Studies on the current state of the limno-chemistry and potential fish yield of Lake Volta (Yeji sector) after three decades of impoundment

P. K. OFORI-DANSON & W. J. NTOW
(P. K. O.-D.: Department of Oceanography and Fisheries, University of Ghana, P. O. Box LG 99, Legon, Ghana; W. J. N.: CSIR-Water Research Institute, P. O. Box M32, Accra, Ghana

ABSTRACT

This study aimed at providing information on the current state of one of the relatively high fish production areas of Lake Volta – the Yeji sector. As in its early life, the water of Lake Volta was found to be oligotrophic, with low concentrations of nitrates, nitrites and phosphates which ranged between 0.51 and 0.82, 0.02 and 0.05, and 0.34 and 0.41 mg l^{-1}, respectively. Sodium was the dominant ion, with a mean concentration of 12.1 mg l^{-1}. Generally, the ionic dominance pattern recorded was Ca>Na>K>Cl>Mg. Considerable increase in turbidity is regarded as a major limiting factor affecting primary production and resultant potential fish yield. As a result of turbidity, oxygen saturation levels were high (>100 %) at the surface, possibly leading to the restriction of primary production at the air-water interface. The difference in temperature between the surface and bottom was narrow (1.7 °C), with practically no thermal stratification in the Yeji sector of the lake. This suggests mixing of waters between the surface and deeper layers, thereby enhancing oxygen availability in sufficient concentrations for fish life clear to the bottom. Based on the morpho-edaphic model, the potential fish yield estimate of the lake has declined from 32.8 kg ha^{-1} in 1974 to 29.0 kg ha^{-1} in 1995/96. The decline is attributed to limnological changes in the lake, notably increased turbidity.

Original scientific paper. Received 03 Jul 03; revised 18 Jun 04.

RÉSUMÉ

Ofori-Danson, P. K. & Ntow, W. J.: *Études sur l'état actuel de la limno-chimie et le rendement potentiel de poisson du Lac Volta (secteur de Yeji) après trois décennies d'endiguement.* Une étude s'est déroulée pour donner d'information sur l'état actuel de l'une des zones de la production de poisson considérablement plus élevée du Lac Volta – le secteur de Yeji. Comme dans les premières années de sa vie, l'eau du Lac Volta était découverte d'être oligotrophique avec faibles concentrations de nitrates, nitrites et phosphates qui varient respectivement entre 0.51-0.82,0.02-0.05, et 0.34-0.41 mg l^{-1}. Sodium était l'ion dominant avec une concentration moyenne de 12.1 mg l^{-1}. Dans l'ensemble le modèle de dominance ionique enregistré était Ca>Na>K>Cl>Mg. Augmentation considerable en turbidité est regardée comme un facteur contraignant majeur influençant la production primaire et le potentiel de rendement résultant de poisson. A la suite de turbidité il y avait des hauts niveaux de saturation d'oxygène (> 100 %) à la surface peut-être menant à la restriction de la production primaire à l'interface d'air - eau. La différence en température entre la surface et le fond est étroite (1.7 °C) avec pratiquement aucun stratification thermique dans le secteur de Yeji du lac. Ceci suggère qu'il y a le mélange des eaux entre la surface et les couches plus profondes améliorant de cette façon, l'oxygène disponible en concentrations suffisantes pour la vie de poisson clair au fond. Basé sur le modèle morpho-édaphique il y avait une diminution de l'estimation du potentiel du rendement de poisson du lac de 32.8 kg ha^{-1} en 1974 à 29.0 kg ha^{-1} en 1995/96. La diminution est liée aux changements des facteurs limnologiques du lac, notamment la turbidité augmentée.

Ghana Jnl agric. Sci. **38**, 65-72	Accra: National Science & Technology Press

Introduction

Lake Volta in Ghana has undergone tremendous changes in its ecology, limno-chemistry, and socio-economic status since it was created in 1964. This is expected because the creation of an artificial lake usually results in limnological changes, notably from lotic to lentic environments. In view of the ongoing over-exploitation of commercially important fish stocks (Ofori-Danson, 1999) and importance of the lake as inland fishery resource of Ghana, it would be of scientific and economic importance to investigate changes in the aquatic environment and fishery potential in the lake after three decades of impoundment.

The primary objective of the study was to provide information on the current limnological state of one of the relatively high fish production areas, the Yeji sector.

It is also envisaged that the information generated from the study would be useful in promoting environmentally sound management of the lake, consistent with sustainable livelihood strategies for local communities directly dependent on the fishery resources of the lake.

Materials and methods

The study area

Lake Volta lies between longitudes 1° 30' W and 0° 20' E and latitudes 6° 15' N and 9° 10' N. The study focussed mainly on the area known as Stratum VII of the lake which lies between longitude 0° 10' and 1° 05' W and latitude 8° 8' and 8° 20' N, and extends 60 km south and 50 km north of Yeji (Fig. 1). Stratum VII was chosen for the study for being

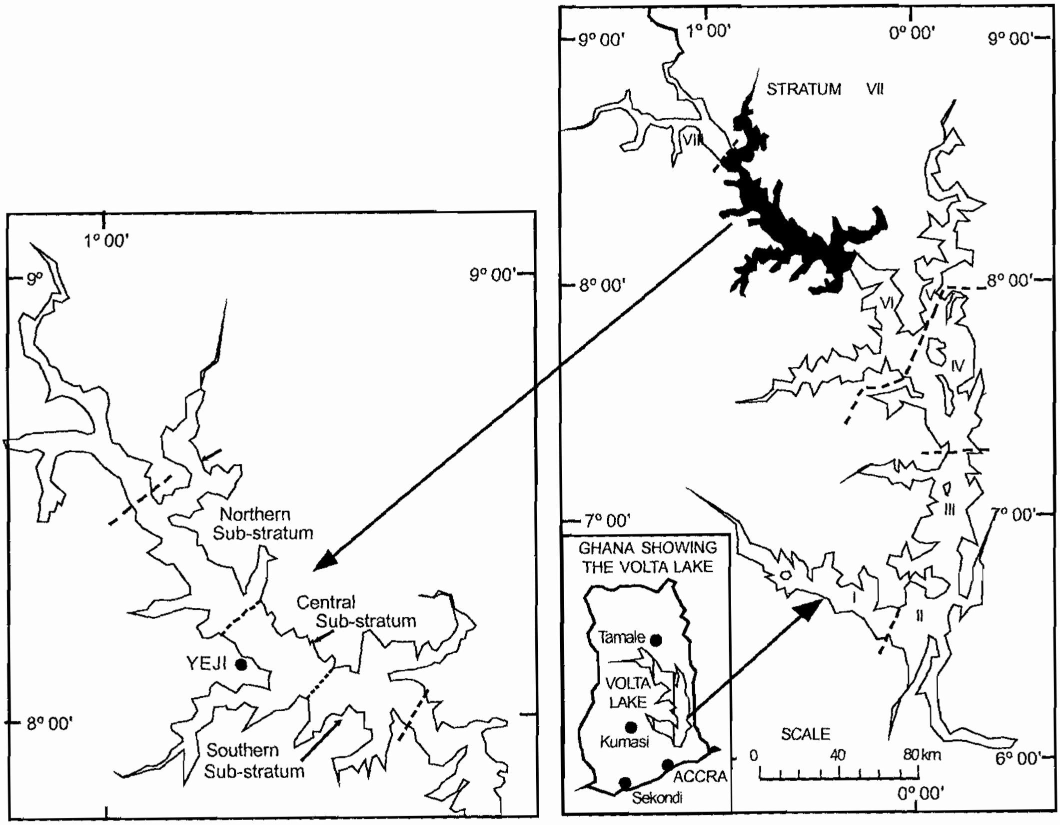

Fig. 1. Map of Lake Volta, Ghana.

one of the areas with the highest fishing activity, and also has the largest fish-market centre at Yeji.

Lake Volta was partitioned into eight commercial fishing areas or strata to assess stock and catch (Bazigos, 1970; Evans & Vanderpuye, 1973) (Fig. 1). The same stratification was adopted in this study to ease comparison with results of earlier studies.

Limno-chemical data

Between February 1995 and January 1996, vertical profiles of lake water samples were collected bi-monthly from the surface to the bottom of the lake, using the 1.7-l Ruttner Bio-Hydro Water Sampler made by Hydrobios (Germany). The limnological factors determined for the water samples were temperature, *p*H, dissolved oxygen (DO), biochemical oxygen demand (BOD), alkalinity, total hardness, total dissolved solids (TDS), conductivity, sodium, calcium, magnesium, chloride, phosphate, nitrate, nitrite, ammonia, silicate, sulphate, and transparency. The methods used in determining each of the factors followed standard methods for examining water and wastewater (APHA-AWWA-WPCF, 1989). Laboratory facilities at the CSIR-Water Research Institute were used for the analyses. The depth of visibility, measured by Secchi disc disappearance, was used as indicator of transparency or level of turbidity.

Fish catch-per-unit effort

The collection of data on fish catch followed a two-stage stratified sampling procedure. In the first stage, the study area was geographically divided into the northern, central, and southern sub-strata (Fig. 1). Further stratification was based on the size of the fishing village and the number of canoes in operation. Three of such categories were small-sized village (0-10 canoes), medium-sized village (11-50 canoes), and large-sized village (more than 50 canoes) as adopted from Bazigos (1970) and Coppola & Agadzi (1976). By these stratification criteria, three fish-landing sites each were selected in the northern (Gbevukpo, Blackiekope and Kejawu) and southern (Abodwese Akura, Pedjai No.1, and Avorkope) sub-strata, and four sites in the central sub-stratum (Fanti Town, Jaklai, Salt Town, and Yeji site area).

As each sub-stratum has many fishing sites and different types of fishing gears are used, it was impossible to collect data on total catch and total fishing effort. Consequently, only canoes using gill-nets were targeted for collection of data on catch and fishing effort.

At each landing site, the total number of operational and non-operational canoes were counted, and other vital information (e.g., mesh size of nets, types of gear, number of fishers per canoe) recorded on the day of sampling. Several canoes using gill-net were randomly selected and their catch of fish weighed. This allowed estimation of fish catch-per-unit effort (CPUE) as kilogram per canoe per day (kg canoe^{-1} d^{-1}).

Relationship between environmental parameters and fish production

Correlation analysis was used to analyse the relationship between species number, fish abundance, fish biomass and water temperature, DO, water level, depth, and TDS.

Potential fish yield

The potential yield of the lake was estimated by Henderson & Welcomme's (1974) model for African lakes:

$$\text{Potential yield (y)} = (14.3136)\,\text{MEI}^{\,0.4681}$$

where MEI is the morpho-edaphic index (Ryder *et al.*, 1974) expressed as TDS or conductivity (in µS cm^{-1}) divided by mean depth (in metres) of the lake.

Results

Limno-chemical factors

Table 1 presents a summary of the results on the limno-chemical analyses of lake water at Yeji area. The lake water showed uniform temperature from the surface down to the 14-m depth (ranging

TABLE 1

Mean Values of Limno-chemical Parameters for the Yeji Sector of Lake Volta During February 1995-January 1996

Limno-chemical factor	*Depth (m)*				
	0	*2*	*6*	*10*	*14*
Temperature (°C)	31.0	30.0	29.5	29.4	29.3
*p*H (*p*H units)	7.2 (7.3)	7.2	7.0	6.9 (6.9)	6.7
DO (mg l^{-1})	8.1	7.9	7.2	6.5	5.2
O_2 saturation (%)	108.9	103.9	94.1	85.2	67.5
BOD (mg l^{-1})	3.9	No data	No data	No data	No data
Alkalinity (mg l^{-1} $CaCO_3$)	44.3 (35.7)	44.3	41.7	40.2 (37.3)	38.5
TDS (mg l^{-1})	25.2	25.8	25.0	24.5	23.8
Conductivity (μScm^{-1})	84	79	76	76	80
Sodium (mg l^{-1})	12.1(4.6)	9.6	11.0	12.1 (4.5)	11.7
Phosphate (mg l^{-1})	0.41 (0)	0.34	0.36	0.5 (0.06)	0.39
Nitrate (mg l^{-1})	0.51	0.63	0.66	0.82	0.97
Nitrite (mg l^{-1})	0.02 (0.02)	0.02	0.02	0.02	0.05
Ammonia-nitrogen (mg l^{-1})	0.83 (0.08)	0.33	0.36	0.57 (0.08)	0.43
Transparency (cm)	50.2	-	-	-	-

Comparative values recorded in 1968/1970 by Czernin-Chudenitz (1971) are in brackets

between 29.3 and 31.0 °C) (Fig. 2). Thus, a narrow difference in temperature (1.7 °C) was recorded between the surface and bottom, with practically no thermal stratification. As a result, the surface waters of the lake were well oxygenated, with mean DO value of 6.98 mg l^{-1}. The dissolved oxygen content in the surface waters had saturation levels higher than 100 per cent (Fig. 2). Thus, the oxygen conditions at Yeji area of Lake Volta were satisfactory all the year round, and in sufficient concentration to support fish life to the bottom.

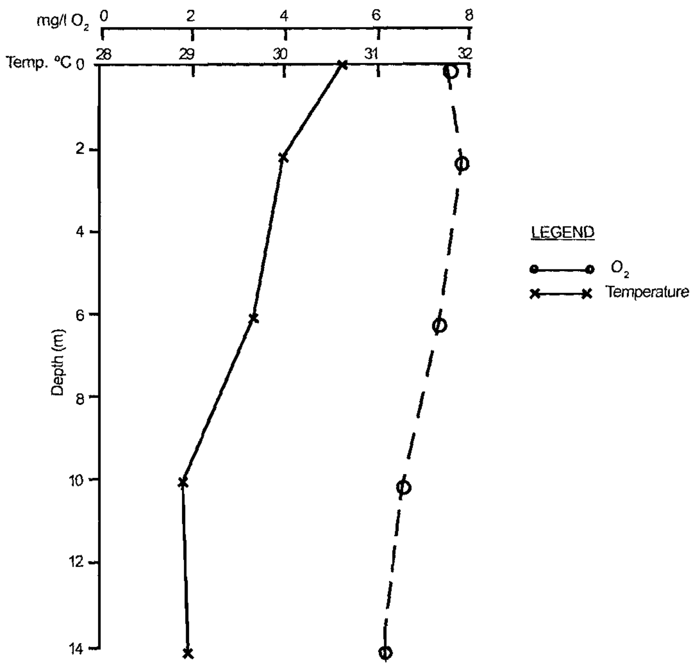

Fig. 2. Vertical temperature and oxygen distribution in the Yeji sector (Stratum VII) of Lake Volta in December 1995.

The *p*H of the lake varied with depth; it dropped from 7.2 at the surface and became uniform from the 10-m depth to the bottom at *p*H value of 6.7 (Table 1). The mean values of TDS and conductivity followed a similar pattern with depth, indicating some mixing between the surface and deeper layers of the lake.

Generally, the ionic dominance pattern recorded was Na>K>Ca>Cl>Mg (Table 1). These ions were in relatively low concentrations compared with other African fresh waters (Table 2). Sodium was the dominant ion with a mean concentration of 12.1 mg l^{-1}. The vertical distribution of these ions in the lake did not follow any particular pattern.

Relationship between environmental factors and catch-per-unit effort

The mean CPUEs were 14.28 ± 4.02 and 11.33 ± 3.45 kg canoe^{-1} d^{-1} for 1995 and 1996, respectively. Table 3 shows the output from partial correlation analyses between six limno-chemical factors and the CPUE of canoes using gill-nets. The monthly mean CPUE correlated positively only with ammonia concentration ($r = 0.8$). A relatively high degree of inverse correlation was recorded between CPUE and NO_3 concentration ($r = -0.6$). A positive correlation was also recorded between the morpho-edaphic index (MEI) and NO_3 concentration in the water ($r = 0.6$), and between MEI and TDS ($r = 0.9$). Conductivity was found to be highly correlated with TDS ($r = 0.9$).

Potential fish yield estimate from the morpho-edaphic index

The MEI was calculated at a mean surface conductivity of 84 µS cm^{-1} (Table 1) and mean depth of 18.6 m (Pitcher & Hart, 1995):

TABLE 2

Relative Average Ionic Composition of Surface Water of Lake Volta

Ion	*Lake Volta mg l^{-1}*	*Lake Volta mg l^{-1}*	*Lake Kariba mg l^{-1}*	*African fresh water mg l^{-1}*
Na^+	3.9	12.1	3.6	11.0
K^+	No data	9.6	No data	No data
Ca^{++}	6.6	9.4	9.3	12.5
Cl^-	No data	7.1	No data	No data
Mg^{++}	3.9	1.6	1.9	3.8

Source: Czernin-Chudenitz (1971), Present study, Marshall (1984a), Livingstone (1963)

TABLE 3

Correlation Coefficients Between the Mean Monthly CPUE (kg canoe^{-1} d^{-1}) and Some Limno-chemical Parameters Recorded in the Yeji Sector of Lake Volta During 1995

Limno-chemical parameter	*CPUE (kg canoe^{-1}d^{-1})*	*PO_4 (mg l^{-1})*	*NO_3 (mg l^{-1})*	*NH_3 (mg l^{-1})*	*TDS (mg l^{-1})*	*Conductivity (µS cm^{-1})*
CPUE (kg canoe^{-1}d^{-1})	1					
PO_4 (mg l^{-1})	0.069	1				
NO_3 (mg l^{-1})	- 0.492	-0.888	1			
NH_3 (mg l^{-1})	0.810	-0.312	0.016	1		
TDS (mg l^{-1})	-0.262	-0.519	0.613	0.207	1	
Conductivity (µS cm^{-1})	-0.307	-0.521	0.616	0.087	0.943	1
MEI	-0.251	-0.538	0.580	-0.038	0.901	0.953

$$\text{MEI} = 84.0\ \mu\text{S cm}^{-1} / 18.60\ \text{m} = 4.516$$

The calculated MEI was inserted into Henderson & Welcomme's (1974) equation, and the potential yield of the lake was then calculated:

$$\text{Potential fish yield (y)} = (14.3136) \times 4.516^{\,0.4681} = 28.99\ \text{kg ha}^{-1}$$

Table 4 compares the estimated potential fish yield of Lake Volta with other African lakes. The estimated potential fish yield for 1974 - 1990 ranged between 12.1 kg ha^{-1} (Lake Tanganyika) and 40.4 kg ha^{-1} (Lake Nasser-Nubia). The potential fish yield estimate of Lake Volta (28.99 kg ha^{-1}) was, therefore, within the estimated range from the earlier studies for the selected African lakes.

Discussion

A narrow difference in temperature (1.7 °C) is observed between the surface and bottom waters of the lake. As a result, practically no thermal stratification was found in Stratum VII throughout the study. Biswas (1969) also made a similar observation in the lake. In some African lakes with similar depths such as Lake Kariba (70 m) and Lake Victoria (60 m), observations have been similar (Talling, 1969).

Lake Volta was described as oligotrophic when it was formed (Entz, 1969; Ewer, 1966). Ofori-Danson & Antwi (1994) reported similar observations; that is, neutral *p*H, low solute and high DO concentrations in the Akosombo gorge area of the lake. It can be surmised from these observations that, chemically, the water in Stratum VII of Lake Volta is low in ionic content. The OECD (1970) reported that the limits of nitrate, nitrite, and phosphate values for oligotrophic lakes were 1.0, 0.05, and 1.0 mg l^{-1}, respectively. On this basis, Lake Volta may still be said to be oligotrophic, as the values ranged from 0.51 to 0.82 mg l^{-1} for nitrates, 0.02 to 0.05 mg l^{-1} for nitrites, and 0.34 to 0.50 mg l^{-1} for phosphates.

The *p*H levels of 7.2 at the surface and 6.7 at the bottom were considered suitable for fish growth and productivity, because the best *p*H values for the survival of fish have been reported to range between 5.0 and 9.0 (Jobling, 1995).

One prime limnological factor which might limit phytoplankton production (and indirectly fish yield) is the increased turbidity of the lake. This might have arisen from colloidal suspended particles, colloidal ferric iron, and phytoplankton (Biswas, 1968; Naumann, 1969; FAO/UNDP, 1971). The inorganic turbidity, caused by these colloidal suspended particles, leads to increased turbidity which prevents solar radiation from penetrating all but the surface waters, thereby effectively

TABLE 4

Comparison of Estimated Potential Fish Yields in African Reservoirs and Lakes Based on the Morpho-edaphic Index (MEI)

Reservoir or lake	*Surface area (km²)*	*Mean depth (m)*	*MEI*	*Potential fish yield (kg ha⁻¹)*
Volta[1] (Ghana)	8,700	18.6	4.52	28.99
Volta [2] (Ghana)	8,700	18.6	6.1	32.77
Nasser-Nubia[2] (Egypt)	6,850[6]	25.2	9.2	40.4
Kainji[2,3] (Nigeria)	1,270[6]	11.0	6.6	34.6
Kariba[4,5] (Zimbabwe)	5,364	29.2	2.7	22.79
Tanganyika[5] (Tanzania)	32,900	700	0.7 - 0.9	12.11
Victoria[5] (Kenya)	68,800	40.0	2.3 - 2.5	21.14 - 21.98

Sources: 1. Present study (1995-1996) 2. Henderson & Welcomme (1974) 3. Ita *et al.* (1985) 4. Marshall (1984a,b) 5. Mitchell & Marshall (1974) 6. Vanden Bossche & Bernaczek (1990) reducing the trophogenic zone. Hence, photosynthetic activity or primary production may be restricted to a zone just below the air-water interface.

The MEI model predicted the potential fish yield as 28.99 kg $ha^{-1} yr^{-1}$, which is lower than the 32.77 kg ha^{-1} yr^{-1} estimated by Henderson & Welcomme (1974) (Table 4). The cause of the decline in fish potential estimate is not very clear, but could be attributed to changes in limnological factors, notably increased turbidity. The decline in fish potential is also supported by the declining CPUE values. This situation is worsened by many fishers chasing few fish in the area. For instance, several frame surveys conducted in Stratum VII (Agyenim-Boateng, 1989; Maembe, 1990, 1992) indicated that the number of fishermen operating in the area increased by at least 300 per cent since the mid 1970s. Fortunately, the rapid growth and early recruitment of individuals to the spawning stock (Ofori-Danson, 1999) seem to improve reproductive rates of fish. However, this natural control needs to be enforced by urgent management and conservation interventions in the lake.

Acknowledgement

The authors are highly indebted to the Food and Agriculture Organization of the United Nations for the opportunity to work on Lake Volta during their participation in the FAO/UNDP Integrated Development of Artisanal Fisheries (IDAF) Project (GHA/93/008) based at Yeji in the Brong Ahafo Region of Ghana. They are also most grateful to the Director, Dr C. A. Biney, for granting them permission to use logistics and space at the Water Research Institute of the Council for Scientific and Industrial Research (CSIR).

REFERENCES

Agyenim-Boateng, C. E. (1989) *Report on the socio-economic conditions in the fishing communities in the Yeji area of the Volta Lake.* FAO/IDAF Project, GHA/88/004. Fld Doc. FAO, Rome, 89 pp.

APHA-AWWA-WPCF (1989) *Standard methods for the examination of water and wastewater,* 17 ed. Washington, DC.

Bazigos, G. P. (1970) *Frame surveys at Lake Volta.* Interim Report prepared for the UNDP/FAO Volta Lake Research Phase I. F10:SF/GHA Statistical Studies St. S/2,. FAO, Rome. 42 pp.

Biswas, S. (1968) Hydrobiology of the Volta River and some of its tributaries before the formation of the Volta Lake. *Ghana J. Sci.* **8,** 152-166.

Coppola, S. R. & Agadzi, K. (1976) *Frame survey of Volta Lake (Ghana).* FAO/GHA/71/533 St. S/5. FAO, Rome. 148 pp.

Czernin-Chudenitz, C. W. (1971) *Volta Lake research, Ghana: Physico-chemical conditions of Lake Volta, Ghana.* Report prepared for the Government of Ghana by the FAO of the UN acting as Executing Agency for the UNDP: FI:SF/GHA 10 Technical Report 1: FAO, Rome.77 pp.

Entz, B. (1969) Observations on the limnochemical conditions of the Volta Lake. In *Man-made lakes: The Accra symposium* (ed. L. E. Obeng), pp. 110-115. Ghana Universities Press for the Academy of Sciences.

Evans, W. A. & Vanderpuye, C. J. (1973) *A stock assessment plan for Volta Lake.* FI: GHA/67/510. FAO, Rome, 29 pp.

Ewer, D. W. (1966) Biological investigations on Volta Lake, May 1964 to May 1965. In *Man-made lakes* (ed. R. H. Lowe-McConnell), pp. 21-31. Symp. Biol. Inst., Lond.

FAO/UNDP (1971) *Physico-chemical conditions of Lake Volta, Ghana.* Report prepared for the Government of Ghana by FAO of the UN acting as Executing Agency for the UNDP. Based on the Work of C.W. Czernin-Chudenitz. FI: SF/GHA/10/ Tech. Report. FAO, Rome. 77 pp.

Henderson, F. & Welcomme, R. A. (1974) The relationship of yield to morphoedaphic index and numbers of fishermen in African inland fisheries. *CIFA Occas. Pap./Doc. Occas. CPCA.* **1.** 19 pp.

Ita, E. O., Sado, J. K., Balogun, J. K., Pandogari, A., & Ibitoye, B. (1985) Inventory survey of Nigeria inland waters and their fishery resources. I. A preliminary checklist of inland water bodies in Nigeria with special reference to ponds, lakes, reservoirs and major rivers. *Kainji Lake Research Institute Tech. Rep. Ser. No.14.* New Bussa, Nigeria.

Jobling, M. (1995) Environmental biology of fishes. Chapman and Hall. *Fish and Fisheries Series 16.* London. 455 pp.

Livingstone, D. A. (1963) Chemical composition of rivers and lakes. In *Data of geochemistry* (ed. M. Fleischer), Chapter G. US Government Printing Office.

Maembe, T. W. (1990) *Socio-economic information system to be used to monitor economic performance of the fisheries community.* A Report prepared from the Project Integrated Development of Artisanal Fisheries, Yeji. FI:DP/GHA/88/004. Field Document. FAO, Rome.

Maembe, T. W. (1992) *Report of the mission on socio-economics and marketing in fishing villages dependent on Yeji as a fish market.* A Report prepared from the Project Integrated Development of Artisanal Fisheries, Yeji. FI:DP/GHA/88/004. Field Document. FAO, Rome.101 pp.

Marshall, B. E. (1984a) Lake Kariba (Zimbabwe/ Zambia). In *Status of African reservoir fisheries* (ed. J. M. Kapetsky and T. Petr.), pp. 105-153. *CIFA Tech. Pap. 10.* FAO, Rome.

Marshall, B. E. (1984b) Predicting ecology and fish yields in African reservoirs from preimpoundment physico-chemical data. *CIFA Technical Paper 12.* FAO, Rome. 36 pp.

Mitchell, D. S. & Marshall, B. E. (1974) Hydro-biological observations on three Rhodesian reservoirs. *Freshwat. Biol.* **4**, 61-72 pp.

Naumann, W. (1969) A survey of limnological studies and proposals regarding limnological researches in the framework of the Volta Lake Research Project. In *UNESCO Annual Report Serial No. 1092. Annex* **1**, 1-10.

OECD (1970) *Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication.* Based on a Report prepared by Richard A. Vollenweider, Paris. 77 pp.

Ofori-Danson, P. K. (1999) Stock assessment of the five major commercial fish species in the Yeji area (Stratum VII) of the Volta Lake (Ph D Thesis). University of Ghana, Legon. 189 pp.

Ofori-Danson, P. K. & Antwi, L. A. K. (1994) Limnology of the Volta Lake (Akosombo gorge area) twenty-five years after impoundment. *Trop. ecol.* **35** (1), 69-82.

Pitcher, T. J. & Hart, P. J. B. (1995) The impact of species changes in African lakes. *Fish and Fisheries Series 18.* Chapman and Hall, London. 601 pp.

Ryder, R. A., Kerr, S. R., Loftus, K. H. & Regier, H. A. (1974) The morphoedaphic index, a fish yield estimator –review and evaluation. *J. Fish. Res. Bd Can.* **31**, 66-68.

Talling, J. F. (1969) The incidence of vertical mixing and some biological and chemical consequences in tropical African lakes. *International Vereinigung fur Theoretische und Angewandte Limnologie Verhandlungen* **17**, 998-1012.

Vanden Bossche, J. P. & Bernacsek, G. M. (1990) Source book for the inland fishery resources of Africa: 1. *CIFA Technical Paper No. 18.1.* Rome, FAO. 240 pp.