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Comparing feeding niche, growth characteristics and exploitation level of the giraffe catfish *Auchenoglanis occidentalis* (Valenciennes, 1775) in the two largest artificial lakes of northern Ghana

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The stomach contents of the giraffe catfish, *Auchenoglanis occidentalis*, populations from Lake Bontanga and Lake Tono, two artificial lakes, were analysed, together with length frequency data collected from July 2016 to June 2017, to gain knowledge of the stock bioecology and exploitation status. The feeding characteristics of the giraffe catfish did not differ significantly between the lakes, as revealed by a Wilcoxon rank-sum test (p > 0.05). Insect larvae and algae dominated stomach content, with proportionate contributions of 43.8% and 14.2% in Lake Bontanga and 49.3% and 10.6% in Lake Tono, respectively. In the larger Lake Tono, the growth coefficient (K = 0.34 year) and asymptotic length (L_∞ = 38.3 cm) were higher than in Lake Bontanga and the exploitation rate was comparatively low (E = 0.24). This lower exploitation level in Lake Tono agrees with a higher mean catch size of 27.6 cm and a high spawning stock biomass >0.4 of the unfished biomass, as well as a higher spawning stock biomass of 3.12 tonnes km^{-2}, suggesting that there is scope for an intensification of the fishery. In the smaller Lake Bontanga, the species growth was lower (K = 0.31 yr^{-1} and L_∞ = 28.9 cm) and the stock is fully exploited (E = 0.48). The mean catch size and spawning stock biomass were critically low; 17.2 cm and <0.4 of the unfished biomass, respectively. Accordingly, this stock requires close monitoring to prevent resource depletion.

Keywords: bioecology, exploitation status, growth rates, length-based indicators, Lake Bontanga, Lake Tono, spawning stock biomass, stomach contents

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Introduction

The study of fish diet based on an analysis of stomach contents is a standard practice in fish ecology (Hyslop 1980) and it allows one to classify fish with respect to their feeding behaviour and trophic role (Boyd 2002). Knowledge of the food spectrum, growth, mortality and stock biomass of fish groups are important for the construction of trophic models for ecosystem-based fisheries management. Notwithstanding, the diet composition of most fish species in the lakes and reservoirs of West Africa is poorly documented. The giraffe catfish *Auchenoglanis occidentalis* has commercial importance and is found in most lakes and rivers of West Africa (FishBase 2019). In Ghana, Quarcoopome et al. (2008) reported that in terms of weight, *Auchenoglanis occidentalis* constituted 13.4% and 5.3% of the fishery harvests in Lake Bontanga and Lake Libga, respectively. Notwithstanding its importance, very limited research has been dedicated to the biology of this species. No information is available on the range of food items available to *A. occidentalis* in the artificial lakes of Ghana (FishBase 2019).

Fish from freshwater systems in northern Ghana play an important role in small-scale fisheries, providing livelihoods to rural communities. This also holds for fisheries in artificial lakes that have yet received only limited scientific assessment in Ghana. Current threats to these waterbodies include environmental degradation, unpredictable changes in water levels and the widely unregulated exploitation of fish stocks. Inland fisheries, including those of artificial lakes, are accorded less importance relative to other uses of water (Welcomme et al. 2010). This results in poorly constrained estimates of the status of stocks and trends in catches, as well as difficulties in estimating their total production, and also their economic and societal values (FAO 2009).

The giraffe catfish *Auchenoglanis occidentalis* belongs to the family Claroteidae, which became separated from the family Bagridae based on genomic analysis, and reflect a monophyletic group of African catfish (Berra 2001). The Claroteidae family in the freshwaters of Ghana is comprised of three genera, namely: *Chrysichthys*, *Clarotes* and *Auchenoglanis*, as well as seven species (Dankwa et al. 1999). Fish of this family are characterised by the presence of two to four pairs of barbels, well-developed pectoral-fin spines, a moderately or strongly developed adipose fin and

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a medium-sized anal fin. The mouth is supported dorsally by the premaxilla and part of the maxilla (Risch 1985). The species are reported to reach up to 70 cm in length and a weight of 4.5 kg and its flesh is considered of a fair quality (Reed 1967; FishBase 2019). *Auchenoglanis occidentalis* is mainly omnivorous and an adaptive generalist feeder, with strong insectivorous tendency (Paugy and Lévêque 1999; Ouéda et al. 2008). However, its feeding habit and food ingestion rate can greatly vary in tandem with the *in situ* food availability, which could differ between waterbodies.

The current study aimed at a comparison of the feeding niche and ecological role of the giraffe catfish and its exploitation level in two artificial lakes, which differ in size, mean depth, water level fluctuation and water volume capacity. Lake Tono is a large lake formed by two water sources. It has dense aquatic vegetation in the littoral zones, which become inundated during the rainy season. Lake Tono has larger deep zone areas than Lake Bontanga. There are also five small islands visible at low water levels. Because the giraffe catfish is known to occur in both lacustrine and riverine systems (Palomares et al. 2003), the population at Lake Tono is expected to have more diverse sources of food, and based on the aforementioned differences in environmental characteristics, we hypothesise that the giraffe catfish population in Lake Tono feeds more on plant material and associated insects than their counterparts in Lake Bontanga do and that growth conditions might well be more favourable in Lake Tono.

The objectives of the study were accordingly to provide information on: (i) the food items ingested by the species and their relative abundance in the two lakes; (ii) the von Bertalanffy growth parameters (asymptotic length and growth coefficient) of the species; (iii) the population size (absolute and per area) and (iv) the fisheries exploitation level, biological reference points and length-based indicators for sustainable levels of exploitation.

Although the stomach analysis was based on occurrence and numerical methods, two complementary approaches were used to analyse the length frequency data. The first was based on an analysis of the length frequency data using the TropFishR software (Mildenberger et al. 2017) in estimating growth parameters and exploitation rates from a catch-curve analysis. The second was based on the use of length-based indicators (Froese 2004; Cope and Punt 2009) in estimating the spawning potential of the species under the current exploitation regime.

Materials and methods

Description of the study sites

Lake Tono (10°52′48″ N, 1°9′36″ W) (Figure 1) is the largest artificial lake in the upper east region of Ghana, with a surface area of 18.6 km^2. Lake Bontanga (9°33′0″ N, 1°1′12″ W; Figure 1) is about one-third of this size (6.7 km^2), but it is the largest artificial lake in the northern region of Ghana. Lake Tono is approximately 210 km away from Lake Bontanga. Lake Tono has a length of 3 471 m and a catchment area of 650 km^2. Its mean depth is 6.6 m and its volume is estimated as 93×10^6 m^3. Lake Bontanga, conversely, has a length of 1 900 m and a catchment area of 165 km^2, a mean depth of 5.9 m and a water volume capacity of 25×10^6 m^3. Both systems are within the Guinea savanna belt where the most prominent rainy season is from June to October. The lakes were primarily constructed to support irrigation agriculture. The fisheries resources of both lakes have provided livelihood opportunities to fishers in the riparian communities for the past four decades. Lake Bontanga has two main landing sites (Voggu and Bontanga), whereas Lake Tono has five landing sites. The catch at Lake Bontanga is dominated by tilapias (73%), *Clarias gariepinus* (9%), *Brycinus nurse* (5.9%), *A. occidentalis* (3%), *Heterotis niloticus* (2.4%) and *Mormyrus* spp. (2.4%). Other landed species include *Malapterurus electricus, Labeo* spp., *Hemichromis* spp., *Citharinus citharinus, Distichodus engycehpalus, Ctenopoma kingsleyae, Pellonula leonensis, Polypterus endlicheri* and *Protopterus annectens.* The total annual catch at Lake Bontanga (from July 2016 to June 2017) was 105.8 tonnes. Similarly, at Lake Tono, catches were dominated by tilapias (89%), *A. occidentalis* (4.1%), *Schilbe* spp. (3.2), *Clarias gariepinus* (1.1%) and *Hemichromis* spp. (1.1%). The rest include *Pellonula leonensis, Labeo* spp., *Mormyrus* spp., *Synodontis* spp. and *Heterotis niloticus*. The total catch at Lake Tono (from July 2016 to June 2017) was 187.2 tonnes.

Fish sampling

Fish specimens were collected each month from fishers operating in Lake Bontanga and Lake Tono. The fish were caught by nylon monofilament gill nets with mesh sizes ranging from 22 to 57 mm at Lake Bontanga and from 51 to 70 mm at Lake Tono. The twine diameter ranged between 0.10 and 0.16 mm. The height of the nets ranged from 1 to 2.5 m. Hook and lines were used occasionally to target the species. Fish measurements of standard and total lengths were done using a fish measuring board to the nearest 0.1 cm and specimens were weighed with a weighing scale to the nearest 0.01 g. Fish samples were taken for a period of six months from July to December 2016 for stomach content analysis, whereas the size frequency data were collected for one full year (from July 2016 to June 2017).

Stomach content analysis

Individuals of *A. occidentalis* from both lakes were obtained fresh from the fishers and retained in an icebox to prevent post-mortem digestion. In the Spanish laboratory of the University for Development Studies, Nyankpala Campus, Ghana, the fish were dissected, the guts removed and the contents were taken with a dropper, placed on slides and examined under a microscope. Stomach contents were analysed using the frequency of occurrence and "points" method of Hyslop (Hyslop 1980). The frequency of occurrence method estimates the percentage of stomachs in a sample containing a given food item, whereas the points method gives the bulk contribution of each food item to the total food consumed. The points method is considered one of the most convenient methods for assessing the feeding habits of herbivorous and omnivorous fish species, because, they feed on microorganisms. It is more complex to measure volumes of food items containing microscopic organisms, such as algae and diatoms, when using other methods (Zacharia

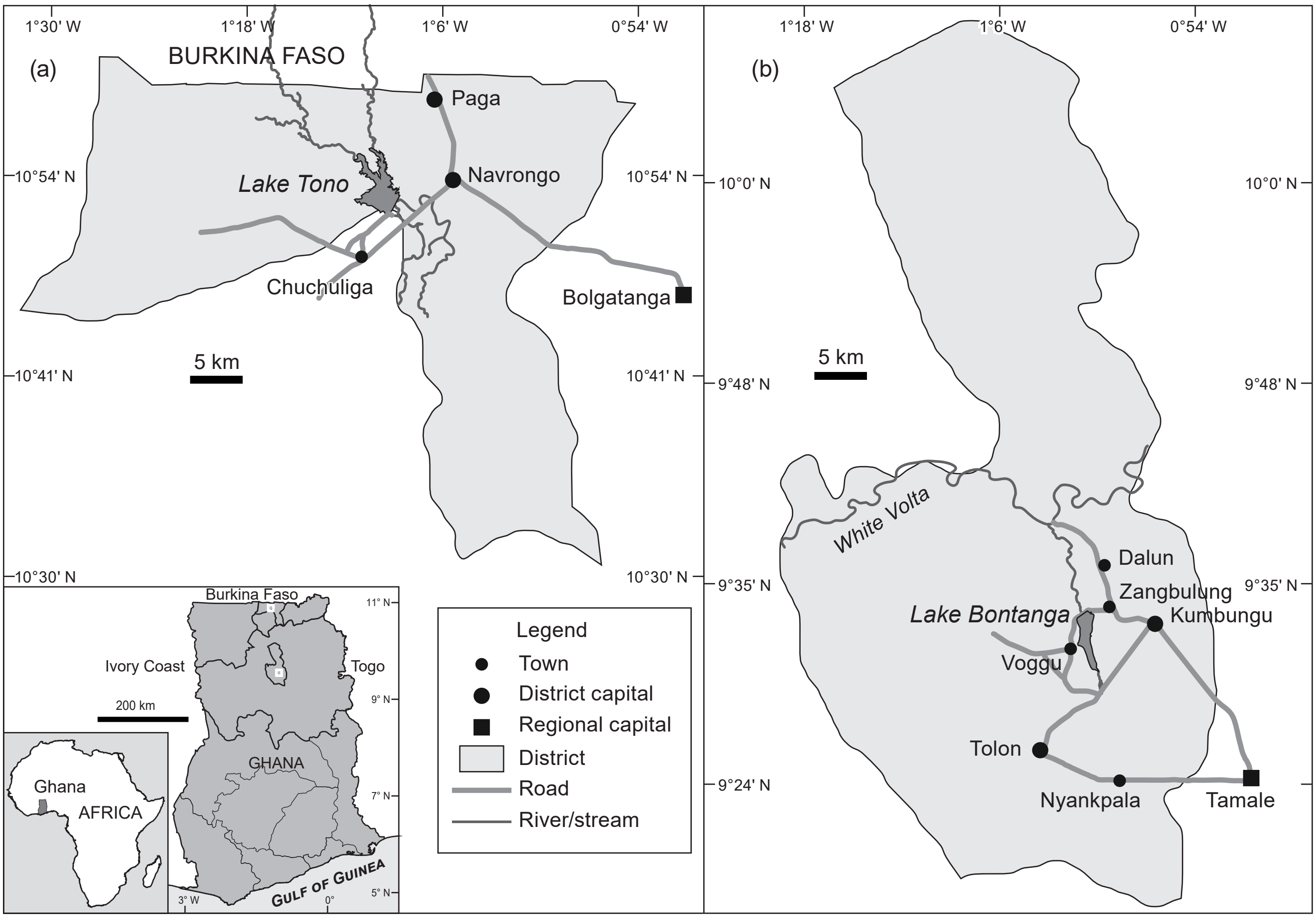

Figure 1: Map showing the locations of Lake Tono in Kassena Nankana East Municipality (formerly Kassena Nankana Municipality) and Lake Bontanga in Kumbungu District (formerly Tolon-Kumbungu District)

and Abdurahiman 2004). Points were given to stomachs that were fully filled, half-filled and quarterly filled, respectively. Empty stomachs were, however, completely excluded from the analysis. The total number of points given to each stomach was subdivided among the food items present, according to their relative contribution to the total stomach content. The percentage composition of each food items was determined by summing up the points awarded to the item and dividing it by the total points awarded to all stomachs containing food and the resulting value was expressed as a percentage. It should be noted that points of 10, 5 and 2.5 represent 100%, 50% and 25% respective contribution of a food item to the stomach content of the fish.

Frequency of occurrence of a food item:

$$\frac{\text{Total number of stomach with a particular food item}}{\text{Total number of stomachs with food}} \times 100$$

Points allocated to a food item:

$$\frac{\text{Number of points of the particular food item}}{\text{Total number of points of all food items}} \times 100$$

The R programming software (Version 3.5.0) was used for the statistical analysis. Tests for normality were done using the Anderson–Darling normality test (Ad.test) and the Cramer–von Mises normality test (Cvm.test). The results of the normality tests on the food items indicated that the *p*-values on all food categories by both tests were below the conventional value of 0.1. Therefore, a comparison of the sample means (between Lake Bontanga and Lake Tono) of the food items followed a non-parametric procedure using a Wilcoxon rank-sum test instead of a Student's *t*-test.

Stock assessment approach

TropFishR (Mildenberger et al. 2017), an R package for tropical fisheries analysis, was used for the stock assessment. TropFishR has enhanced functions of the FAO-ICLARM Stock Assessment Tools II FISAT II (Gayanilo et al. 2005). It includes some additional recent methods. The length frequency data (LFQ) were raised to the monthly catches observed for the species before conducting the electronic length frequency analysis (ELEFAN), catch-curve analysis, virtual population analysis (VPA) and yield per recruit analysis (YPR). The total weight of *A. occidentalis* landed at each lake was observed and recorded for five fishing days per month and using the average number of fishing days, the total catch was extrapolated. The LFQ data were raised to match up with monthly catches, with the assumption that the number and weight of fish measured for the LFQ data are an adequate representation of the length distribution of the total catch for the month. The individual steps of the length-based stock assessment, outlined by Sparre and Venema (1998) and for TropFishR by Mildenberger et al. (2017), were implemented within a bootstrapping framework (Schwamborn et al. 2019). This allows to estimate uncertainty intervals for all parameters and avoid the seed effect (Schwamborn et al. 2019).

Growth parameters

Total length measurements grouped into 1 cm class intervals were used to assess the growth parameters of the species, using a seasonally oscillating von Bertalanffy growth equation (soVBGF) (Pauly and Gaschutz 1979; Somers 1988):

$$L_t = L_\infty \left(1 - e^{-(K(t-t_0)+S(t)-S(t_0))}\right)$$

where L_t is the total length of the fish at time t, L_∞ is the asymptotic length of fish in cm, K the rate at which Lt approaches L_∞ and t_0 is the theoretical age of the fish when Lt is equal to zero. In $S(t) = (CK/2\pi)\sin 2\pi(t - t_s)$, C is a constant indicating the amplitude of the oscillation, typically ranging from 0 to 1 (a value >1 implies periods of shrinkage in length, which is rare) and t_s is the fraction of a year (relative to the age of recruitment, t = 0), where the sine wave oscillation begins (i.e. turns positive). A seasonally oscillating VBGF was used to assess the growth parameters, because seasonal changes in the growth of tropical fish have frequently been reported, which are attributed to changes in water temperature, precipitation and/or to the availability of food (Morales-Nin and Panfili 2005; Herrón et al. 2018). The bootstrapped ELEFAN with genetic algorithm optimisation (bootstrapped ELEFAN with genetic algorithm (GA)) function of TropFishR (Mildenberger et al. 2017; Schwamborn et al. 2019) was used to determine the parameters L_∞ and K of the von Bertalanffy equation. An initial seed value of L_∞ was based on L_{max}, derived from the mean of the 1% largest fish in the sample and following the equation of Taylor (1958): $L_\infty = L_{max}/0.95$. The VBGF parameters were assessed using a moving average (MA) over seven size intervals. Because the VBGF parameters are known to be sensitive to the MA setting (Taylor and Mildenberger 2017), the bootstrapped ELEFAN with a GA function was also rerun for each assessment with MA over five and nine size intervals, respectively. The genetic algorithm (GA) is an optimisation approach for growth function fitting, using the open-source software 'R' (Taylor and Mildenberger 2017).

The L_∞ and K were used to calculate the growth performance index (Ø') = log$K$ + 2logL_∞ (Pauly and Munro 1984) to compare the growth performance of the giraffe catfish between the two lakes. The bootstrapping approach included in the TropFishR allowed for the estimation of confidence intervals around the mean growth parameter estimates. The parameter t_{anchor} indicates the fraction of the year where yearly repeating growth curves cross length equal to zero.

Mortality and exploitation rate

The instantaneous total mortality coefficient (Z) was estimated by means of the linearised length-converted catch-curve analysis method incorporated in the TropFishR package using the relation: Ln(Ni/dt$i$) 'with age t or relative age', where Ni is the number of individuals in length class i and dt$i$ the time needed by the fish to grow in class i (Pauly 1990; Pauly et al. 1995). The rate of natural mortality (M) was estimated according to the empirical equation of Then et al. (2015):

$$M = 4.118K^{0.73}L_\infty^{-0.33}$$

Fishing mortality rate (F) was estimated using the relationship: $F = Z - M$. The exploitation rate (E) was obtained from: $E = F/Z$. Estimated values of E were then compared with a reference value of 0.5, which has been proposed as an upper level of sustainable exploitation for fish species (Gulland 1971). The estimated exploitation rates were derived from maximum density values of distributions for each parameter obtained from the linearised length-converted catch curve, using a bootstrapping approach. Although F and M add up to Z on the level of the resamples, the maximum density estimates (and medians) do not have to add up, because the maximum density of each distribution is determined independently from the other parameters. The total mortality (Z) was estimated using both the conventional linearised length-converted catch curve and the bootstrapping approach.

Size at first capture

The size (L_c) at which 50% of the fish are retained by the gear, was estimated using the ogive selection of the bootstrapped, linearised, length-converted catch curve, assuming that the chance of capturing a fish is solely dependent on its length.

Stock size estimates

Cohort analysis (Jones 1984) was conducted to study the dynamics of the fish stocks and to estimate fishing mortality for different length groups using the estimated L_∞ and K values. The annual mean value of F derived through the length converted catch curve was used as an estimate for the fishing mortality of the last length group ('terminal F'). The last length groups, with low catch numbers, were grouped into one plus group. Biomass of the different length groups was then calculated with the length-weight relationship (LWR) equation, using the constant a and the exponent b values, derived from the study data (Table 1). The cohort analysis is based on the following equations:

$$N_{i+1} = N_i \exp\left(-(F_i + M)\right)$$

$$C_i = N_i \frac{F_i\left(1 - \exp\left(-(F_i + M)\right)\right)}{F_i + M}$$

where N is the stock size in numbers, C is the catch, F is the fishing mortality and M is the natural mortality.

Relative-yield-per-recruit curve and reference points

The fishing mortality that produces the highest biomass per recruit (F_{max}), the fishing mortality that will result in

50% reduction of the biomass of unexploited population ($F_{0.5}$) and a fishing mortality that corresponds to 10% of the slope of the yield-per-recruit curve at its origin ($F_{0.1}$) were predicted using the Thompson and Bell model (Thompson and Bell 1934). The model builds on the output of the cohort analysis with the following input parameters: K (annual growth coefficient); t_{anchor} (anchor point); L_∞ (asymptotic length); M (natural mortality); a (constant of LWR); b (exponent of LWR); L_r (length at recruitment to fishery); L_{50} and L_{75} (selectivity parameters) (Thompson and Bell 1934; Sparre and Venema 1998). The reference points F_{max}, $F_{0.5}$ and $F_{0.1}$, with their confidence intervals, were used as the first set of indicators of the exploitation status.

Length-based indicators for sustainable fisheries

Three indicators proposed by Froese (2004) formed the second set of indicators for the assessment of stock status. The indicators are:

- P_{mat}: refers to the proportion of mature fish in the catch, with 100% as the reference target point, based on the equation: P_{mat} = % fish in sample > L_m; where L_m is the length at first sexual maturity. This suggests that all fish should be allowed to spawn at least once before they are caught to rebuild and maintain healthy spawning stocks. The L_m values used were taken from studies by Kwarfo-Apegyah (2008) and Akongyuure et al. (2017). The corresponding total lengths at first sexual maturity were 14.8 and 17.8 cm for Lake Bontanga and Lake Tono, respectively.
- P_{opt}: is the proportion of fish within a 10% range around the optimum length (L_{opt}) in the catch, with 100% as the reference target, based on the equation: P_{opt} = % fish > L_{opt} − 10% and < L_{opt} + 10%; where: log(L_{opt}) = 1.053*log(L_m) − 0.0565 (Froese and Binohlan 2000). The L_{opt} for the target species based on the equation were 15.0 cm and 18.2 cm at Lake Bontanga and Lake Tono, respectively.
- P_{mega}: indicates the proportion of 'megaspawners' in the catch, with 30% to 40% as a desired target reference point, based on the equation: P_{mega} = % fish > L_{opt} + 10% (Froese 2004).

Using a decision tree procedure by Cope and Punt (2009), the three proportions were summed (P_{mat} + P_{opt} + P_{mega}) to obtain P_{obj}, which defines indicator values of stock status above spawning stock biomass (SSB) reference points. The P_{obj} allows for differentiation of selectivity patterns, because the authors observed that P_{obj} had a more consistent relationship with spawning stock biomass (SSB) than any

Table 1: Descriptive variables and length-weight relationships of *Auchenoglanis occidentalis* from Lake Bontanga and Lake Tono

Variable	Symbol	Lake Bontanga	Lake Tono
Total number of specimens	n	1 553	798
Total length (cm)	TL range	6.3–36.5	12.4–50.2
Body weight (g)	BW range	4.3–479.6	17.6–1 400.6
Length at first capture (cm)	L_c (CI95%)	14.3 (12.4–15.7)	29.07 (24.4–30.7)
Mean catch length (cm)	L_{mean}	17.2	27.6
Time corresponding to L_c (yr)	t_{50}	2.3	3.8
Constant	a (CI95%a)	0.012 (0.011–0.013)	0.007 (0.006–0.009)
Allometric coefficient	b (CI95%b)	2.93 (2.90–2.97)	3.10 (3.06–3.15)
Coefficient of determination	r^2	0.9544	0.9528

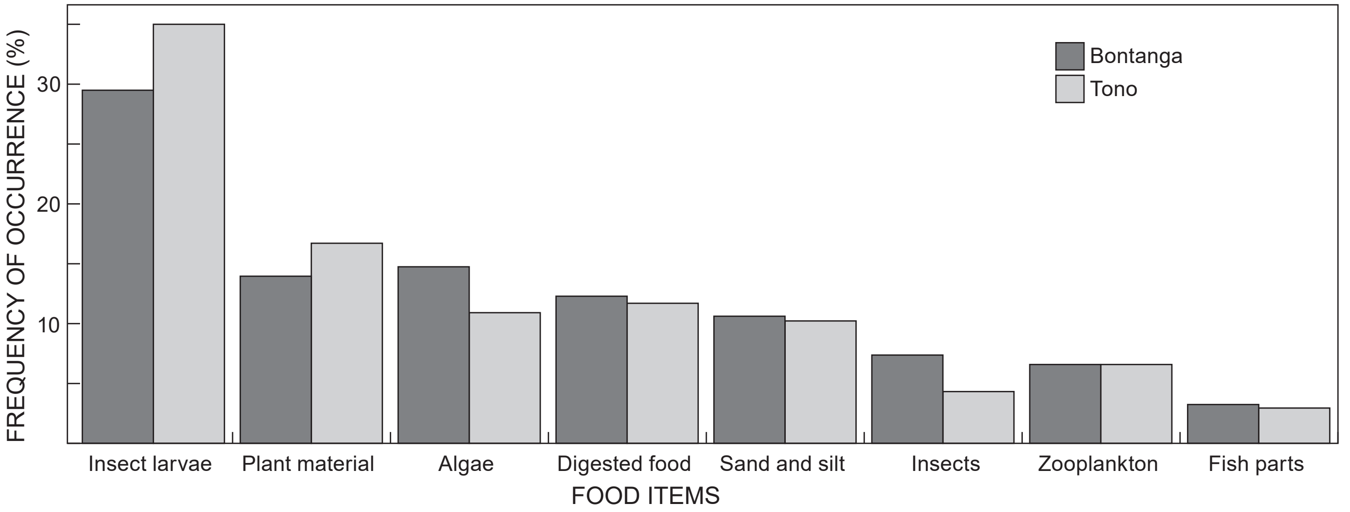

Figure 2: Frequency of occurrence of food items in the stomachs of *Auchenoglanis occidentalis* from Lake Bontanga and Lake Tono

of the individual metric (P_{mat}, P_{opt} or P_{mega}) and that different selectivity patterns in the fishery were associated to a range of values of P_{obj}. Once a selectivity pattern is established, based on P_{obj}, threshold values of P_{mat}, P_{obj} and/or the L_{opt}/L_m ratio point to an estimated probability of the spawning stock biomass (SSB) being below established reference points, either 40% or 20% of the unfished spawning stock biomass (0.4SSB or 0.2SSB) is established.

Results

Food spectrum of Auchenoglanis occidentalis

Lake Tono had more full and half-full stomachs than Lake Bontanga, whereas quarter-filled stomachs were more predominant in Lake Bontanga. Of the 72 stomachs of *A. occidentalis* examined from Lake Bontanga, 35% were empty. Of the 47 stomachs with food, 34.04% were fully filled, 29.8% were half filled and 36.2% were quarter filled. Of the 82 stomachs of *A. occidentalis* examined from Lake Tono, 27% were empty. Of the 73% stomachs containing food, 44.1% were fully filled, 32.2% were half filled and 23.7 were quarter filled.

The food items identified were insect larvae, adult insects, digested food, fish parts, sand and silt particles, algae, other plant material and zooplankton. Insect larvae and fish parts occurred in 30% and 3.3%, respectively, of the total stomachs examined at Lake Bontanga and in 35.6% and 3%, respectively, of those examined at Lake Tono (Figure 2). Similarly, insect larvae and fish parts had the highest and the lowest bulk contributions, respectively, to the stomach contents of the fish from Lake Bontanga (43.8% and 1.8%) and Lake Tono (49.3% and 1.1%) (Table 2; Figure 3). No significant difference in the bulk contribution of food items was found between the stomach contents of *A. occidentalis* from Lake Bontanga and Lake Tono (Table 3).

Size composition

The *A. occidentalis* populations at Lake Tono and Lake Bontanga had total length ranges of 12.4 to 50.2 cm and 6.3 to 36.5 cm, respectively (Figure S1). This size range difference is evident by the estimates of length at first capture (L_c) and mean catch length (L_{mean}). Both estimates were significantly higher for Lake Tono than for Lake Bontanga. The time corresponding to the L_c indicates that the mean age of the catch at Lake Bontanga is 2.3 years and 3.8 years at Lake Tono (Table 1; Figure S4).

Growth parameters

The asymptotic length (L_∞) for the fish populations at Lake Bontanga is approximately 10 cm lower than the estimate for the populations at Lake Tono. Although K was close in range for both systems (Table 4; Figure 4), the growth performance index is substantially higher at Lake Tono. The estimates of the parameter t_{anchor} indicate that August and September are the months close to the hatching period, where the yearly repeating growth curves cross the length equal to zero for the populations at Lake Tono and Lake Bontanga, respectively. The confidence intervals around the growth parameters were similar for both systems (Table 4; Figures S2 and S3).

Table 2: Total points and bulk contribution of food items to the stomach contents of *Auchenoglanis occidentalis* from Lake Bontanga and Lake Tono

	Lake Bontanga		Lake Tono	
	Total points	Contribution (%)	Total points	Contribution (%)
Algae	38.5	14.2	39.5	10.6
Digested food	50.0	18.5	65.0	17.5
Fish parts	5.0	1.8	4.0	1.1
Insect larvae	118.5	43.8	183.5	49.3
Insect parts	9.0	3.3	9.0	2.4
Plant material	23.5	8.7	35.0	9.4
Sand and silt particles	19.5	7.2	24.0	6.5
Zooplankton	6.5	2.4	12.0	3.2
Total	270.5	100.0	372.0	100.0

Mortality and exploitation rate

The populations at Lake Tono had higher natural mortality than fishing mortality, whereas the reverse is true for the populations at Lake Bontanga. Consequently, the exploitation rate is was significantly higher at Lake Bontanga than Lake Tono. The maximum density values suggest that the fish populations are underexploited in Lake Tono, whereas the upper limit of the confidence interval of the exploitation rate for the populations at Lake Bontanga is above the recommended optimal exploitation level (E = 0.5) (Table 5). The exploitation rates of the fish stock remained unchanged for the populations at Lake Tono, when the assessment was rerun with MA setting of five and nine. However, the exploitation rates for the populations at Lake Bontanga, when assessed with MA settings of five and nine size intervals were slightly above the optimal exploitation rate (Tables S1 and S2). The total mortality values estimated using the conventional length-converted catch curves (Figure 5) were consistent with those obtained with the bootstrapped, linearised length-converted catch curves, but with different confidence intervals (Table 5; Figure S3). Because the bootstrap approach allowed for unbiased selection of data points in the length-converted catch curve for the estimation of total mortality (Z), the results of that approach (Table 5) were used for the yield-per-recruit analysis and stock size estimation.

Stock biomass

The biomass of *A. occidentalis* per unit of lake area is substantially higher at Lake Tono (3.12 tonnes km^{-2}) than Lake Bontanga (1.82 tonnes km^{-2}) (Table 5).

Biological reference points

The $F_{0.1}$ values are similar for both systems, whereas F_{max} for Lake Tono is more than twice as high as the value for Lake Bontanga. Similarly, the $F_{0.5}$ of Lake Tono is higher than Lake Bontanga (Table 5).

Length-based indicators (*LBI*)

The proportion of immature fish in the catches was higher in Lake Bontanga than Lake Tono. Although the fish exploitation at Lake Tono met the 100% target reference for P_{mat}, the proportion of fish within the P_{opt} range was very low (0.4%)

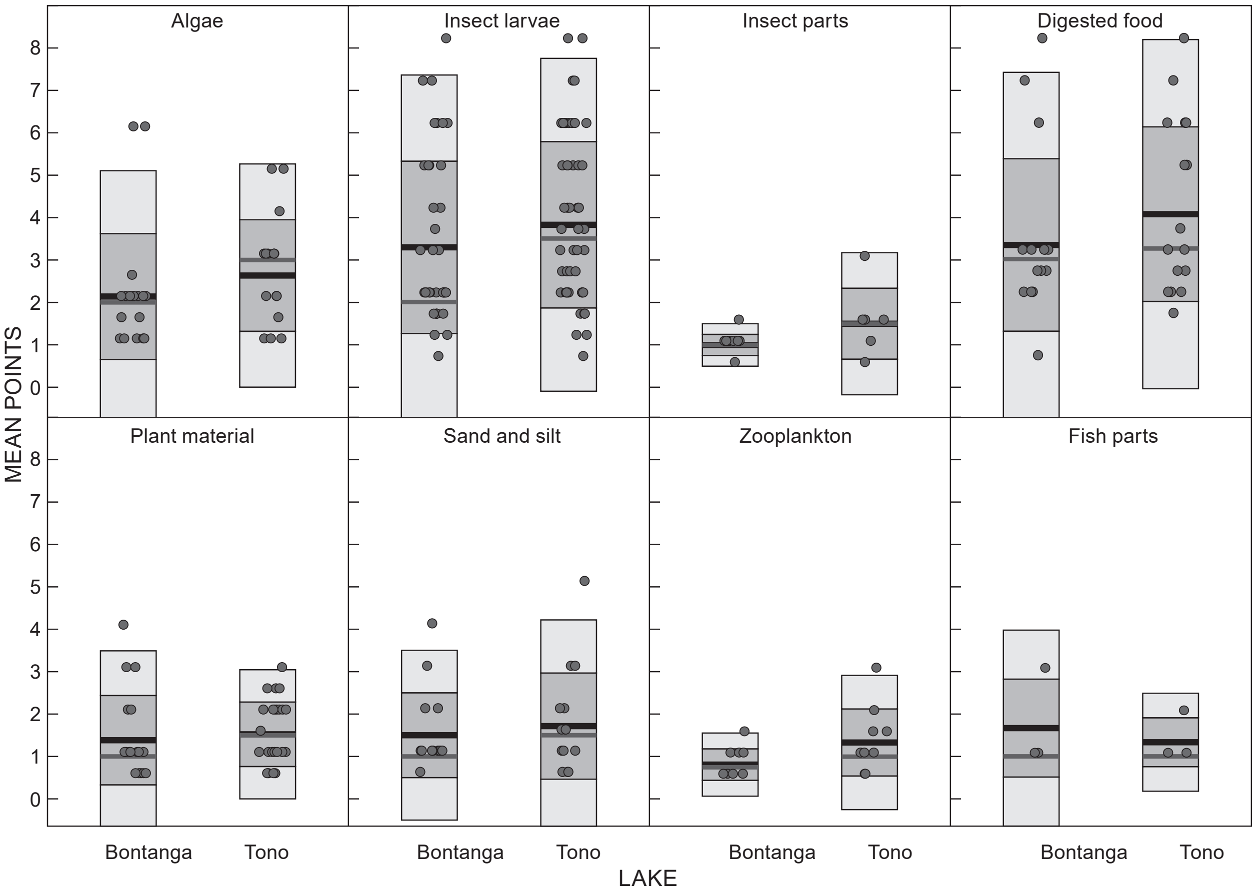

Figure 3: Mean point distribution of food items found in the stomach *Auchenoglanis occidentalis* from Lake Bontanga and Lake Tono. Points 10, 5 and 2.5 represent stomachs that are fully filled, half-filled and quarterly filled, respectively. The lower quartile, median (grey line), mean (black line) and upper quartile are indicated.

Table 3: Wilcoxon rank sum test with continuity correction and mean points of food items for *Auchenoglanis occidentalis* from the Lake Bontanga and Lake Tono artificial lake systems. It should be noted that because of limited data, fish parts were not included in the comparisons

Food items	Mean points ± SD of food items from Lake Bontanga	Mean points ± SD of food items from Lake Tono	Wilcoxon rank-sum test	*p*-value (0.05)
Algae	2.14 ± 1.48	2.63 ± 1.32	95.5	0.147
Digested food	3.33 ± 2.04	4.06 ± 2.06	100.0	0.435
Insect larvae	3.29 ± 2.03	3.82 ± 1.96	704.5	0.147
Insects	1.00 ± 0.25	1.50 ± 0.84	14.5	0.121
Plant materials	1.38 ± 1.05	1.52 ± 0.76	161.5	0.343
Sand and silt	1.50 ± 1.00	1.71 ± 1.25	82.5	0.686
Zooplankton	0.81 ± 0.37	1.33 ± 0.79	20.5	0.130

α at 5% significance level

(Table 6). Additionally, the catches at Lake Tono were full of large-sized *A. occidentalis*, with the P_{mega} being above the desired target range of 30% to 40%. Lake Bontanga had a higher proportion of fish within the P_{opt} than Lake Tono. Moreover, the P_{mega} value for Lake Bontanga was within the desired target range. The decision tree analysis indicated that the spawning stock biomass of the stock at Lake Bontanga was below the reference point of 40% of the unfished biomass, whereas the stock at Lake Tono had a spawning stock biomass above this reference point (Table 6; Figure 6).

Discussion

Feeding habits of Auchenoglanis occidentalis

The food items recorded in this study for the giraffe catfish *Auchenoglanis occidentalis* are similar to

Table 4: Parameter estimates of seasonalised von Bertalanffy growth equation for *Auchenoglanis occidentalis* specimens from Lake Bontanga and Lake Tono assessed with the bootstrapped electronic length frequency analysis with genetic algorithm function of TropFishR. Estimates based on length frequency samples collected from July 2016 to June 2017. Maximum, maximum density, and Lower and Upper denote 95% confidence interval of the estimates

Parameter	Symbol	Lake Bontanga			Lake Tono		
		Maximum	Lower	Upper	Maximum	Lower	Upper
Asymptotic length	L_∞ (cm)	28.91	27.19	35.62	38.27	36.25	42.25
Coefficient of growth rate	K (yr)	0.31	0.12	0.43	0.34	0.19	0.48
	t_{anchor}	0.72	0.12	0.87	0.60	0.20	0.77
	C	0.68	0.16	0.93	0.49	0.25	0.83
	t_s	0.45	0.14	0.78	0.73	0.24	0.82
Growth performance index	Ø	2.41	1.93	2.74	2.70	2.40	2.93

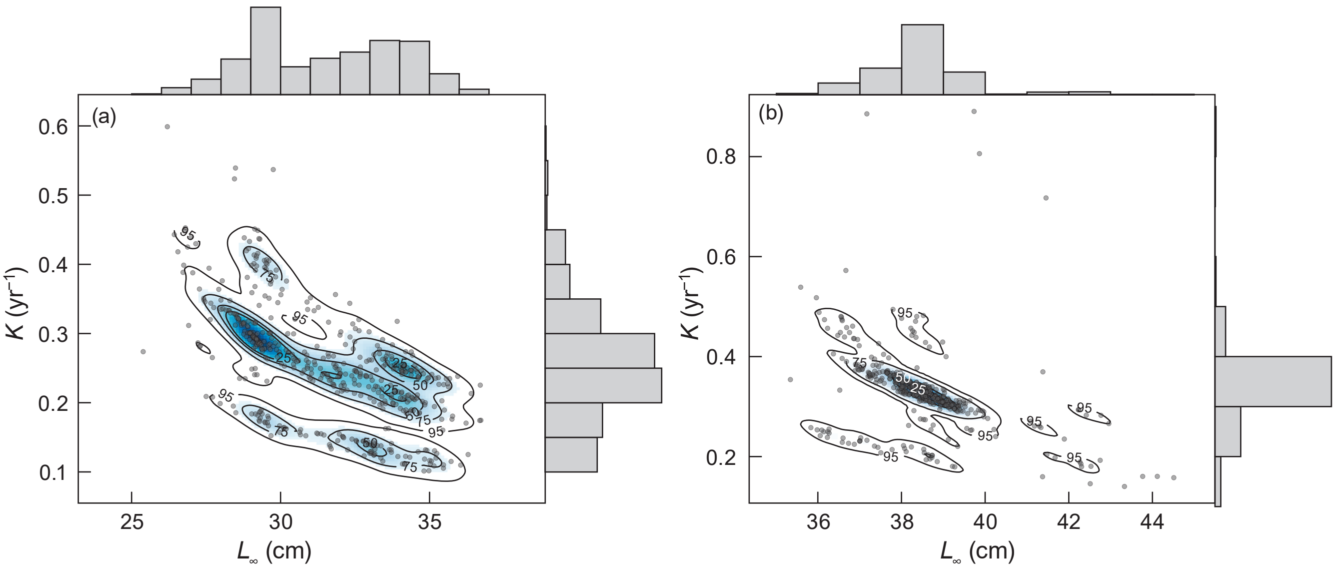

Figure 4: Scatter histogram of bootstrapped ELEFAN with genetic algorithm optimisation for *Auchenoglanis occidentalis* collected from (a) Lake Bontanga and (b) Lake Tono. Dots represent estimated L_∞ and K (growth parameters of the von Bertalanffy equation) per resampled length frequency catch data

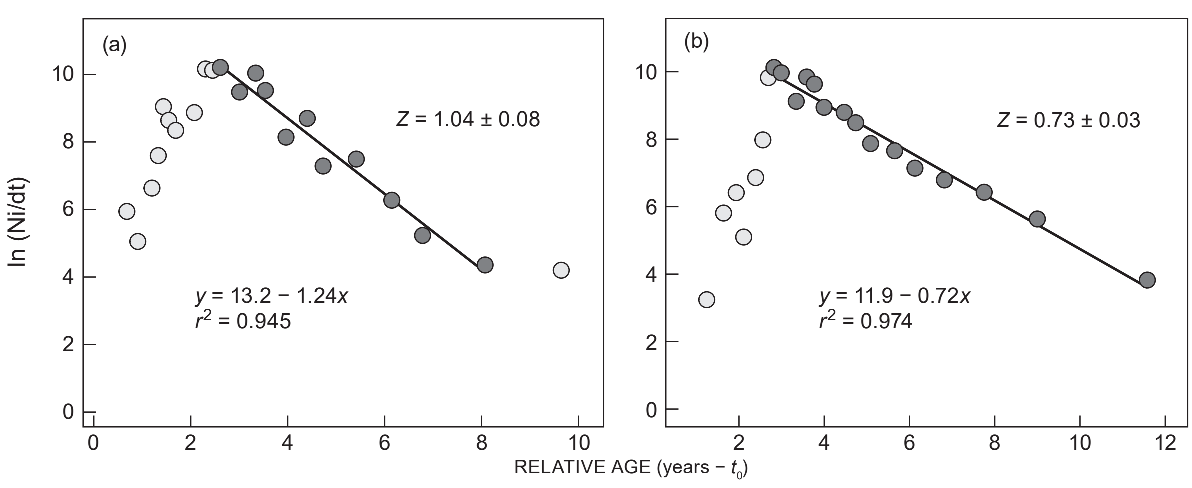

Figure 5: Linearised length-converted catch curves for *Auchenoglanis occidentalis* collected from (a) Lake Bontanga and (b) Lake Tono

Table 5: Mortalities (Z, M and F), exploitation rate (E), biological reference points of fishing mortality (F_{max}, $F_{0.1}$, $F_{0.5}$) and stock size estimates of *Auchenoglanis occidentalis* from Lake Bontanga and Lake Tono. Lower and upper denote 95% confidence interval of the estimates. Estimates were based on a bootstrapping approach

Parameter	Lake Bontanga			Lake Tono		
	Maximum	Lower	Upper	Maximum	Lower	Upper
Z	1.04	0.38	1.62	0.73	0.44	1.04
M	0.47	0.27	0.74	0.55	0.36	0.73
F	0.50	0.09	0.90	0.17	0.01	0.42
E	0.48	0.24	0.56	0.23	0.02	0.40
$F_{0.1}$	1.04	0.68	2.05	1.00	0.66	1.84
F_{max}	1.86	1.24	4.37	4.14	2.25	7.00
$F_{0.5}$	0.59	0.39	1.39	0.89	0.54	1.72
N	369 127	227 215	2 994 478	550 517	359 142	16 709 314
B	12.17	7.09	124.18	57.97	43.68	1 880.40

those found by Ikongbeh et al. (2014), who reported that *A. occidentalis* from Lake Akata, Nigeria, fed on a variety of food items ranging from insect larvae to algae and considered *A. occidentalis* to be omnivorous. *Auchenoglanis occidentalis* from Lake Bontanga and Lake Tono systems fed more on insect larvae than on algae. The high percentage of insect larvae encountered in the stomachs of *A. occidentalis* from Lake Tono and Lake Bontanga supports the findings of Eccles (1992), according to whom *A. occidentalis* occurs in shallow waters with a muddy bottom, where insects occur in the benthic zone of the aquatic environment and consequently their larvae are prone to be preyed on by *A. occidentalis*. Our findings also confirmed a study by Chukwuemeka et al. (2015), which indicated that the stomach contents of *A. occidentalis* population in Lake Tagwai, Minna Niger State, Nigeria, were dominated by insects (31.75%), fish (12.70%), chyme (20.63%), plant material (20.63%), protozoa (1.59%) and soil (12.70%). The dominance of insect larvae among the food items in both systems as observed from July to December could be related to the high rainfall that occurs during the flood and post-flood seasons of northern Ghana, during which insects find conditions suitable for reproduction in the lakes. The ecological niche for the giraffe catfish is very similar in both lakes, as evidenced by the similar food spectrum found through the stomach analysis. The generally higher stomach fullness and lower proportion of empty stomachs found for Lake Tono might be indicative of better food conditions in this lake.

Although Ouéda et al. (2008) reported seasonal shift in the diets of the fish population in a Sahelo-Soudanian artificial lake (Loumbila, Burkina Faso), a recent study by Chukwuemeka et al. (2015) noted that there was no remarkable difference in food composition of the species population in Lake Tagwai, Minna Niger State, Nigeria, between the dry and rainy season months. Additional studies on the species' feeding ecology are required, especially in the semi-arid lakes of sub-Saharan Africa, in order to gain a better understanding of the seasonal profile of the feeding behaviour of *A. occidentalis*.

Table 6: Proportions of mature fish (P_{mat}), optimum-sized fish (P_{opt}), larger than optimum size fish (P_{mega}) and P_{obj} (= P_{mat} + P_{opt} + P_{mega}) for *Auchenoglanis occidentalis* from Lake Bontanga and Lake Tono based on the indicators proposed by Froese (2004) and the formulas described in Methods. Stock condition interpretation is based on a decision tree proposed by Cope and Punt (2009), aimed to assess whether spawning stock biomass (SSB) is above (>) or below (<) a reference point (RP) of 0.4 unfished biomass. The last column indicates the estimated probability of SB being lower than 0.4 of unfished biomass, based on the same authors

Variable	Lake Bontanga	Lake Tono
P_{mat}	0.77	1.00
P_{opt}	0.26	0.004
P_{mega}	0.68	0.99
P_{obj}	1.70	1.99
Stock condition interpretation	SB < RP	SB > RP
Probability	100%	0%

Growth parameter estimates

Although K was similar in both lakes, L_∞ greatly differed between the lakes, with a higher value in Lake Tono (Table 4) resulting in a substantially higher growth performance estimate for this lake. This might reflect real differences in attainable sizes between lakes in relation to lake size and stock density, but could also have been the result of the higher fishing pressure in Lake Bontanga, causing a greater depletion of larger fish close to the size of L_∞. Overall, the estimated growth performance indexes for the giraffe catfish in Lake Bontanga and Lake Tono are lower than the one (Ø' = 2.92) reported for Lake Bangweulu, Zambia (Cosmas 1992). Moreover, the estimate of the asymptotic length (L_∞ = 52.8) in Lake Bangweulu is far higher, possibly as a result of differences in fisheries impact and environmental conditions among Lake Bangweulu and Lake Bontanga and Lake Tono.

Fisheries exploitation and biological reference points

The exploitation of *A. occidentalis* in Lake Tono appeared to be low and it seems that fishing pressure could be increased to achieve higher yields. At Lake Bontanga, to the contrary, the stock already seemed fully exploited, if not slightly overexploited, and an additional increase in the species' exploitation rate is not advisable.

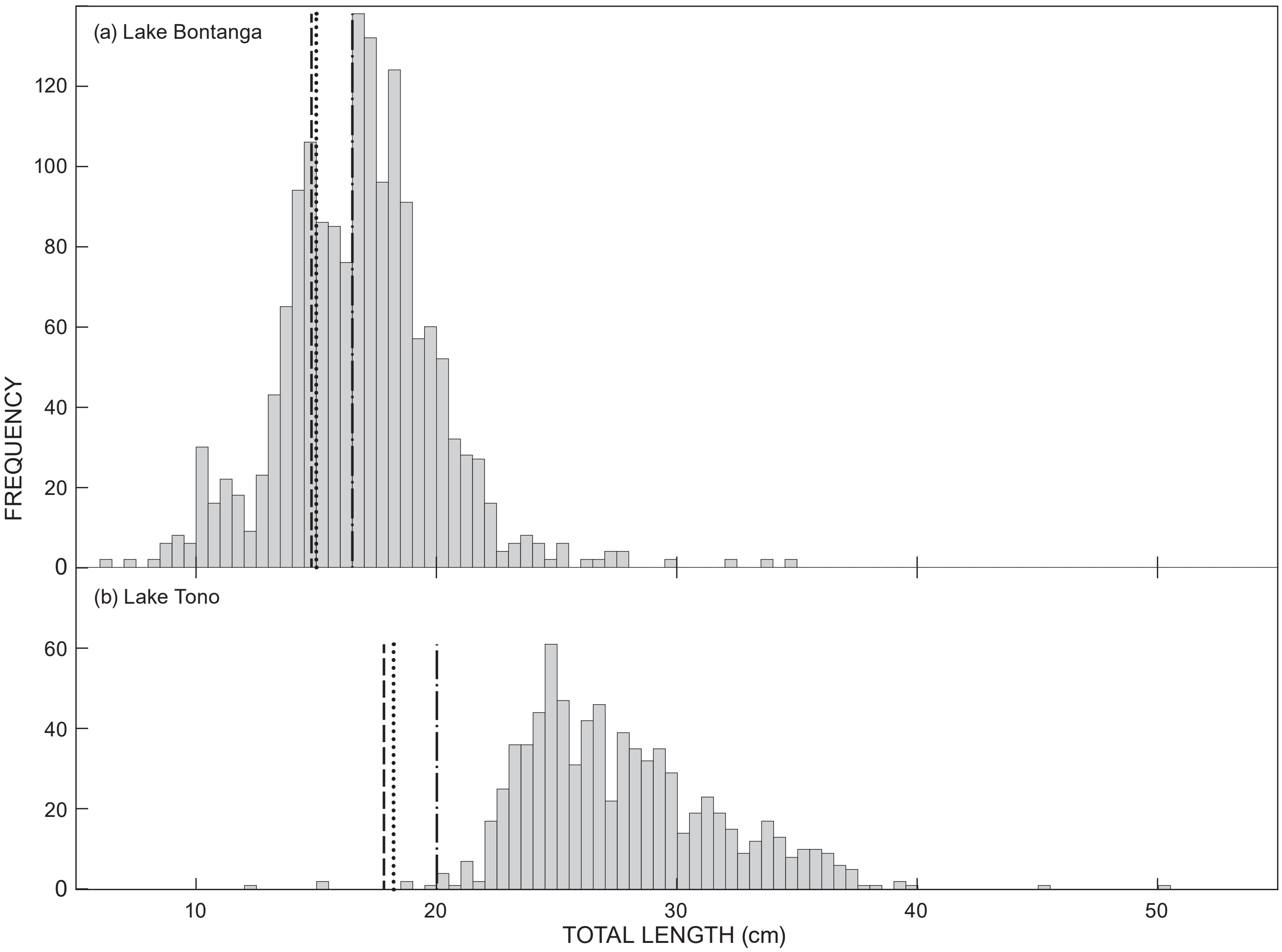

Figure 6: Size distribution of *Auchenoglanis occidentalis* landings observed from July 2016 to June 2017 at Lake Bontanga and Lake Tono. The vertical lines represent the length-based reference values: length at first maturity (dashed line), optimum length L_{opt} (dotted line) and starting length of mega-spawners ('dot-dashed' line)

The estimates using the YPR model indicated that the fishing mortality rates of the stocks in both systems were below the rates (F_{max} values) predicted to maximise equilibrium yield per recruit for the stocks under the model assumption that continues recruitment would prevail, and were again lower than the rates which would maintain 50% of the stock biomass, denoting that the stocks are not overexploited in Lake Tono. However, considering our estimates of the current exploitation rates in both systems, the stock at Lake Bontanga does not appear to be underexploited (see also below the confirming LBI analysis). The stocks in this lake should be monitored every two years, where possible, to assess changes in exploitation and to improve management advice.

Length-based indicators (LBI)

Although the stock at Lake Tono has a spawning stock biomass above the reference point, indicating a state of uncritical and sustainable fisheries, more yield could be obtained if exploitation within the L_{opt} range is increased to 20% or 30%, although simultaneously reducing the fishing pressure on the large individuals. For Lake Bontanga, to the contrary, the pressure on immature individuals would have to be reduced in order to attain a sustainable fishery. Froese (2004) proposed reducing percentage of mature fish in the catch by 100% as a target and as a simple indicator, with the potential to allow more stakeholders to participate in fisheries management. The target indicator suggests that all (100%) fish should be allowed to spawn at least once before they are caught, in order to rebuild and maintain healthy spawning stocks. The proportion of 23% of immature fish in the catches at Lake Bontanga, and the low percentage of spawners in the population, might accordingly imply a current situation of both growth and recruitment overfishing.

Stock biomass

The estimates of the stock size show that per unit area, Lake Tono had nearly double the species population biomass than Lake Bontanga. This supports our findings with regard to the low current exploitation level, and the recommendation that the current exploitation rate of the species at Lake Tono could be increased to increase the yield. The estimate of the biomass of *Auchenoglanis* in Bagré reservoir in Burkina Faso is 1.64 tonnes km^{-2} (Villanueva et al. 2006), comparable with that of the stock size in Lake Bontanga. The low fishing pressure and higher biomass of the species in Lake Tono might be attributed to lower market availability around the Lake Tono area for the species' exploitation. The Navrongo market, which is the closest to Lake Tono, has not yet had much demand for smoked fish (the principal form of commercialisation), compared with the Tamale market, which is supplied by Lake Bontanga.

The larger biomass of Lake Tono accordingly seems to be a reflection of good growth conditions, stemming from a rich food supply and low fishing pressure allowing the population to flourish.

Conclusion

The giraffe catfish, Auchenoglanis occidentalis, populations in both systems exhibited omnivorous feeding behaviour, feeding more on insect larvae and as bottom feeders. Substantial amount of sand and silt particles were found in their stomach contents. The study did not reveal any significant difference in the bulk contribution of the food items from the Lake Bontanga and the Lake Tono artificial systems, but found a generally higher stomach fullness in Lake Tono.

The population size and stock density of *A. occidentalis* was larger in Lake Tono and the growth performance was better. Here the species attains substantially larger sizes and the estimated growth performance index exceeded that of Lake Bontanga (2.70 compared with 2.41 for Lake Bontanga). The exploitation rate of the species in Lake Tono is low. Complementarily, the LBI analysis and the estimates of the stock size indicate that the fishing mortality could be greatly enhanced (about doubled) to increase yield at Lake Tono, whereas at Lake Bontanga, fishing effort should not be increased, because the current exploitation rate is at an optimum, and the fishing pressure on immature individuals should be reduced, in order to prevent growth overfishing. We recommend that a full year's study on stomach contents should be carried out to assess seasonal variation in the range of food items available to *A. occidentalis* populations in Lake Tono and Lake Bontanga and suggest that the stock of both lakes should be monitored continuously.

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