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Modelling catch per unit effort of the Black Volta near the Bui dam in Ghana

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Abstract

The chlorophyll *a* concentration and water level of the Black Volta near the Bui dam were studied in relation to fish production as measured by catch per unit effort (CPUE) between February 2011 and December 2012. The primary objective was to develop a simple linear regression model for predicting CPUE levels. The mean estimated CPUE for 2011 and 2012 was lower (6.23 kg canoe^{-1} day^{-1}) in the postwet season than in the dry season (10.86 kg canoe^{-1} day^{-1}) with a mean of 7.95 kg canoe^{-1} day^{-1}. Hence, the dry season was the most important season for fish catches in the study area. Predictor variables that significantly explained CPUE levels were chlorophyll *a* (positive correlation) and water level (negative correlation) ($P = 0.0002$). The model was validated with independent data from the same Black Volta in 2011 and 2012. This model, CPUE = (0.062 × chlorophyll *a*) − (0.456 × water level) + 3.363, explained 91% CPUE variability. Independent validation indicated that the model had the potential to predict CPUE (as a measure of fish production) in the Black Volta near the Bui dam. Hence, the model is also a valuable tool to predict future trends in the CPUE levels of the Black Volta.

Key words: chlorophyll *a*, fish catches, model, predictor variables, seasons, water level

Résumé

La concentration en chlorophylle *a* et le niveau d'eau de la Volta Noire ont été étudiés près du barrage de Bui, en lien avec la production de poisson mesurée en prises par unité d'effort (PUE) entre février 2011 et décembre 2012. Le premier objectif était de développer un modèle de régression linéaire simple pour prévoir les niveaux de PUE. La PUE moyenne estimée pour 2011 et 2012 était plus basse (6,23 kg canoë/jour) après la saison des pluies qu'en saison sèche (10,86 kg/canoë/jour), avec une moyenne de 7,95 kg/canoë/jour. La saison sèche était donc la saison la plus importante pour la pêche dans la zone étudiée. Les variables prédictives qui expliquaient de façon significative les taux de PUE étaient la chlorophylle *a* (corrélation positive) et le niveau de l'eau (corrélation négative) ($P = 0{,}0002$). Le modèle a été validé au moyen de données indépendantes provenant de la même Volta Noire en 2011 et 2012. Ce modèle – PUE = (0,062 × chlorophylle *a*) − (0,456 × niveau de l'eau) + 3,363 – expliquait 91% de la variabilité de la PUE. Une validation indépendante indiquait que ce modèle permettait de prédire la PUE (comme mesure de la production de poisson) dans la Volta Noire près du barrage de Bui. Ce modèle est donc un outil intéressant pour prédire les tendances futures des taux de PUE de la Volta Noire.

Introduction

Dams are an inextricable element of our society and are built for a multitude of reasons such as irrigation, power generation, drinking water supply and flood control at increasing financial cost (Collier, Webb & Schmidt, 1996). Various studies have been carried out on changes brought about in abiotic and biotic factors of parent rivers as a result of damming; however, responses of rivers and river ecosystem to dams are complex and varied as they depend on local sediment supplies, dam structure and operation, and key attributes of the biota.

Soon after the creation of the Volta Lake in Ghana, several studies were undertaken to provide information for the new ecosystem caused by environmental change. According to Lawson *et al.* (1969), the dominant changes

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in fish species composition were characterized by the disappearance of certain fish families, and the establishment of fish species which were lowly represented in the river prior to the formation. There was a shift in the fish community from riverine to a composition dominated by lacustrine species (PETR, 1968). It is anticipated that similar changes in the fisheries of the Black Volta would take place soon after the creation of the Bui dam.

Despite these studies, relatively few have been carried out and those studies that have been carried out tend to be descriptive accounts of the river system without making predictions about future conditions in the lake. Predictions are required to anticipate the future dynamics of a system (Pace, 2001) and to help in the formulation of appropriate management measures for sustainable exploitation of fish resources. An intuitive premise for ecological modelling is that interacting abiotic variables create environmental gradients that shape the spatial patterns of natural populations (Rocha *et al.*, 2009). According to Gomes & Miranda (2001), prediction is usually in the form of regression models, using a small number of variables with a long-term data set. Regression and correlation analysis are widely used in water quality management as supplementary tools for dynamic models (Rocha *et al.*, 2009). However, few predictive models have been developed for tropical freshwater bodies. Water level and chlorophyll *a* are relevant parameters in estimating catch per unit effort (CPUE). Water level fluctuations influence the abundance of fishes in tropical freshwaters (Amarasinghe & Pitcher, 1986; Amarasinghe, 1987; Blay & Asabere-Ameyaw, 1993; Braimah, 1995; Quarcoopone, Amevenku & Ansa-Asare, 2008; Abobi *et al.*, 2013) while chlorophyll *a* concentration constitutes an important carbon source for fish (Lopes, Benedito-Cecílio & Martinelle, 2007). It should, however, be noted that chlorophyll *a* abundance is not a causative factor on its own but an indicator of other factors such as primary production and phytoplankton abundance. This study therefore used predictor variables (chlorophyll *a* concentration and water level) to predict fish production as measured by CPUE levels. Generally, CPUE is used in estimating total fish catch. Hence, a model developed to predict CPUE will also be useful to resource economists in assessing the contribution of small-scale fisheries to food security and poverty alleviation in tropical inland water bodies. The predictive power of this model was also validated with independent data set. This model can therefore be used to predict the future state of fish production and invariably the livelihoods of fishers in the Black Volta as well as other similar tropical freshwater bodies.

Materials and methods

Study area

The study was conducted on the Bui dam section of the Black Volta. The study area stretched from the Bui reservoir (upstream) to Bamboi (downstream) within latitudes 8° 09′ to 8° 16′ N and longitudes 2° 01′ to 2° 15′ W and a distance of about 37.5 km. This formed part of the Black Volta basin primarily located in north-western Ghana approximately 150 km upstream of Lake Volta. The basin covers portions of the upper, northern and Brong Ahafo regions of Ghana. The basin has a total catchment area of 142,056 km^2 including areas outside Ghana.

Measurement of changes in water levels

The water level of the river was measured monthly by taking readings in metres from permanent calibrated poles mounted in the river at the Bamboi Bridge. The poles were established by the Ghana Highway Authority.

Collection of water samples

Triplicate surface (10 cm) and bottom (50 cm) water samples were collected monthly between 0600 and 0700 GMT using a 2.0-litre Hydro-Bios Kiel TP water sampler for 23 months (February 2011–December 2012). The water samples were kept in 1 l plastic sampling bottles at each of the two sampling stations. The samples were then taken to the CSIR-Water Research Institute Water Quality Laboratory in Tamale, Ghana, for analysis of chlorophyll *a* content as a function of primary productivity. The data obtained were used in a simple linear regression model for prediction of fish production of the Black Volta in the study area.

Chlorophyll a *analysis*

For analysis of chlorophyll *a* concentration, 500 ml of subsample was taken from the water sample. About three to five drops of aqueous solution of 50% magnesium carbonate were added to avoid the degradation of chlorophyll. The sample was then centrifuged at 448 ***g*** for 15 min. The filtrate was transferred into dark bottle and capped tightly. It was then placed in a refrigerator for 14 h to allow complete extraction of chlorophyll. The content of bottle was again centrifuged at 1008 ***g*** for about 15 min. The supernatant was transferred to a volumetric flask of 10 ml, and the volume of the content was raised to 10 ml by adding 90% acetone. The optical density of the extract was recorded in mg L^{-1} on a spectrophotometer at 630, 663 and 750 nm following the methods described in APHA (1998).

Sampling design

To provide an all-year picture of the catch per unit effort (CPUE) as a measure of fish production of the study area, a two-level stratified random sampling approach was adopted. The first stratum which was defined by the four designated hydrological seasons in the study area was referred to as follows: dry season (January–March), prewet season (April–June), wet season (July–September) and postwet season (October–December) (Abban, Kwarfo-Apegyah & Amedome, 2000). The second stratum, on the other hand, which was defined to improve sampling for accuracy was as follows: above the dam site or reservoir area with sampling station at Bui (old town currently submerged) and below the dam site area with sampling station at Bamboi.

Fish catch assessment

Monthly fish sampling surveys were undertaken during the four designated hydrological seasons for 23 months (February 2011–December 2012) at the Bui and Bamboi sampling stations. During the survey, a sampling unit was considered as a commercial fisher utilizing a canoe normally with gill net. The gears used by the commercial fishermen consisted of a mixed battery of multifilament gill nets of mesh sizes of between 20 and 80 mm. These gears were standardized between fishermen. At each sampling station, the catch from a sampling unit was then weighed in grams and the number of fish counted for individual species caught. The fish caught were identified individually using identification keys by Dankwa, Abban & Teugels (1999) and Paugy, Leveque & Teugels (2003).

Estimation of total fish catches

The estimated total quantity of fish produced by local fishers utilizing gill nets was carried out as follows: Total fish catch (kg or metric tonnes) = (mean canoe-day per month × mean CPUE) × (fifty per cent (50%) of canoes assumed active or half the fishing effort) (after Ofori-Danson *et al.*, 2012). The total estimated canoes (total effort) were 35. Hence, 50% of canoes assumed active were 18 for each year of sampling.

Predictive model for fish production

To develop a simple linear regression model for predicting fish production of the Black Volta near the Bui dam, a regression analysis was performed using the STATISTICA software v. 8.0 (StatSoft.Inc., 2007) to analyse the relationship between water level, chlorophyll *a* concentration and CPUE. Regression analysis provides the most comprehensive sensitivity measure and is commonly utilized to build response surfaces that approximate complex models (Hamby, 1994). Regression methods are often used to replace a highly complex model with a simplified ‘response surface’ (Cox, 1977). The response surface is simply a regression equation that approximates model output using only the most sensitive model input parameters. Regression coefficients provide a means of applying sensitive rankings to input parameters and have been used for such in several investigations (Iman & Conover, 1980; Iman, Helton & Campbell, 1981; Helton *et al.*, 1993). The use of the regression technique allows the sensitivity ranking to be determined based on the relative magnitude of the regression coefficient (Hamby, 1994). This value is indicative of the amount of influence the parameter has on the whole model.

The assumptions made in this present model, however, were that: a sampling unit was considered as a fisher utilizing a canoe normally with gill net (the dominant fishing gears used by the fishers during the study were gill nets); the contribution of other fishing gears to total fish catch is negligible; 50% of local canoes were active throughout the year (i.e. because effort on small-scale inland fisheries in Ghana is approximately constant); the water level was taken from the downstream station; and that the threshold for model input parameters were water level = 0.5 m and chlorophyll *a* = 1.5 mg L^{-1} (the water body must not dry up and there must also be some levels of chlorophyll *a* concentration for this model to work successfully).

Results

Water level and chlorophyll a *concentration*

In 2011, water level was lowest (0.86 m) in March and highest (8.9 m) in September. In 2012, there was an unusual water level throughout the year and was lowest (0.84 m) in August and highest (3.1) in June. Chlorophyll *a* concentration decreased from 126.1 mg L^{-1} in March to 5.12 mg L^{-1} in June in 2011. In 2012, however, chlorophyll *a* concentration decreased from 218.9 mg L^{-1} in February to 41.41 mg L^{-1} in April (Fig. 1).

Estimation of mean catch per unit effort and total catch

Figure 2 shows the mean monthly variations in CPUE and total catch for canoes utilizing gill nets during 2011 and 2012. Mean monthly CPUE of fishes was lowest in August (0.71 kg canoe^{-1} day^{-1}) and highest in March (11.03 kg canoe^{-1} day^{-1}) with an annual mean of 5.16 kg canoe^{-1} day^{-1} in 2011. CPUE was highest in February (17.92 kg canoe^{-1} day^{-1}) and lowest in March (6.8 kg canoe^{-1} day^{-1}) with an annual mean of 10.29 kg canoe^{-1} day^{-1} in 2012. Mean monthly total catch of fish decreased from March (5361 kg) to August (37.3 kg) and a mean of 2568 kg in 2011. In 2012, however, total catch decreased from February (8064 kg) to March (3305 kg) and a mean of 5160 kg. Assuming 50% of all local canoes utilizing gill nets were active, a total fish catch of 26,748 kg or 26.75 metric tonnes was estimated for 2011 and 58,655 kg or 58.65 metric tonnes for 2012 and a mean of 42,702 kg or 42.70 metric tonnes for the whole study period.

Seasonal variations in CPUE levels were also observed during the study period (Fig. 3). CPUE was lowest (3.4 kg canoe^{-1} day^{-1}) in the wet season and highest (10.59 kg canoe^{-1} day^{-1}) during the dry season in 2011. By comparison, in 2012, CPUE was lowest (8.42 kg canoe^{-1} day^{-1}) in the postwet season and highest (12.52 kg canoe^{-1} day^{-1}) in the wet season. The mean estimated CPUE for the 2 years (2011 and 2012) was lowest (6.23 kg canoe^{-1} day^{-1}) in the postwet season and highest (10.86 kg canoe^{-1} day^{-1}) in the dry season with a mean of 7.95 kg canoe^{-1} day^{-1}. Hence, the dry season was the most important season for catches, while the postwet season was the lean season in the study area.

Predictive fish catch model

Figure 4 shows a plot of multiple variables (water level and chlorophyll *a*) against CPUE. Predictor variables that significantly explained CPUE levels were chlorophyll *a* (positive correlation) and water level (negative correlation) ($P = 0.0002$). The coefficient of determination, R^2, of CPUE against water level was 0.317 while that of CPUE against chlorophyll *a* was 0.855. The coefficient of determination, R^2, of the multiple variables (water level and chlorophyll *a*) against CPUE of 0.906 indicates that 91% of the variations in CPUE were explained by water level and chlorophyll *a* concentration. Hence, knowing water level and chlorophyll *a* concentration, fish production as measured by CPUE levels could be predicted. The best, most prudent simple regression model to predict CPUE levels was described as follows:

$$\text{CPUE} = (0.062 \times \text{chlorophyll}\, a) - (0.456 \times \text{water level}) + 3.363$$

The regression line expresses the best prediction of the dependent variable (CPUE), given the independent variables (water level and chlorophyll *a*). However, nature is rarely (if ever) perfectly predictable, and usually, there is substantial variation of the observed points around the fitted regression line. The deviation of a particular point from the regression line (its predicted value) is called the residual value. The smaller the variability of the residual values around the regression line relative to the overall variability, the better the prediction. Residual analysis indicated that this model was adequate for describing

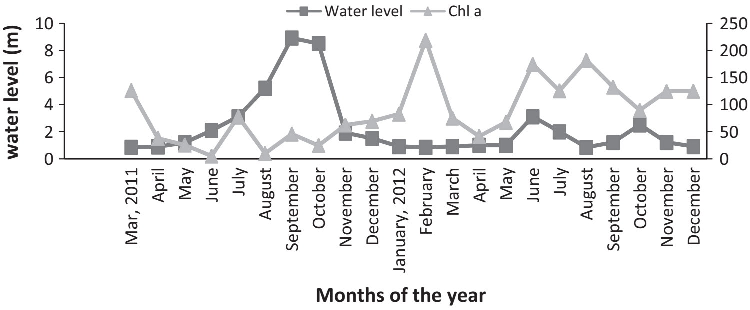

Fig 1 Monthly variations in water level and chlorophyll *a* concentration during the study period

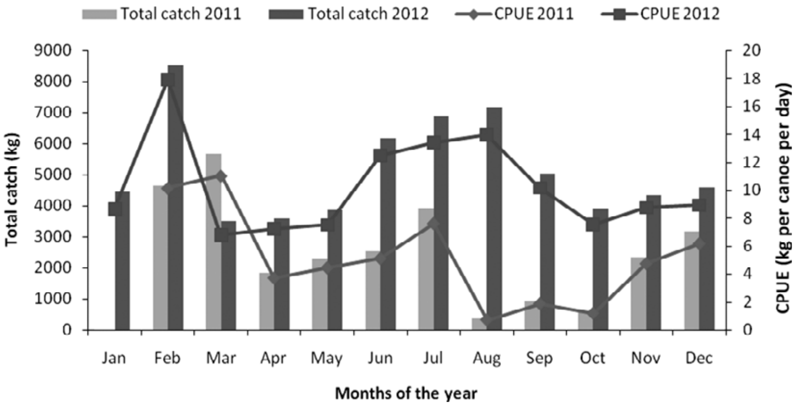

Fig 2 Mean monthly variations in catch per unit effort (CPUE) and total catch of canoes utilizing gill nets in 2011 and 2012

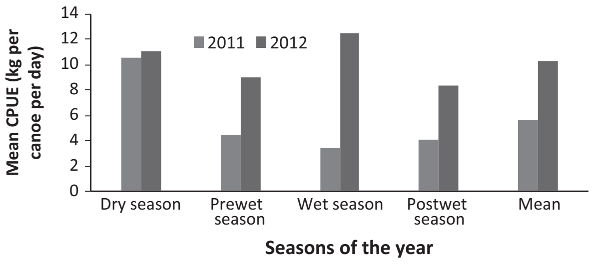

Fig 3 Mean seasonal variations in catch per unit effort (CPUE) of canoes utilizing gill nets in 2011 and 2012

CPUE as there was no trend in residuals along the CPUE gradient (Fig. 5). This is therefore an indication that the resulting model is adequate to predict CPUE levels in the Black Volta near the Bui dam.

To test the predictive power of the model, observed values of CPUE from the Black Volta during 2011 and 2012 were used. A significant relationship ($R^2 = 0.908$) was observed between CPUE predicted through the model and the CPUE measured independently in 2011 and 2012 (Fig. 6). Therefore, independent validation also indicated that the model had potential to predict CPUE (as a measure of fish production) in the Black Volta near the Bui dam.

Discussion

The study revealed a direct relationship between primary productivity as measured by chlorophyll *a* content and fish production as measured by CPUE. Hence, when primary productivity was high, CPUE was also high and vice versa. This compares favourably with earlier findings of Oglesby (1977), Jones & Hoyer (1982) and Quiros (1990) who suggested that CPUE was strongly correlated to chlorophyll *a* concentration.

There was, however, an inverse relationship between flood regime as measured by water level and fish production as measured by CPUE. Thus, when water level was high, CPUE was low and vice versa. This corroborates the findings of Braimah (1995). Using lake level fluctuations and monthly commercial fish catches recorded in the Yeji portion of the lake (Stratum VII) from July 1989 to December 1991, Braimah (1995) showed an inverse relationship between fish catch and lake level: fish catches were high when lake levels were low and vice versa. Abobi *et al.* (2013) also showed an inverse relationship between water level and CPUE in the lower reaches of the White Volta near Yapei. Increasing CPUE with decreasing water level was observed in all the landing sites during the postflood season (October to December 2011). The dry season (January to March 2012), on the other hand, had fluctuating CPUE with the decreasing water levels (Abobi *et al.*, 2013). According to de De Graaf & Ofori-Danson (1997), CPUE in Lake Volta was, however, directly related to the water level. This perhaps still calls for an urgent and comprehensive assessment of Lake Volta fisheries through re-analysis of the fragmented but long-term data sets that have been collected in the past (Béné, 2007).

In the Bontanga Reservoir in the Northern Region of Ghana, increasing CPUE was also related to decreasing water levels between September 1995 and January 1996 as shown by CPUE values which rose from 12.35 kg to 16.73 kg (Quarcoopone, Amevenku & Ansa-Asare, 2008). The relatively low CPUE associated with high water levels in the present study was also comparable to earlier works by Amarasinghe & Pitcher (1986), Amarasinghe (1987) and Blay & Asabere-Ameyaw (1993). These were attributed to the less success of reproduction and the generally

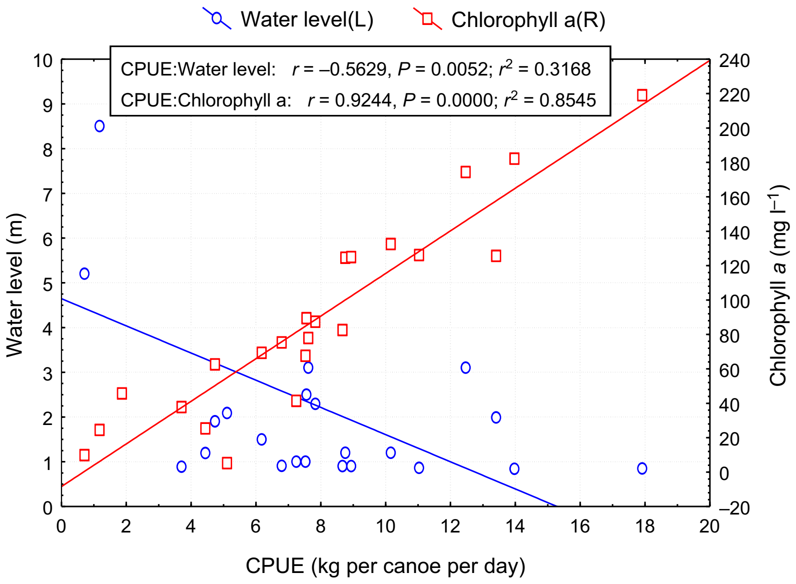

Fig 4 Effect of water level and chlorophyll *a* concentration on catch per unit effort (CPUE). [Colour figure can be viewed at wileyonlinelibrary.com]

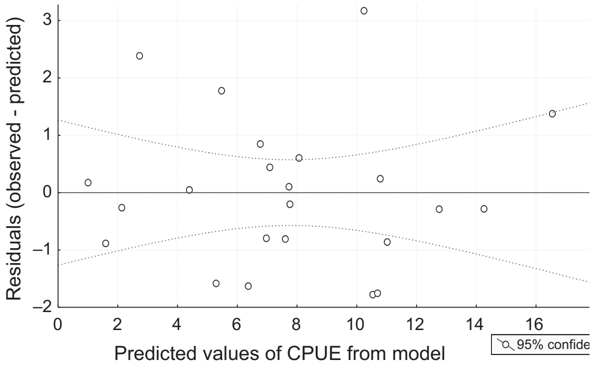

Fig 5 Relationship between residuals and predicted values of catch per unit effort (CPUE)

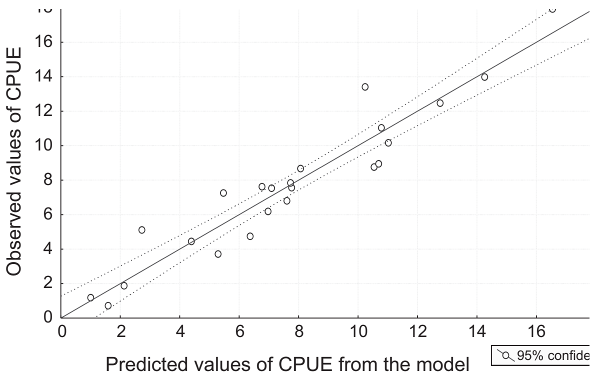

Fig 6 Relationship between catch per unit effort (CPUE) predicted through the model and those observed in 2011 and 2012

poor representation of semi-pelagic fishes in the water bodies.

A multilinear regression analysis of both water level and chlorophyll *a* content on the CPUE indicated that both partial coefficients were significant ($P < 0.05$). Hence, the best predictors of CPUE in the Black Volta were chlorophyll *a* and water level. Testing the present model using independent data set (obtained during 2011 and 2012 sampling years), the coefficient of determination, R^2, of 0.908 between the predicted values (model) and independent data demonstrated the substantial predictive power of the model.

Simple regression models can be valuable and practical tools for understanding the dynamics of ecosystems if these models meet certain requirements such as simplicity, general applicability and validity (Rocha *et al.*, 2009). It is therefore believed that this present model met these requirements and could be used to study other tropical freshwater bodies. The model here is also a valuable tool to predict future trends in the CPUE levels of the Black Volta.

Predictor variables that significantly explained CPUE were chlorophyll *a* (direct relationship) and water level (inverse relationship). This model explained about 91% of CPUE variability. Hence, predictive models are valuable and practical tools for understanding the dynamics of fish populations and that predictive limnology should be considered an approach by research scientists in monitoring the CPUE of the Black Volta in the Bui dam area.

The monthly mean CPUE for 2011 decreased from 11.03 kg canoe^{-1} day^{-1} in March to 0.71 kg canoe^{-1} day^{-1} in August with a mean of 5.16 kg canoe^{-1} day^{-1}. These values were not yet uniform possibly because of the formation of the impoundment in June the same year. Hence, the reservoir was still in the interphase between the lacustrine and riverine conditions. The CPUE values for 2012 were, however, uniform and decreased from 17.92 kg canoe^{-1} day^{-1} in February to 6.8 kg canoe^{-1} day^{-1} in March with a mean of 10.29 kg canoe^{-1} day^{-1}. This phenomenon could be due to the unusual low water level throughout the 2012 sampling year (Alhassan, 2013). Also, the unusual high CPUE from July to September (wet season) during 2012 was also due to the exceptionally low water level during the same period, as CPUE was inversely proportional to water level (Braimah, 1995).

The decline in CPUE immediately after the creation of the impoundment was apparently due to changes in trophic state, as well as to the construction of the dam upstream. The higher variability of CPUE that was observed before and after the impoundment was a reflection of fish community instability in these periods.

From the estimated CPUE and fishing effort, the total quantity of fish produced by commercial fishermen using gill nets was 26,748 kg or 26.75 metric tonnes for 2011 and 58,655 kg or 58.65 metric tonnes for 2012 and a mean of 42,702 kg or 42.70 metric tonnes for the 2 years of sampling. The mean total catch of 42.70 metric tonnes forms only 0.03% of the total inland capture fishery production which is about 150,000 metric tonnes (Anon, 2009) and 0.01% of an estimate of 319,000 metric tonnes (comprising 251,000 metric tonnes from the Volta Lake and 68,000 metric tonnes from other sources) for the year 2000 (MOFA, 2006). Hence, the contribution of the Black Volta gill net fisheries near the Bui dam area to total inland fishery production in Ghana is negligible. This therefore confirms the assumption that Lake Volta is the main 'component' of inland fisheries in Ghana (MOFA, 2006).

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References

Abban, E.K., Kwarfo-Apegyah, K. & Amedome, E. (2000) *Annual Report on Fish Monitoring in Relation to Onchocerciasis Control Programme in the Volta Basin in Ghana*. CSIR-Water Research Institute, Accra, Ghana, 80 pp.

Abobi, S.M., Ekau, W., Wolff, M., Blay, J. & Campion, B.B. (2013) Catch per unit effort (CPUE) and water level variations in the lower reaches of the White Volta River (Yapei), Ghana. *Afr. J. Agric. Res.* **8**, 2870–2876.

Alhassan, E.H. (2013) *Hydro-Biology and Fish Production of the Black Volta Near the Bui Dam During the pre- and Post-Impoundment Periods*. PhD Dissertation. University of Ghana, Legon, 190pp.

Amarasinghe, U.S. (1987) Status of the fishery of Pimburettewa wewe, a man-made lake in Sri Lanka. *Aquac. Fish. Manage.* **18**, 375–385.

Amarasinghe, U.S. & Pitcher, T.J. (1986) Assessment of fishing effort in Parakrama Samudra, an ancient man-made lake in Sri Lanka. *Fish. Res.* **4**, 271–282.

American Public Health Association (APHA). (1998) *Standard Methods for the Examination of Water and Wastewater*, 20th edn. American Public Health Association Inc., New York.

Anon. (2009) *Republic of Ghana Fisheries and Aquaculture Sector Development Plan 2010 to 2015*, 37 pp.

Béné, C. (2007) *Diagnostic Study of the Volta Basin Fisheries Part 1 – Overview of the Volta Basin Fisheries Resources. Report Commissioned by the Focal Basin Project – Volta*. World Fish Center Regional Offices for Africa and West Asia, Cairo Egypt, p 31.

Blay, J. Jr & Asabere-Ameyaw, A. (1993) Assessment of the fishery of a stunted population of the cichlid, *Sarotherodon melanotheron*, in a closed lagoon in Ghana. *J. Appl. Ichthyol.* **9**, 1–11.

Braimah, L.I. (1995) Recent developments in the fisheries of Volta Lake. In: *Current Status of Fisheries and Fish Stocks of the Four Largest African Reservoirs: Kainji, Kariba, Nasser/Nubia and Volta*, (Eds. R.C.M. Crul and F.C. Roest). CIFA Technical Papers, Rome, Italy, 115–134 pp.

Collier, M., Webb, R.H. & Schmidt, J.C. (1996) *Dams and Rivers: Primers on the Downstream Effects of Dam: Circular 1126* . U.S Geological Survey, Tucson, AZ, USA.

Cox, N.D. (1977) Comparison of two uncertainty analysis methods. *Nucl. Sci. Eng.* **64**, 258–265.

Dankwa, H.R., Abban, E.K. & Teugels, G.G. (1999) *Freshwater Fishes of Ghana: Identification, Distribution, Ecological and Economic Importance*. Annales des Sciences Naturelles, Brussels, 283 pp.

De Graaf, G.J. & Ofori-Danson, P.K. (1997) *Catch and Fish Stock Assessment in Stratum VII of Lake Volta*. IDAF/Technical Report/97/I.

Gomes, L.C. & Miranda, L.E. (2001) Hydrologic and climatic regimes limit phytoplankton biomass in reservoirs of the upper Paraná River Basin, Brazil. *Hydrobiologia* **457**, 205–214.

Hamby, D.M. (1994) A review of techniques for parameter sensitivity analysis of environmental models. *Environ. Monit. Assess.* **32**, 135–154.

Helton, J.C., Garner, J.W., Marietta, M.G., Rechard, R.P., Rudeen, D.K. & Swift, P.N. (1993) Uncertainty and sensitivity analysis results obtained in a preliminary performance assessment for the waste isolation pilot plant. *Nucl. Sci. Eng.* **114**, 286–331.

Iman, R.L. & Conover, W.J. (1980) Small sample sensitivity analysis techniques for computer models, with an application to risk assessment. *Commun. Stat. A Theor.*, **9**, 1749–1842.

Iman, R.L., Helton, J.C. & Campbell, J.E. (1981) An approach to sensitivity analysis of computer models: part II – ranking of input variables, response surface validation, distribution effect and technique synopsis. *J. Qual. Tech.* **13**, 232–240.

Jones, J.R. & Hoyer, M.V. (1982) Sport fish harvest predicted by summer chlorophyll *a* concentration in mid western lakes and reservoirs. *Trans. Am. Fish. Soc.* **111**, 176–179.

Lawson, G.W., Petr, T., Biswas, R. & Reynolds, J.D. (1969) Hydrobiological work of the Volta Basin Research Project 1963–1968 . *Bull. de l' I.F.A.N Serie A. XXI* **3**, 965–1003.

Lopes, C.A., Benedito-Cecílio, E. & Martinelle, L.A. (2007) Variability in the carbon isotope signature of *Prochilodus lineatus* (Prochilodontidae, Characiformes) a bottom-feeding fish of the Neotropical region. *J. Fish Biol.* **70**, 1649–1659.

Ministry of Food & Agriculture (MOFA). (2006) *Inland Fisheries Policy Document*. Ministry of Food and Agriculture, Directorate of Fisheries, Accra, Ghana, p 18.

Ofori-Danson, P.K., Kwarfo-Apegyah, K., Atsu, D.K., Berchie, A. & Alhassan, E.H. (2012) *Final Report on Stock Assessment Study and Fisheries Management Plan for the Bui Reservoir*. A report prepared for the Bui Power Authority, Accra, Ghana, 106 pp.

Oglesby, R.T. (1977) Relationship of fish yields to lake phytoplankton standing crop production and morhoedaphic factors. *J. Fish. Res. Board Can.* **34**, 2271–2279.

Pace, M.L. (2001) Prediction and the aquatic sciences. *Can. J. Fish Aquat. Sci.* **58**, 63–72.

Paugy, D., Leveque, C. & Teugels, G.G. (2003) *The Fresh and Brackish Water Fishes of West Africa*, **2**. IRD/MNHN/MRAC, Paris, France, 815.

PETR, T. (1968) The establishment of lacustrine fish populations in the Volta Lake in Ghana during 1964–1966. *Bull. de l'I.F.A.N. 1 (Serie A)* **30**, 257–269.

Quarcoopone, T., Amevenku, F.Y.K. & Ansa-Asare, O.D. (2008) Fisheries and limnology of two reservoirs in northern Ghana. *West Afr. J. Appl. Ecol* **12**, 25–32.

Quiros, R. (1990) Predictors of relative fish biomass in lakes and reservoirs of Argentina. *Can. J. Fish Aquat. Sci.* **47**, 928–939.

Rocha, R.R.A., Thomas, S.M., Carvalho, P. & Gomes, L.C. (2009) Modeling chlorophyll *a* and dissolved oxygen concentration in tropical floodplain lakes (Parana River, Brazil). *Braz. J. Biol*, **69** (2, Suppl.), 491–500.

Statsoft.Inc. (2007). *STATISTICA (Data Analysis Software) Version 8.0* www.statsoft.com (Accessed on 20 February 2013).

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