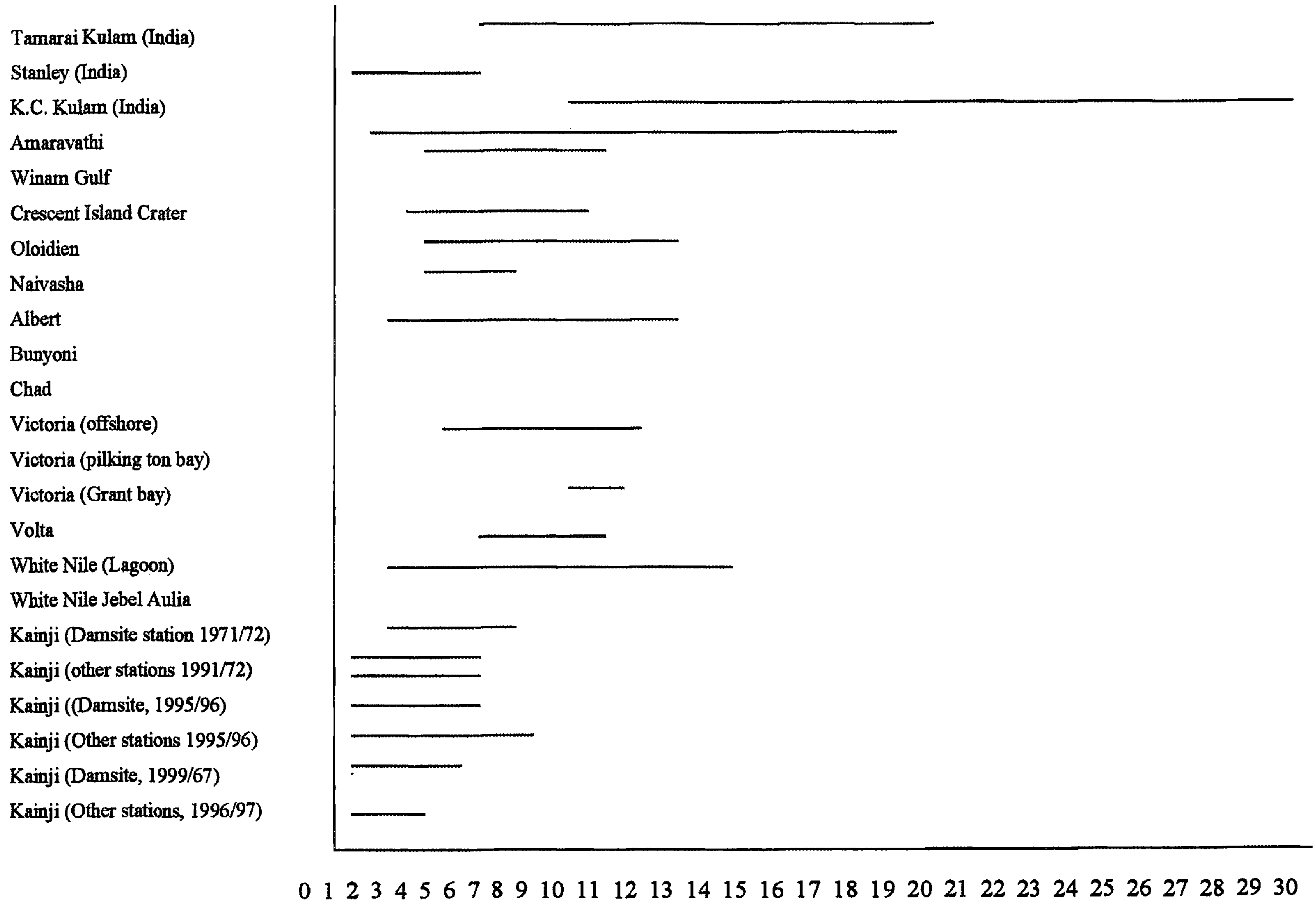


Fig. 11: Range of Pelage Primary Production ($go_2m^{-2}d^{-1}$) of some African and India Lakes and reservoirs in comparison to Kainji Lake

The unusually high levels of conductivity (about 600 umhos cm^{-1}) in January 1996 at the damsite and in October 1995 at the NB and MLW (Fig. 4), while indicating a trend in nutrient enrichment, is yet to manifest in primary production. As pointed out by Karlman (1973), Kainji Lake is nutrient-poor, a situation that is principally due to two factors- low nutrient level of basin soil and high flushing rate. The water retention time of a lake potentially affects its productivity through influence on the input and output of nutrients and by the washout of phytoplankton (Oglesby, 1977). Kainji lake is estimated to be flushed four times a year, giving a hydraulic retention time of 0.32 yr. According to Kerekes (1975), flushing rate becomes critical for primary production at a water retention time of <0.2-0.4yr.

10. POTENTIAL YIELD ESTIMATES

Potential fish yield estimates are indicative of the total annual production of fish that may be expected from an optimum fishery, using empirically derived regression equations. These yield models are basically forecasting tools which provide useful information necessary for decision-making in fisheries management and development. The fish yield estimates from the morphoedaphic index (MEI), are in general agreement with actual catch assessment data from the KLFPP survey for the two years under consideration. Since these are two independent methods, the results complement each other and consequently, of high value in considering the current level of fish production in the lake. The significant correlation coefficients between these parameters (Tables 1-3) tend to reinforce this relationship.

Estimates of fish yields in Kainji lake in the early 70s, include those of Henderson (1971), Lelek and El-Zarka (1971) and Bazigos (1972). Henderson (1971), using the MEI method, reported a yield of 4000 t yr^{-1} while Lelek and El-Zarka (1971), using catch based on the average number of days a fisherman spent and the average catch per canoe reported a yield of 8,000 t yr^{-1}. Bazigos's (1972), estimates of 28,638 t yr^{-1} was much higher than the previous two estimates but approximates very closely with current yield estimates from MEI and the KLFPP. While estimates of Bazigos (1972) appear high compared to the records of Henderson (1971) and Lelek and El-Zarka (1971), Bazigos's statistical design for catch assessment survey was well acclaimed by several workers and was even adopted by the FAO (Henderson and Welcome,1974; Toews, 1977; Bazigos, 1974; Muncy,1973 Toews and Griffith, 1979). Compared to the MEI estimates, annual catch figure from the KLFPP in 1995/96 was below potential yield but in 1996/97, the catch exceeded the potential yield from the MEI. The generally low fish yield estimates from pelagic primary production compared from the KLFPP might suggest overexploitation above the potential yield capacity of the lake. This conclusion might be misleading as not much premium can be placed on the latter method because of its limited use in the literature.

Henderson (1973) and Melack (1979), found only a fair relationship between primary production and fish yield. The problem may have to do with the intricacies of measurements and as pointed out by Melack (1976), errors usually occur when 'estimates of primary production obtained from few stations and measurements are converted to an annual lake-wide average'. Considering the large size of Kainji lake, it is difficult to say whether the three strata of the lake sampled is representative enough of the entire lake, although in terms of sampling intensity, it ranks second to offshore Lake Victoria (Table 5).

11.0 SUMMARY AND CONCLUSION

The environmental conditions of Kainji Lake from 1971/72 to date, appear to have stabilised to a large extent, judging from the similarity of physico-chemical parameters investigated in this study over the period. Solar radiation (as reflected in variation in temperature) and pH have remained largely constant over the years, while conductivity (index of nutrient enrichment), though significantly higher in 1995/96, could be described as sporadic and needs further monitoring to ascertain its trend in the lake. While water transparency and dissolved oxygen were higher in 1971/72 compared to the other years, these increases cannot be said to be overwhelming. The lower transparency in 1995/96 was due to the exceptional flood of that year and may have also accounted for the poorer dissolved oxygen concentration compared to the other years due to its impact on photosynthesis.

There is no evidence from this study to indicate that primary productivity has increased over the years. Consequently, the observed increase in fish yield by the KLFPP from CAS, which is corroborated by estimates from the MEI, cannot be supported on the basis of improved photosynthetic production. The phenomenal high levels of conductivity recorded during certain periods in 1995 (600 μmhos cm^{-1}) are hitherto unknown in the lake and may indicate a trend towards nutrient enrichment. However, it is premature at this stage to conclude on its long-term impact on primary production and consequently, on fish yield. Secondly, the notion of overfishing in the 80s (Ita, 1993), may need to be further examined as low or dwindling catches could be due to a number of factors among which are the level of fishing effort, the type and efficiency of gears and the intensity of sampling. It would appear that with the intervention of KLFPP, the better management of the lake's fisheries would increase the current level of catch. It also needs to be examined how much of the clupeid fisheries, which is now known to account for a substantial proportion of the total fish yield in Kainji Lake, was included in the sampling of the 80s.

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