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# Aspects of Reproductive Ecology of Chrysichthys Auratus in the Volta Lake, Ghana

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## Abstract
*The study was conducted in 2018, on the Chrysichthys auratus in the Volta Lake, due to its socio-economic importance to the many and varied dependent fishermen, fish processors and fish traders. The objective was to determine the reproductive strategy to facilitate sustainable management of the fish stocks. A total of 452 fish samples collected on monthly basis were measured, weighed and dissected for determination of, sexual maturity, sex ratio, gonadosomatic index GSI, hepasomatic index HSI, condition factor k, visceral fat index VFI, and monthly stomach fullness in relation to sexual maturity. According to the length at first maturity determined, 89% of the female fish caught, fell below that critical length, suggesting growth overfishing, attributed to size and sex selective tendencies of bamboo pipe fishing. During gonad development, the correlation of the GSI to the HSI and the VFI was inverse and insignificant but in the post gonad development phase it switched to a positive and insignificant relationship. The point of switch, in September, was synonymous with spawning and indicative of the spawning period. It was concluded that the reproductive strategy was to time the spawning process, in September, to coincide with the upwelling phenomenon (June – September), associated with fish food abundance, thereby enhancing the survival of the offspring. A seasonal ban on fishing and a total ban on bamboo pipe fishing were recommended.*

**Keywords:** *Chrysichthys Auratus*, Sex Ratio, Length at First Maturity, Gonadosomatic Index, Visceral Fat Index, Spawning Season, Condition Factor

## Introduction
The genus *Chrysichthys* is native to Africa and mostly represented by *Chrysichthys auratus* and *Chrysichthys nigrodigitatus* in the West Africa hydrographic basins [1]. These species are most abundant in the deeper inshore areas of African water bodies, especially characterized by petrified drown trees [1-3]. As they are abundant, they are exploited so well they have been included in the 2010 International Union for Conservation of Nature's (ICUN) Red list of threatened species. However, the species continue to provide, food security and nutrition, employment and income to many fishermen, fish processors and fish traders [4]. The importance and dynamics of the fishery consequently have drawn the attention and interest of researchers to work towards reversing the 'threatened' status to 'long-term sustainability' in order to sustain the livelihoods of its many and varied dependent beneficiaries. It was in contributing to the growing research that the study was initiated initially on *Chrysichthys auratus* with the aim of examining some aspects of the reproductive ecology in order to determine the reproductive strategies to facilitate the long-term sustainable management of the fish stocks.

Usually the reproductive cycle of a sexually matured fish commences with gonad development and ends with spawning. Estimating the gonad weight in relation to the somatic weight (gonadosomatic index) indicates the status of the reproductive effort of a fish after sexual maturity [5, 6]. Fishes like other vertebrates, store energy for the reproductive effort in such places as the liver and visceral fat. The relation of the liver weight to somatic weight (hepatosomatic index) and visceral fat to somatic weight (visceral fat index) are likely indications of spawning periods of fish [5, 7, 8]. The condition factor is a measurement of the wellbeing of fish. A condition factor above 1 means the fish is in good health and below 1 means it is not. Monitoring of this factor may also show an association with the spawning pattern [5, 7-9]. Assessing the trends of these relationships leads to the determination of the reproductive strategy of a fish species, in relation to changes in environment, food availability, feeding and reproduction which facilitates management of the fish stocks on a sustainable basis.

The main aspects of the study to determine the species reproductive strategy for prudent management, comprised, collecting fish samples on monthly basis to: 1. examine the reproductive biology of the fish: maturity of fish; length at first capture; sex ratios and gonadosomatic index and 2. study other aspects related to reproduction: hepasomatic index; condition factor; visceral fat index; and stomach fullness in relation to sexual maturity.

## Materials and Methods

### Reproductive Biology

A total of 452 fish samples was collected from February to November of 2018 from fishermen in the northern arm of the Volta Lake, on monthly basis, and examined, for:

### Gonad Maturity Stages

The fish samples were dissected, sexed and the stage of gonad maturity determined by a gonad maturity stage table prepared for the study (Table 1).

**Table 1** Gonad maturity stages of fish in the Volta Lake

| Stage | Description | Ovaries/testes | Eggs |
|---|---|---|---|
| I (0) | *Immature* Young individuals which have not yet engaged in reproduction, young small sexual organs close under vertebral column; gonad of very small size | Transparent, colourless to gray. | Eggs invisible to naked eye. |
| II (1) | *Resting* Sexual products have not yet begun to develop; gonads of very small size | Underdeveloped, small, translucent | None visible to naked eye |
| III (2) | *Developing* Ovary/testes occupy about half of ventral cavity | Opaque, reddish with blood capillaries | Eggs visible and opaque, appear as whitish granular |
| IV (3) | *Ripe* (*Mature*) Sexual products ripe, sexual organs filling ventral cavity but the sexual products are still not extruded when light pressure is applied | Fills body cavity | Translucent, large and round |
| V (4) | *Spawning* Sexual products are extruded in response to very light pressure on the belly | Releases eggs/milt when pressed | Large translucent, some free in ovary |
| VI (5) | *Spent* Sexual products have been discharged, genital aperture inflamed, gonads have appearance of deflated sacs | Shrinking slack, the ovaries usually containing a few left over eggs and testes some residual sperm | Some residual eggs. |

### Length at First Maturity

Length frequency measurements were taken for female fish for determination of the length at first maturity $L_m$, using the logistic curve equation,

$$P = 1/ (1 + \exp (-r (L - L_m))$$

Transformed into a straight line as:

$$1 = P + P \exp (-r (L – L_c))$$

Where $L_c$ is the length which corresponds to the proportion of 0.5 (or 50%) of fish caught.

By rearrangement:

$$(1 – P)/P = \exp (-r (L - L_c)$$

In reproductive condition, $L_m$ is equated to $L_c$, where $L_m$ is the length at first maturity, therefore:

$$\ln ((1 – P)/P) = rL_m – rl$$

Where, $-r$ is the slope and the intercept ($a$) is $rL_m$. Ln $((1 – P)/P)$ was plotted against $L$, to provide an estimate of $-r$, and $L_m$, where $r$ is $–(b)$ and $L_m$ is $a/r$.

It was necessary to adjust the proportion of mature individuals to take account of all mature individuals not being reproductively active at the same time. If the highest proportion ($P$) for the length classes is, $n$, the correction factor to be multiplied by for all the proportions in the length classes is $1/n$ hence $(1/n \times P)$ will be the adjusted proportion for the length class.

### Sex Ratio

Length frequency measurements were taken for the fish samples and tested for differences between sexes and between mature and immature males and females using the statistical Chi-test. The Chi-square distribution table was used to determine whether the value of $\chi^2$, is significant at 95% confidence level ($P<0.05$), that is when the value of $\chi^2$, is higher over the Chi-square distribution table's value at n-1 degrees of freedom.

### Gonadosomatic Index *GSI*

Trends in reproductive activity of females were determined using the gonadosomatic index. To determine this, ovaries of fish were removed and weighed $GW$, on monthly basis, to the nearest gram, and the gonadosomatic index $GSI$, calculated as:

$$GSI = (GW \times 100)/ (BW – GW)$$

A trend line was fitted, as a running average over two classes (order of 2), to smooth out irregularities in the data.

Iles (1984) classified *GSI*, as a partial condition factor, accordingly, its analysis was associated with the other condition factors mentioned in 2.2.2 below.

### Aspects Related to Reproduction of Fish

#### Stomach Fullness in Relation to the Sexual Maturity Stage of Fish

To determine whether fish cease feeding during the reproductive cycle and what sexual stage that happens, for each fish, the condition of the stomach (presence or absence of food) was determined in relation to the sexual maturity stage of the fish. Fish in advanced stage of maturity, ripe and running, were specifically classified as stage IV – V in the analyses.

## Other Monthly Condition Factors Related to Fish Reproduction

*Condition factor (k)*

Trends in condition which reflects the wellbeing of the fish were determined from individual's weight (*BW* to the nearest gram) and standard length (*SL* to the nearest millimeter) on monthly basis, using:

$$k = BW \times 100/SL^3$$

A trend line was fitted as a running average over two classes (order of 2) to smooth out irregularities in the data.

*Hepasomatic index* (*HSI*)

The liver of each fish was weighed (*LW*) to the nearest gram, on monthly basis, for determination of the hepasomatic index *HSI*, using:

$$HSI = (LW \times 100)/ (BW - LW)$$

A trend line was fitted as a running average over two classes (order of 2) to smooth out irregularities in the data.

*Visceral fat index* (*VFI*)

Visceral fat (*VF*) was carefully scraped off the fish and weighed on monthly basis to the nearest gram, for determination of the visceral fat index *VFI*, using:

$$VFI = (VF \times 100)/ (BW - VF)$$

A trend line was fitted, as a running average over two classes (order of 2), to smooth out irregularities in the data.

## Determination of The Relationship of *GSI* with The Other Condition Factors for Indication of the Spawning Season

The linear correlation coefficient *r*, was calculated for determination of the strength and direction of the relationship of *GSI* with the other condition factors (*HSI*, *VFI*, and *k*). The analysis of variance (ANOVA) test of the means of the condition factors, was not applied in this case due to the distributions not being positively skewed – inverse relationships were involved.

The linear correlation coefficient *r*, of *GSI*, with the other condition factors was determined by:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2][n(\sum y^2) - (\sum y)^2]}}$$

The significance of *r*, was tested using the *t* test:

$$t = r\sqrt{\frac{n-2}{1-r^2}}$$

with degrees of freedom equal to *n* - 2, where *n* is the number of ordered pairs (*x*, *y*). The critical value of the *t* distribution at P<0.05 was used to determine the significance of *r*, that is when the value of the *t* test is higher over the *t* distribution value at n – 2 degrees of freedom.

The *coefficient of determination* $r^2$ was determined to ascertain the ratio of the explained variation to the total variation of the relationship of *GSI* (independent variable) with the other condition factors (dependent variables).

The *coefficient of nondetermination* was found by subtracting the *coefficient of determination* from 1 ($1 - r^2$) which is a measure for variations that cannot be accounted for by the relationships.

For the relationships with significant values of *r*, the equation of the regression line was determined.

## Results

## Seasonal Gonad Maturity

The monthly examination of the fish samples showed that: mature fish (stage IV) were present throughout the year (Figure 1); spawning fish (stage V) were found mostly in September, a few in October; and spent fish (stage VI) were observed only in October indicating that the fish may have spawned in September. It was indicative that the major spawning period of *C. auratus* could be September even though fish could be seen in the mature stage throughout the year suggesting a yearly spread of minor and insignificant spawning [1].

## Length at First Maturity

The length at first maturity of *C. auratus*, using Table 2 below, and by the linearized logistic equation, was calculated as 149 mm (14.9 cm), the intercept *a*, being 7.0711 and the slope *r*, 0.0475 shown by the line equation (Figure 2) [1]. The factor for adjustment of the proportion of mature individuals for each length class was 1/0.833326 (refer to Section 2.1.2). By this determination, it was established that 89% of the female in the fish samples fell below the length at first maturity on capture.

## Sex Ratio

The general sex ratio of the fish specimens examined was 1: 2.9 males to females (Table 2) which was significantly different from the expected 1: 1 ratio ($\chi^2$ – 22.20, df = 1, P<0.05). The immature male to immature female ratio was 1: 2.3 also significantly different ($\chi^2$ – 14.52, df = 10, P<0.05). The proportion of mature females in the fish sample was 13.0% but no mature males were present.

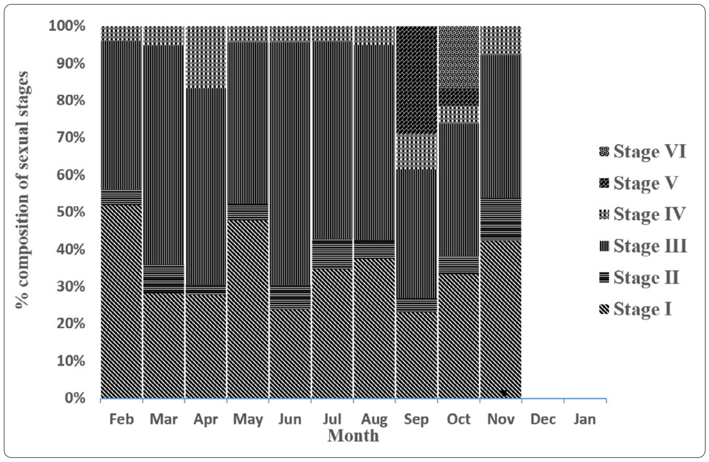


**Figure 1:** Monthly composition of gonad maturity stages of *Chrysichthys* auratus (Geoff. St. Hill., 1808) fish samples caught in the northern arm of the Volta Lake in 2018

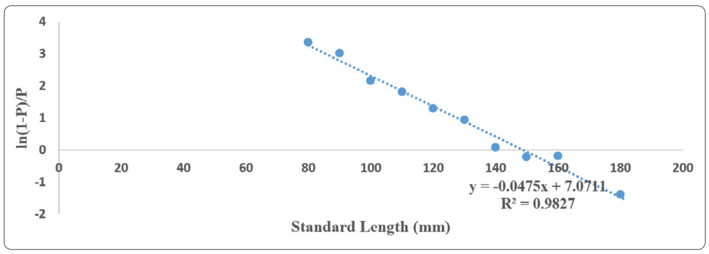


**Figure 2:** A linearized logistic relationship of ln (1-P)/P and standard length *L*, showing the intercept *a*, and the slope *r*, for determination of the length at first maturity for the *Chrysichthys auratus* (Geoff. St. Hill., 1808) in the Volta Lake

**Table 2:** Length frequency distribution of *Chrysichthys auratus* (Geoff. St. Hill., 1808), for the determination of the length at first maturity and significance of the sex ratio

| Standard length (mm) | Male | | Female | | Total |
|---|---|---|---|---|---|
| | Immature | Mature | Immature | Mature | |
| 80 | 8 | | 35 | 1 | 44 |
| 90 | 11 | | 25 | 1 | 37 |
| 100 | 13 | | 64 | 6 | 83 |
| 110 | 15 | | 53 | 7 | 75 |
| 120 | 20 | | 50 | 7 | 77 |
| 130 | 25 | | 23 | 7 | 55 |
| 140 | 17 | | 9 | 6 | 32 |
| 150 | 6 | | 7 | 6 | 19 |
| 160 | 4 | | 6 | 5 | 15 |
| 170 | 1 | | 1 | 5 | 7 |
| 180 | 1 | | 1 | 2 | 4 |
| 190 | 1 | | 2 | | 3 |
| 200 | | | 1 | | 1 |
| Total | **122** | | **277** | **53** | **452** |
| % Composition | 27 | | 61 | 12 | |
| % Sex composition | 27 | | 73 | | |

## Stomach Fullness in Relation to the Sexual Maturity Stage of Fish

Examination of the stomachs of the fish specimen for presence or absence of food showed that fish in sexual stages IV-V (advanced stage of maturity, ripe, and running) and V (spawning stage), had a very high percentage (>90%) of empty stomachs (Table 3). A high percentage (85.7%) of fish resumed eating after spawning, at the spent stage (VI). It was apparent that most of *C. auratus* fish species fed mainly during stages I to IV and ceased feeding just prior to and during spawning [1].

## Monthly Condition Factors in Relation to Fish Reproduction

Running average (order of 2) trend lines projected over scatter plots of monthly average condition factors of *GSI*, *k*, *HSI*, and *VFI* (Figure 3), showed that when the gonadosomatic index *GSI*, dipped from February to April, the condition factor *k*, the visceral fat index *VFI*, and the hepasomatic index, *HSI*, rose. Conversely when the *GSI*, rose from April to the highest point in August, the three factors dipped. In September when the *GSI* sharply plummeted, the inverse relationship earlier exhibited with the other condition factors, from March to August disintegrated and rather also tended to dip, untill October/November. During the sharp decline of *GSI*, it could be said that sexual products were being discharged and suggestive that September could be the spawning period and associated with the point of switch in direction of the relationship of *GSI*, with *k*, *VFI*, and *HSI*.

## Correlation Analyses of the Relationship of *GSI* to Other Condition Factors

### Gonad Development Phase (April – August)

Using the running average (order of 2) trend lines outputs, (Figure 3) the degree and direction of relationship of *GSI* to the other condition factors, during the period of gonad development, from April to the peak in August, was determined from the coefficients of correlation worked out:

*GSI* to *HSI*: $r = -0.974$;
*GSI* to *VFI*: $r = -0.962$; and
*GSI* to *k*: $r = -0.509$

By the negative signs of the correlation coefficients, it showed that the relationships were negative or inverse.

The significance of the correlation coefficients tested showed:

*GSI* to *HSI*: *t* test = 7.472, df = 3, P<0.05 (Significant)
*GSI* to *VFI*: *t* test = 6.083, df = 3, P<0.05 (Significant)
*GSI* to *k*: *t* test = 1.024, df = 3, P<0.05 (Insignificant)

With the critical value of 3.182 from the *t* distribution table at 3 degrees of freedom and P<0.05, only the correlation coefficients of the relationships of *GSI* to *HSI*, and *GSI* to *VFI* were significant.

The *coefficient of determination* $r^2$, of the relationship of *GSI* to *HSI* was calculated as 0.949 and *GSI* to *VFI* as 0.925 which means that 94.9% of the variation of *HSI* and 92.5% of the variation of *VFI* were accounted for by the variation in *GSI*.

Consequently, the *nondetermination coefficient* of 5.1% of the variation of *HSI* and 7.5% of the variation of *VFI* were unexplained variations or residual error.

The equations of the regression lines for the two significant relationships were determined as:

*GSI* to *HSI* y = -0.0785x + 1.5033
*GSI* to *VFI* y = - 0.0335x + 1.3115

Generally, it could be said that the relationship of *GSI* to *HSI* and *VFI*, during the gonad development phase was negative (inverse) and significant.

## Post-Gonad Development Phase (August – November)

The correlation coefficients for the post-gonad development phase, from August to November, (Figure 3) were calculated for the relationships as:

*GSI* to *HSI* $r = 0.5082$
*GSI* to *VFI* $r = 0.387$

The relationships were shown to be positive, this time around.

Using the *t* test, the significance of the correlation coefficients was determined:

*GSI* to *HSI* *t* test = 1.642, df = 2, P<0.05 (Insignificant)
*GSI* to *VFI* *t* test = 1.533, df = 2, P<0.05 (Insignificant)

With the critical value of 9.925 from the *t* distribution table at 2 degrees of freedom and P<0.05 the relationships were both insignificant.

Generally, therefore during post-gonad development, synonymous with spawning, the relationship of *GSI* to *HSI* and *VFI* was positive but insignificant.

**Table 3:** Proportion of fish with empty stomachs by sexual maturity stage, including the sexual stage IV – V (advance stage of maturity, ripe and running), of *Chrysichthys auratus* (Geoff. St. Hill., 1808) in the northern arm of the Volta Lake

| Description | I | II | III | IV | IV-V | V | VI |
|---|---|---|---|---|---|---|---|
| No. of fish examined | 160 | 27 | 212 | 14 | 15 | 17 | 7 |
| No. of fish with empty stomachs | 2 | 1 | 3 | 1 | 14 | 17 | 1 |
| No. of fish with food in stomachs | 158 | 26 | 209 | 13 | 1 | 0 | 6 |
| % of fish with empty stomachs by sexual stage | 1.25 | 3.7 | 1.4 | 7.1 | 93.0 | 100 | 14.3 |

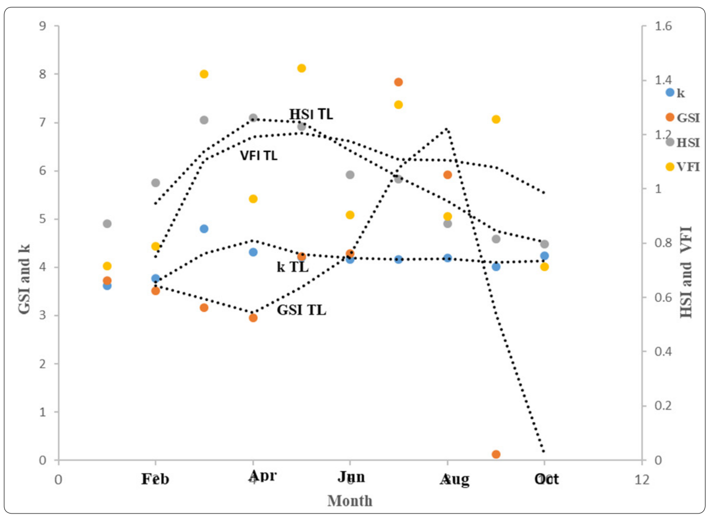


**Figure 3:** Running average (order of 2) trend lines fitted over scatter plots of monthly averages of, gonadosomatic index *GSI*, condition factor *k*, visceral fat index *VFI*, and hepasomatic index *HSI*, for *Chrysichthys auratus* (Geoff. St. Hill., 1808) in the northern arm of the Volta Lake

## Discussion

The sex ratio of males to females, shows significant difference from the expected 1: 1 ratio at P<0.05, portraying a skew, with females more dominant in fishermen catches. This conforms to the findings of Ragheb in the Nile but contravenes Adekoya's in the Ogun State estuary where males are rather dominant [1, 10]. Species with the sex ratio for mature fish, being equal or nearly equal, exercise parental care by both parents [11]. Besides, the case where males are involved directly as mouth brooders, generally the acquisition of territories for breeding is an arduous task and once acquired, much of the male territorial effort is directed towards fending off predators [12]. A near 1: 1 ratio is therefore essential in the survival of eggs for fish species especially for *C. auratus*, with relatively few eggs [1]. Blanche working on the same species in Lake Chad confirms parental care exhibited by this species [13].

Sex reversal of species in the Volta Lake has not been reported and Lowe-McConnel studying cichlids generally, also a dominant fish species in the lake, confirms the nonoccurrence of such a phenomenon [14]. It can be concluded therefore that the dominance of mature females over the mature males is attributed to anthropogenic activities. Distortion in sex ratios has been shown to be caused by unequal, sex selective fish catching techniques exerted on female fish populations of the species in the lake. Collison reports of bamboo pipe fishing being practiced extensively on the lake targeting the *Chrysichthys* species and a high proportion of fish caught being gravid females [15]. The side or through cut openings of the submerged bamboo pipes simulate dark crevices when submerged in the lake, which entice gravid females to enter for spawning purposes and once inside are trapped for capture. Such sex ratio distortions ultimately affect the reproductive potential of the species and require urgent management measures to curtail, including placing a total ban on the bamboo pipe fishing.

The length frequency distribution analyses show a significant difference for mature and immature males and females species of *C. auratus* [1]. This finding supports the recommendation of Spare and Venema for separation of sexes in length frequency distribution analyses for growth and population dynamics studies [4].

The results of the length at first maturity calculation show that 89% of *C. auratus* females are likely to be caught before they can reach that critical length, in order to spawn at least once [1]. This testifies that the phenomenon of growth overfishing is actively occurring which has been pointed out by Braimah when very many small-sized *Chrysichthys* fish were found in bamboo pipe landings and advised that action be taken to ban the fishing gear [16]. Suffice to say that the menace has now reached unprecedented proportions and it is clear urgent legislation is required and enforced to stop bamboo pipe fishing in the Volta Lake.

Iles refers to the gonadosomatic index *GSI*, hepasomatic index *HSI*, and visceral fat index *VFI*, as partial condition factors which positively or negatively relate to the condition factor *k* [7]. Although the study shows a negative scatter of *GSI*, plotted against all the other condition factors from February to August, it particularly records from April to August, during gonad development, a significant negative correlation against *HSI,* and *VFI*. However immediately on commencement of the post-gonad development phase, the negative and significant correlation phenomenon ceases and in its place is insignificant and positive relationship. This suggests that there is a point of switch somewhere after August, synonymous with spawning, drawing further evidence from the monthly maturity stages in Figure 1. Monitoring of this point of switch therefore could be indicative of the major spawning period which must be essential to resource managers for sustainable management of the species. It can also be inferred from the relationships, from April to August, that major gonad development corresponds significantly with, liver weight loss and reduction in visceral fat. Iles reports that maturation of the gonad represents a major utilization of protein for the adult fish and resources are diverted from other sources, especially accumulated fat surrounding tissue and liver [17]. The loss of body reserves during maturation and pre-spawning is further compounded by the apparent starvation which takes place at this time [17]. Nearly all *C. auratus* specimen in stages IV – V (ripe – running), and V (spawning) did not feed [1]. A similar observation of empty stomachs around spawning was noted by Adiase for *Chrysichthys* species in the Volta Lake [18]. Ikomi also for *Brienomyrus longianalis* in the upper Warri River, in Nigeria did not feed immediately prior to spawning [19]. Cessation of feeding is common in *S. galileus* and *O. niloticus*, which are mouth brooders [14, 20]. All endemic cichlids in Lake Malawi are also mouth brooders and require extensive fat energy reserves to support females through to the time when eggs hatch [12]. The study shows that in the Volta Lake, *C. auratus* species commence feeding immediately after spawning as only a few fish examined had empty stomachs at sexual stage VI (spent) [1]. It would therefore seem, for the species that, cessation of feeding is triggered just prior to spawning, early in September, and commencement of feeding early in October when spent fish are observed.

Ewer, Viner and Biswas report that the rainy season of the Volta Lake commences from May to October, with a major upwelling phenomenon occurring from June to September, due to the heavy inflows from the tributaries causing mixing from top to bottom [21-23]. Upwelling brings up abundant nutrients from the bottom promoting abundant production of plankton, the food of fish. Oluwatsin also reports that the highest mean monthly condition factor for both species of *C. auratus* and *C. nigrodigitatus* was recorded in September in the Aiba Reservoir in Nigeria, attributing this to abundant food and prey items due to the same upwelling phenomenon [24]. It would therefore seem that *C. auratus* utilizes the benefits of the rainy season by spawning during the period and timing the process to coincide with the upwelling period in September [1]. This reproductive strategy which takes advantage of the rainy season particularly the upwelling period is bound to enhance the survival rate of the young due to the abundant availability of fish food, then.

## Conclusions and Recommendations

1. The exploitation of 89% of the female *C. auratus* population before they can reach the length at first maturity, attributed to size and sex selective fishing gear, notably bamboo pipe fishing, is pointer to the phenomenon of growth overfishing in the lake and it is recommended that urgent legislation is enacted and enforced to eliminate the menace of bamboo pipe fishing [1].

2. *C. auratus* species utilize the benefits of the rainy season by spawning during the period and timing the process to coincide with the upwelling phenomenon from June to September, associated with fish food abundance [1]. This reproductive strategy enhances the survival rate of the young. It is therefore recommended that a seasonal ban on fishing during the upwelling period of the lake be placed to protect gravid female fish populations to ensure success of the spawning process.

3. The gonadosomatic index *GSI*, of *C. auratus* has been shown to be significantly negatively correlated to the hepasomatic index *HSI*, and the visceral fat index *VFI*, indicating that major gonad development corresponds with liver weight loss and reduction in visceral fat [1]. However, the point of switch, of the inverse and significant correlation, to a positive and insignificant relationship, early in post gonad development, synonymous with spawning, is indicative of the major spawning period and necessary to be monitored for sustainable management of the fishery by resource managers and researchers.

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