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DYNAMICS OF THE POPULATION AND BIOTIC POTENTIALS OF *Aphyosemion gardneri* (BOULENGER, 1911) (CYPRINODONTIFORMES: APLOCHEILIDAE) IN A NIGERIAN RAINFOREST POND

EKWU[1]*, A. O., KING[2], R. P. AND AKPAN[3] B. E.
[1&2]Department of Fisheries and Aquatic Environmental Management, University of Uyo, Akwa Ibom State, Nigeria
[3]Department of Animal and Environmental Biology, University of Uyo, Nigeria.
alyceekwu14@gmail.com +234 7034493343

ABSTRACT

The Population dynamics and biotic potential of *Aphyosemion gardneri* (Boulenger, 1911) were studied for twelve months in Mfangmfang Pond, an artificial rainforest pond in Uyo, Niger Delta, Nigeria using timed pond net catches as proxies of natural ecological population changes. The fish habitat was the air-water interface of the pond epipelagic zone of the vegetated littoral margin. The fish maintained a perennial population in the pond as shown by its occurrence in catches throughout the 12 months of the year. The catch abundance varied broadly (c. 18 – fold) from a minimum N_{min} =16 in November to a maximum N_{max} = 284 in May. The monthly mean catch was N_{mean} = 103. Monthly catch abundance was significantly correlated with habitat Phenological parameters (rainfall, air temperature, mean evaporation rate and photoperiod), Hydrophysical parameters (water level and transparency) and Hydrochemical parameters (dissolved oxygen concentration, free carbon dioxide, total alkalinity, total hardness, pH and conductivity). It is inferred that the pond's environmental factors contributed significantly to the observed population changes. *A. gardneri* attained a maximum total length of 55mm in Mfangmfang Pond. The length growth impetus was low at 0.33mm mo^{-1}, thus resulting in a relatively high longevity estimate of T_{max} = 14 yrs. The body size–catch abundance functions suggest the existence of a size-structured population. Monthly biotic potential (r_{max} 1 mo^{-1}) and yearly biotic potential (r_{max} 2, yr^{-1}) were computed for this *A. gardneri* population. Values of r_{max} 1 varied from a minimum of -1.881mo^{-1} in October to a maximum of + 1.960 mo^{-1} in May. Annual mean value was + 0.924 mo^{-1}. Monthly values were significantly pond-level correlated with pond Limnological parameters, (surface temperature, dissolved oxygen concentration, and pH). The yearly biotic potential varied from a minimum of r_{max} 2 = -22.572 yr^{-1} in October to a maximum of r_{max}2 = 23.520yr^{-1} in May (mean r_{max} 2 = + 0.0686 yr^{-1}). The January – December biotic potential estimates (r_{max} 1 = +0.895 mo^{-1}; r_{max} 2 = + + 10.740 yr^{-1}) indicate a moderately high population increase over the year, a trait which probably ensures population resilience and survival despite variations in environmental attributes.

KEYWORDS: *Aphyosemion gardneri*, Niger Delta, pond, population ecology pond level

INTRODUCTION

Rivulins are generally small non-food fish for humans but are important ecologically in aquatic food chains and webs. The species, *Aphyosemion gardneri* (Boulenger, 1911) (*sensu stricto*) is common in freshwater ecosystems (gently flowing streams, ponds, pools, and swamps) of the rainforest biogeographic zone of Cameroon and Nigeria.

A. gardneri is a particularly highly prized Ornamental species and is easily a candidate for the global market, as other species of freshwater aquariology (Mogalekar and Jawahar, 2015; King, 2019; Vasantharajan, 2023), on account of its exceptionally attractive chromatic characteristics. However, not much is known about the natural life history of this species. Available records (Antony and Silas, 1984; Teugels *et al*, 1992; Ekwu, 1998, 2004; Akpan and King, 2003) indicate that the natural population dynamics and biotic potential of *A. gardneri* have hitherto not been studied. Therefore, the present study (January – December, 2020) focused on the dynamics of the population and biotic potential of *A. gardneri* in Mfangmfang pond, an artificial perennial pond in Uyo, Eastern Niger Delta, Nigeria.

MATERIALS AND METHODS

Mfangmfang Pong (Fig 1) is an instream reservoir located in Uyo (5° 03`N, 7° 01`E) behind the temporary site of the University of Uyo. It has a surface area of 2.9 ha, a maximum length of 1,500m, a maximum width of 575m, and a mean depth of 3.9m.

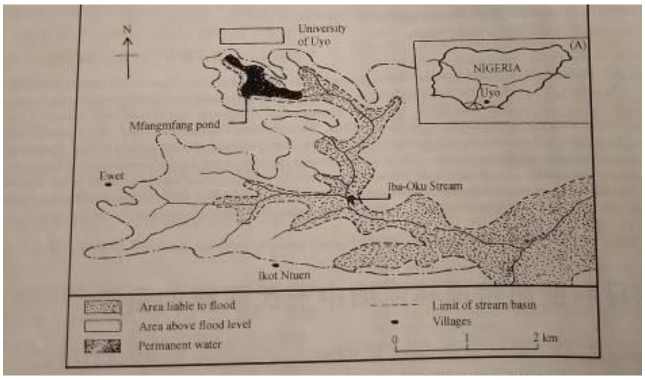

Fig.1 Map of the drainage basin of Iba-Oku Stream showing Mfangmfang Pond

It was formed in 1980 by partially impounding the headwater of Iba – Oku stream during a gully erosion/ landslide control exercise in the area (King, 1991). King

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(1991, 1998) described the physicochemical hydrology of the pond while Akpan and Akpan described the plankton dynamics of the pond. Long-term rainfall records for Uyo (Table 1; Tahal, 1982) suggest the existence of six ecoclimatic seasons *viz*: Early Dry Season (EDS~ November), Mid Dry Season (MDS ~ December – February), Late Dry Season (LDS~ March –April), Early wet season (EWS ~ May – July), Mid Wet Season (MWS ~ August), and Late Wet Season (LWS ~ September – October).

Monthly samples of *A. gardneri* were obtained from Mfangmfang Pond (January – December, 2019 inclusive) using a circular pond net at three sites on the pond. Each month`s sample comprised two days of mid-month sampling (8.00 am -12 noon local time) from the vegetated littoral zone of the pond. Thus 8 hours of active sampling effort was put in per month. The month–to–month catch numbers were used to estimate the specific rate of population change (SRC, %) in equation (1):

$$SRC = [\ln N_2/N_1)]\ 100 \quad (1)$$

where N_1 = catch abundance in month1; N_2 = catch abundance in month 2 (i.e one month post N_1). In this equation, SRC may be positive (i.e. population increase) or negative (i.e. population decrease). The monthly catch abundances were used to estimate biotic potential (r_{max}, mo^{-1}) according to Odum 1971 and Dajoz (1977). Each month`s biotic potential was multiplied by 12 to obtain yearly Values (i.e $r_{max}$ $yr^{-1}$). Representative specimens from each month`s sample were used to compute mean total length (MTL, mm) and dominant total length (DTL, mm). The pond hydrological parameters were obtained from records maintained by the Department of Fisheries and Aquatic Environmental Management, University of Uyo, Akwa Ibom State, Nigeria. Statistical analyses were conducted with the Excel package in Microsoft 2010

Table 1. Mean Monthly Rainfall in Uyo, Nigeria (Based on Tahal, 1982)

Months	No. of rainy days	Rainfall (mm)
January	3	35
February	3	71
March	12	135
April	13	230
May	15	277
June	19	323
July	22	347
August	21	290
September	22	392
October	20	273
November	10	169
December	4	38
Total	165	2581
Mean	14	215.1

where N_1 = catch abundance in month1; N_2 = catch abundance in month 2 (i.e one month post N_1). In this equation, SRC may be positive (i.e. population increase) or

negative (i.e. population decrease). The monthly catch abundances were used to estimate biotic potential (r_{max}, mo^{-1}) according to Odum 1971 and Dajoz (1977). Each month`s biotic potential was multiplied by 12 to obtain yearly Values (i.e $r_{max}$ $yr^{-1}$). Representative specimens from each month`s sample were used to compute mean total length (MTL, mm) and dominant total length (DTL, mm). The pond hydrological parameters were obtained from records maintained by the Department of Fisheries and Aquatic Environmental Management, University of Uyo, Uyo, Akwa Ibom State, Nigeria. Statistical analyses were conducted with the Excel package in Microsoft 2010.
The monthly catch numbers were used to estimate the specific rate of change ((SRC, %) according to the equation (2);

$$SRC = [In(N_2 /N_1)]100 \quad (2)$$

where N_1 = catch number in month 1; N_2 = catch number in month2 (i.e. one month post N_1). In this equation, the change factor may be positive (i.e. population increase) or negative (i.e. population decrease. The number of size classes in the overall population (N_c) was estimated from Sturge`s rule (in: Scherrer, 1984; Kouamelan *et al*, 1999) as in equation (3)

$$N_c = 1+(3.3\log10\ N) \quad (3)$$

where N = total number of specimens examined.
The monthly biotic potential (r_{max}, mo^{-1}) was estimated from the numerical catch abundance according to Odum (1971). Each month`s r_{max} was multiplied by 12 to obtain the yearly biotic potential (i.e. r_{max} yr^{-1}). Long-term records of key phonological parameters for Uyo were obtained from Enplan, (1974) and Tahal (1982). The pond key Hydrophysical and Hydrochemical routine records are maintained by the Department of Fisheries and Aquatic Environmental Management, University of Uyo, Uyo, Akwa Ibom State, Nigeria.

A circular pond net (with plastic mosquito netting material) was used to sample *A. gardneri* from the vegetated littoral zone of the pond on 5 days during mid-month. On each sampling day, approximately 4 hours of continuous sampling were spent (8.00 – 12.00 hrs local time). Thus the sampling effort for each month was about 20 hours. All the catches for the 5 days were summed as the catch abundance for the month. Representative samples of the fish were taken and measured for total length (mm). The number of size classes in 1mm units was defined as size richness (SR) while the mean total length (MTL, mm) and dominant total length (DTL, mm) were estimated as measures of body size.

RESULTS

Occurrence and habitat

A. gardneri was present in pond net catches throughout the 12 months of the study period. It lived in sympatry with *Epiplatys fasciatus* Gill, 1863, *Aphyosemion splendopleura* (Meinken, 1930), and juveniles of *Pelmatolapia mariae* (Boulenger, 1899). The primary habitat of *A. gardneri* in

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Mfangmfang Pond was the air–water interface of the epipelagic vegetated littoral zone.

Evolution of catch abundance

A total of 1230 specimens of *A. gardneri* were caught. The monthly catches varied 17.8 – fold, from a minimum of N_{min} =16 in November to a maximum of N_{max} = 284 in May (Table 2). Annual mean catch was N_{mean} =103.Primary catches were made in May (23.09%), June (14.63%), July (21.95%), and September (17.07%). Secondary catches were made in January (3.09%), April (3.25%), August (6.50%), October (2.60%) and December (2.76%) while tertiary catches (< 2.00%) were noted in February, March and November.

The spectrum of monthly specific rate of change in catch abundance (Table 2) revealed positive values (i.e. increases) in January, March – May, July, September and December whereas negative values (i.e. decreases) were recorded in February, June, August and October. The sum of the increase factors was Σ + SRC = + 479.3 while the sum of the decrease factors was Σ –SRC = - 479.3. Therefore, the summed magnitudes of the increase and decrease factors balanced one another.

The overall population oscillation profile of *A. gardneri* (Table 2) revealed the existence of a demographic pattern with a brief lag phase (December – January) when the population growth was very slow at 10.5%. This was followed by a protracted exponential or geometric phase (February – May) with a very rapid
(92.3%) population growth. The equilibrium phase was next in June – Septemberwhen the po pulation remained relatively stable except for a -70.4% decline in August. The January – December change in population depicted a -11.8% decrease.

Table 2. Monthly Catches and Related Statistics of *Aphyosemion gardneri* in Mfangmfang Pond, Uyo, Nigeria.

Months	N	%N	SRC	$r_{max}(1)$	$r_{max}(2)$
		(%)	(%)	(mo^{-1})	(yr^{-1})
January	38	3.09	+11.1	0.111	+1.332
February	22	1.79	-54.7	-0.547	-6.564
March	24	1.95	+8.7	+0.087	1.044
April	40	3.25	+51.1	+0.511	+6.132
May	284	23.09	+196.0	+1.960	+23.520
June	180	14.63	-45.6	-0.456	-5.472
July	270	21.95	+40.5	+0.406	+4.872
August	80	6.50	-40.6	-1.216	-14.592
September	210	17.07	+15.4	+0.965	+11.580
October	32	2.60	-188.1	-1.881	-22.872
November	16	1.30	-69.3	-0.693	-8.316
December	34	2.76	+75.4	+0.754	+9.048
Total	1230	99.98			
Mean	103				

N = catch abundance; SRC = specific rate of change of catch abundance;
r_{max} = biotic potential; r_{max} (1) = monthly biotic potential; r_{max} (2) = annual biotic potential.

Figure 2 depicts the seasonal plasticity in the catch abundance of *A. gardneri*. It varied from 1% in the Early Dry Season to a maximum of 59% in the Early Wet Season. Other seasons yielded low catches of 5 – 20%

Size Correlates

The Sturge`s rule suggested the existence of a multi-size assemblage with a minimum of 11 size classes. This is corroborated by the multimodal size frequency distribution in Fig. 3 (*vide supra*). Small specimens measuring 1 – 13 mm TL were poorly represented in the overall population. Larger sizes measuring 14 – 40 mm TL were more well represented (Fig.3).

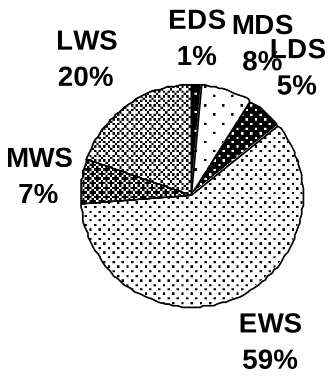

Fig.2: Seasonality in Catch Abundance of *Aphyosemion gardneri* in Mfangmfang Pond, Uyo, Nigeria.
EDS = Early Dry Season; MDS = Mid Dry Season; LDS = Late Dry Season; EWS = Early Wet Season; MWS = Mid Wet Season; LWS = Late Wet Season

The monthly size richness (SR) (i.e. number of size categories in 1 mm units), mean total length (MTL, mm) and dominant total length (DTL mm) of *A gardneri* specimens caught are shown in Table 3. The size richness varied 4.7-fold, from a minimum SR = 6 in November to a maximum SR = 28 in September. Mean size richness was $(SR)_{mean}$ = 16. The monthly catch abundance significantly Increased with fish size richness (r^2 = 0.8890, n=12, P < 0.002) and mean total
Length (MTL) (r^2 = 0.6695, n=12, P<0.02) according to the respective equations (4) and (5):

$$N = 0.3624(SR)^{1.926} \quad (4)$$

$$N = -0.7241(MTL)^6 + 105.22(MTL)5 -6348.6(MTL)\ 4 + 203574(MTL)3 - 4E + 4E +06(MTL)2 + 3E +3E +07(MTL) - 1E +08 \quad (5)$$

which respectively explained 88.9% and 66.5% of the variation in catch number. Catch abundance was also significantly correlated with dominant total length (DTL) (r^2 = 0.9371, n=12, P<0.002) according to a polynomial equation (6) of the form:

$$N = -0.2416(DTL)^5 + 27.097(DTL)^4 - 1200.3(DTL)^3 + 26234(DTL)^2 - 282633(DTL) + 1E +06 \quad (6)$$

which explained 93.7% of the variation in catch abundance

Growth Pattern

The largest specimen of *A. gardneri* encountered in Mfangmfang Pond measured
L_{max} = 55 mmTL. Monthly changes in mean total length (MTL, mm) and dominant total length (DTL, mm) were used as indices of growth of *A. gardneri* (Table 3). Using January as the inception of growth (MTL = 21mm), the fish attained 25 mmTL in December (i.e. 0.33mm mo^{-1}). By this growth rate, it takes the fish a minimum of 16 months to achieve its L_{max}.

Table 3. Monthly Catch Abundance of *Aphyosemion gardneri vis-à-vis* Size Richness, Mean Total Length and Dominant Total Length of the fish in Mfangmfang Pond, Uyo, Nigeria

Months	N	SR	MTL (mm)	DTL (mm)
January	38	9	21	19
February	22	10	26	29
March	24	10	27	23
April	40	12	29	29
May	284	24	24	21
June	180	26	27	27
July	270	25	24	20
August	80	22	20	29
September	210	28	25	21
October	32	12	20	15
November	16	6	23	19
December	34	11	25	30

N= catch abundance; SR = Size Richness; MTL = Mean Total Length; DTL = Dominant Total Length.

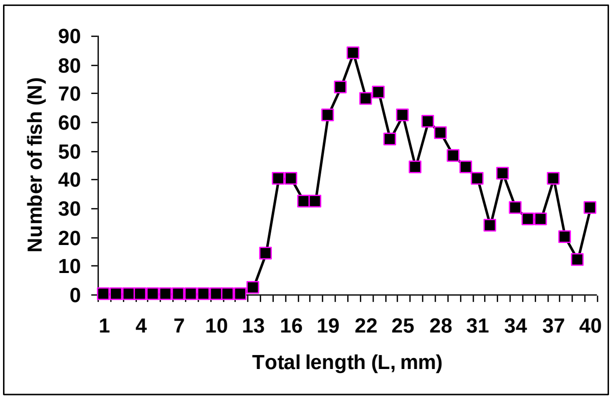

Fig. 3. Size Composition of *Aphyosemion gardneri* in Mfangmfang Pond, Nigeria

Phenological Correlates

In view of the microhabitat of *A. gardneri* at the air –water interface, the fish is exposed to the interacting effects of Phenological parameters. Hence, the catch abundances were significantly correlated with rainfall (RF, mm) (r2 = 0.6117,
n= 12, P< 0.01), air temperature (AT, ºC) (r^2 = 0.7966, P<0.002), sunshine hours
per day (SH) (r^2 = 3421, n=12, P< 0.05) and evaporation rate (EVR, mm) (r^2 = 0.4733, n=12, P<0.02). The respective trend equations (7, 8, 9 and 10) for these relationships are:

$$N = 18.361e^{0.0059(RF)} \quad (7)$$

$$N = 147.87(AT)^5 - 1997(AT)^4 + 1E + 06(AT)^3 - 3E + 07(AT)^2 + 4E + 08 (AT) - 2E + 09 \quad (8)$$

$$N = -46.87(SH) + 297.01 \quad (9)$$

$$N = 2E + 08 (EVR)^{-3.1959} \quad (10)$$

Equation (7) is an exponential model while equation (8) is polynomial, hence, a wave function. Equations (9) and (10) are respectively negative linear and inverse power models. The coefficients of determination revealed the following decreasing order of importance of these phenological parameters: air temperature (r^2 = 79.7%) , rainfall (r^2 = 61.1%), evaporation rate (r^2 = 47.3%) and photo period (r^2 = 34.2%).

Hydrophysical Correlates

The monthly catch abundances of *A. gardneri* were significantly correlated with pond Hydrophysical parameters, including surface temperature (T, ºC)
(r2 = 0.4246, n=12, P<0.05), water level (L, m) (r2 = 0.3474, n=12, P< 0.05) and transparency (TR, m) (r2 = 0.3376, n=12, P< 0.05). The respective trend equations (11-13) for these relationships are:

$$N = -905.7 T^4 + 93818T^3 - 4E + 06T^2 + 6E + 07T - 4E + 08 \quad (11)$$

$$N = 134.9L^6 + 3192.9L^5 - 31002L^4 + 158014L^3 - 445825L^2 + 660268L\ 168.23(TR - 491074 \quad (12)$$

$$N = - 168.23(TR) + 296 .81 \quad (13)$$

Equations 10 and 11 are polynomials, hence wave functions. Thus, increases in pond temperature and water level resulted in increased catches and vice versa. Equation (12) is an inverse linear model that indicates that catch abundance decreases as transparency increases and vice versa. The coefficients of determination show the following increasing order of the importance ($100r^2$) of the hydrophysical parameters as determinants of catch abundance: transparency (33.8%), pond level (34.7%), and surface temperature (42.5%).

Hydrochemical Correlates

Several pond Hydrochemical parameters were found to significantly correlate with the catch abundance of *A. gardneri* in Mfangmfang Pond. These include: dissolved oxygen concentration (O, mg/l) (r^2 = 0.4714, n=12, P<0.05), free carbon dioxide (CO_2, mg/l) (r^2 = 0.3529, n=12, P<0.05), total alkalinity (ALK, mg/l CaCO3) (r^2 = 0.4217, n=12, P<0.05), total hardness
(HD, mg/l Ca CO3) (r^2 = 0.4509, n=12, P< 0.05), hydrogen ion concentration
(pH) (r^2 =0.3306, n=12, P<0.05) and conductivity (C, µS cm-1) (r^2 = 0.3392,
N=12, P< 0.05). The respective trend equations (14-19) for these relationships are:

$$N = 0.00002O^{6.9797} \quad (14)$$

$$N = 535.39 (CO_2))^{-2.523} \quad (15)$$

$N = 5E – 08(ALK)^{6.9776}$ (16)
$N = -27.35(HD) + 676.69$ (17)
$N = - 59.284(pH)^3 + 1308.2(pH)^2 -9443.9(pH) + 22463$ (18)
$N = 3.409C^{1.4794}$ (19)

Equations (13), (14) (15) and (18) depict power functions in catch abundance with increasing levels of dissolved oxygen concentration, free carbon dioxide, total alkalinity and conductivity. Equation (16) is an inverse linear function. The catch abundance –pH relationship (Eqn. 16) is cubic polynomial, hence wave function Equation (18) depicts a power increase in abundance per unit increase in pond conductivity.

Growth Pattern
The largest specimen of *A. gardneri* encountered in Mfangmfang Pond measured L_{max} = 55 mmTL. Monthly changes in mean total length (MTL, mm) and dominant total length (DTL, mm) were used as indices of growth of *A. gardneri* (Table 3). Using January as the inception of growth (MTL = 21mm), the attained 25 mmTL in December (i.e. 0.33mm mo^{-1}). By this growth rate, it takes the fish a minimum of 166 months to achieve its L_{max} of 55 mm TL(i.e. longevity T_{max} = 14 years). The monthly changes in mean total length were significantly correlated with the pond surface temperature (T, °C) ($r^2 = 0.5077$, n=12 =12, P< 0.01) and dissolved oxygen concentration (DO, mg/l) ($r^2 = 0.536$, n=12, P< 0.01) according to the equations (20) and (21):

$MTL = -4.4743T^3 + 339T^2 – 8556.3T + 71971$ (20)

$MTL = 233.59O^6 – 8564O^5 + 130611O^4 – 1E +06O^3 +5E +06O^2 -1E +07O \quad +1E +07$ (21)

which respectively explained 50.8% and 53.6% of the variation in MTL.
With January as growth inception (DTL= 19mm TL), the fish increased in length by 11 mm TL in December (i.e. 0.92mm mo^{-1}). By this growth rate, this will attain its L_{max} in a minimum of 60 months or 5 years. From the foregoing, both the MTL and DTL analyses indicate low length growth impetus for the Mfangmfang Pond population of *A. gardneri*.

Evolution of Monthly Biotic Potential
Table 2 shows the spectrum of monthly biotic potential of *A. gardneri* in Mfangmfang Pond. It varied minimally from a minimum of r_{max} (1) = -1.881 mo-1 in October to a maximum of r_{max} (1) = 1.960 mo-1 in May with an annual mean of r_{max} (1) = 0.083 mo^{-1}. If the signs are ignored, the annual range showed a
1.04 –fold variation. There were seven months (i.e 58.3% of the year) of positive r_{max} values (i.e. increases) viz: January, March- May, July, September and
December and five months (i.e 41.7% of the year) of negative
r_{max} 1 values (i.e .population decreases) viz: February, June, August and October – November. The monthly biotic potentials were significantly correlated with fish mean total length (MTL, mm) (r2 = 0.4171, n=12, P< 0.05) according to a hyperbola of the form (eqn 22:

$r_{max} (1) = -0.0583(MTL)^2 + 2972(MTL) – 37.249$ (22)
which explained 41.7% of the variance in the monthly biotic potential. The peak
r_{max} = 0.965 mo^{-1} was recorded at a mean size of 25mmTL. The monthly biotic potentials were also significantly correlated with pond surface temperature (T, oC) (r2 = 0.3307, n=12, P<0.05) and dissolved oxygen concentration (O, mg/l)
(r2 = 0.4339, n=12, P<0.05) according to the following respective equations (23) and 24):

$r_{max} (1) = -1.5164T^3 + 115.69T^2 – 501.23T +24919$ (23)

$r_{max} (1) = -4.758O^3 + 84. 788O^2 – 501.23O + 983.38$ (24)

which respectively explained 33.1% and 34.4% of the variation in monthly biotic potential.

Table 4. Seasonality in the Indices of Biotic Potential of *Aphyosemion gardneri* in Mfangmgmfang Pond, Nigeria

Seasons	Mean monthly biotic potential (r_{max} mo^{-1})	Mean yearly biotic Potential (r_{max}, yr^{-1})
Early Dry Season	-.693	-8.316
Mid Dry Season	+0.106	+1.272
Late Dry Season	+0.299	+3.588
Early Wet Season	+0.637	+7.640
Mid Wet Season	-1.216	-14.592
Late Wet Season	-0.458	-5.496

Seasonality in mean monthly biotic potential (Table 4) revealed progressive population decreases in the Mid Wet Season, Late Wet Season and Early Dry Season and increases in the Mid Dry Season, Late dry Season and Early Wet Season.

Evolution of yearly biotic potential
The spectrum of yearly biotic potential of *A. gardneri* (i.e. r_{max} 2) (Table 2) showed minimal (1.04 –fold) variation, from a minimum r_{max} 2 = -22.872 yr-1in October to a maximum r_{max} 2 = +23.520 yr-1 in May. Unlike the monthly biotic potential, the January to December yearly biotic potential was negative i.e. r_{max} 2 = -1.335 yr-1), thus suggesting a decline in population as the year progressed. The r_{max} 2 values were significantly correlated with fish mean total length ($r^2 = 0.5511$, n=12, P<0.05) according to the equation (25):

$r_{max}2 = 0.2839(MTL)^3 – 21.485(MTL)^2+ 33.149(MTL) -417.27$ (25)

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Which explained 55.1% of the variance in biotic potential. The yearly biotic potential was significantly correlated with pond surface temperature (T, oC)
($r2 = 0.3307$, n=12, $P<0.05$|) and water level (L, m) ($r2 = 0.3411$, n=12, $P<0.05$)
According to the following respective equations (26) and (27):

$$r_{max}\ 2 = -18.197T^3 + 1388.3T^2 - 35296T + 299029 \quad (26)$$

$$r_{max}\ 2 = -0.012L^5 + 0.7576L^4 - 15.747L^3 + 122.54L^2 - 403.34L + 476.18 \quad (27)$$

which respectively explained 33.1% and 34.1% of the variation in yearly biotic potential. The seasonal yearly biotic potential (Table 4) suggests population increases in the Mid Dry Season, Late Dry Season and Early Wet Season while population decreases were registered in Early Dry Season, Mid Wet Season and Late Wet Season, a pattern analogous to that of monthly biotic potential.

DISCUSSION

The abundance dynamics of *A. gardneri* have hitherto not been evaluated in any Nigerian aquatic ecosystem. There are therefore no previous records with which to compare the present findings. Although Ekpo (2013) reported a study on Ornamental fish in a river system in this area, the survey did not provide information on Cyprinodonts, notably Aphyosemion species, probably because these species are known to inhabit smaller and more quiescent water bodies. The occurrence of specimens in catches over the twelve months of the study period indicates that the classical Cyprinodontiforme zygotic diapause in the bottom mud (Ekwu, 1998; Dankwa *et al*, 1999) may not apply to this case. This is probably because the annual hydrological cycle of Mfangmfang Pond does not involve any dry-out phase. This makes the fish an ideal species for the study of population dynamics. Moreover, it suggests that the potential physiological longevity of the fish exceeds one year, thus eroding the concept of annualism with particular reference to the Mfangmfang Pond population of *A. gardneri* (*cf* Akpan and King, 2003). This report corroborates the findings of Ekwu, (1998) who reported non-annualism in the species when kept in aquarium tanks for more than a year. Previous studies of Cyprinodontiforme species have always been carried out in the natural rain forest streams and ponds, which are prone to annual drying out periods (Scheel, 1975; Reid, 1982). Thus, the species was hitherto regarded as an annual species.

While ornamental fishes including cyprinodontiformes have secured an important niche in the global market (Samala and Kapute, 2019; Livengood and Chapman, 2023; Jaji and Odesola, 2015), reports on global trade of Apyosemion species are still scanty, hence the importance of this study.

In this study, the catch abundance was used as proxi of natural population. This is plausible because the pond is a `closed system` where immigration and emigration are precluded. Mfangmfang Pond therefore harbours a resident population of *A. gardneri*. Hybridization with heterospecifics may easily occur in this kind of environment, a phenomenon commonplace in the Cyprinodontiformes (Ekwu, 1998). However, this kind of gene dilution is yet to be established in the Mfangmfang Pond population of *A. gardneri*. The high abundance of *A gardneri* in Mfangmfang Pond indicates that this pond is probably a representative of a typical optimal habitat where the fish exhibits its maximal abundance. This is particularly so because of the well-established riparian vegetation which ensures a continuous input of allochthonous invertebrate fauna, a major food resource of *A. gardneri* (Akpan *et al*., 2006).

Since possible immigration and emigration were precluded from this study, the specific rate of change factors (Table 2) may be viewed as reflecting natality (i.e.
positive values) or mortality (i.e. negative values). Therefore, the equality in the summed positive and negative factors suggest the existence of a dynamic equilibrium population where natality balances mortality. The population growth pattern of *A. gardneri* revealed the existence of typical lag, exponential and equilibrium phases (Table 2) (Reid, 1961; Boughey, 1973; Allen *et al*, 1999). This is probably due to the interplay of natality and mortality. The - 70.4% decline in the fish population during the equilibrium phase may be attributed to the onset of the natural regulatory forces of environmental resistance which prevent the population from achieving maximal growth impetus.

The study revealed significant relationships between the catch abundance of *A. gardneri* and fish size richness (Eqn.4), mean total length (Eqn.5), and dominant total length (Eq.6). These imply that the fish population does not exist as random – sized individuals. It rather exists socially as size–structured aggregates of individuals. The selective advantage of a size–structured population is that it facilitates the optimal exploitation of most of the size–related ecological niches.

The study established relationships between habitat phenological parameters and the catch abundance of *A. gardneri*. This is possible because of the unique microhabitat of the fish at the air-water interface of the epipelagic zone of the pond littoral zone. Due to its lentic nature, the pond ecosystem is often subject to periods of low dissolved oxygen concentration which can adversely affect fish life. However, when it rains, the kinetic energy of the mechanical rain droppings on the pond surface increases oxygen dissolution. *A gardneri* therefore aggregates at the epipelagic zone to benefit from the oxic condition, thus resulting in its being abundantly caught and *vice versa*.
It is inferred that the Pond environmental factors probably interact individually or synergistically in ways that influence catchability, hence the observed population changes.

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These probably explain the significant relationship between rainfall and catch abundance of *A. gardneri* (Eq. 7). Increase in photoperiod (i.e. sunshine hours) leads to an increase in air temperature and evaporation rate, both of which can cause dehydration and death of the fish. The fish probably evades dehydration by moving into shaded places and *vice versa* during low photoperiodism. Hence, the interplay of these parameters culminates in the significant relationships between catch abundance and air temperature (Eqn. 8), photoperiod (Eqn. 9) and mean evaporation rate (Eqn.10).

This study showed relationships between the catch abundance of *A. gardneri* and pond hydrophysical parameters, including surface temperature (Eq. 11), water level (Eqn.12), and transparency (Eqn. 13). Habitat temperature is important for general activity regime, general metabolism and growth (Pauly, 1983). *A. gardneri* is probably thermophilic, being attracted to the Air–water interface of the pond epipelagic zone where it is easily caught. However, the converse is true when the ambient temperature decreases. This cyclic temperature regime is probably responsible for the observed quartic relationship between catch abundance of *A. gardneri* and pond surface temperature (Eqn.10. In tropical aquatic ecosystems, high water level generally occurs during the rains, the period when the fishes are more widely dispersed In the expanded habitats. Some forage more actively and reproduce (Wellman, 1948; Reed *et al*, 1967; Moses, 1986). The converse is the case during the dry spells of the overall hydrological cycle. The fish catch is thus higher during high water level than during low water level. This is probably explains the pond level – catch abundance polynomial relationship of *A. gardneri* (Eq. 11). Clear water (i.e. high transparency) is required for a number of purposes, including prey selection, optimal foraging, choice of mate and predator evasion. In this regard, *A. gardneri* may be photophilic, aggregating at the pond surface during clear water/sunshine hours and vice versa during low transparency/photo periodism. These are probably responsible for the transparency–catch an abundance of *A. gardneri* (Eqn. 12). The above three relationships were polynomial, hence wave models. Thus increases in habitat temperature, water level and transparency resulted in increased pondnet catches and vice versa.

The study also demonstrated significant relationships between catch abundance of *A. gardneri* and pond hydrochemical parameters, including dissolved oxygen concentration (EQ. 13), free carbon dioxide (Eq. 14), total alkalinity (Eqn. 15), total hardness (Eqn. 16), pH (Eqn. 17) and conductivity (Eqn. 18). The power function between catch abundance of and dissolved oxygen concentration (Eqn.13) emphasizes the relevance of dissolved oxygen in the life of this species while the reverse is the case with free carbon dioxide (Eqn. 14) which can be toxic to the fish. *A. gardneri* is probably acidophobic, thus accounting for the power relationship between catch abundance and pond total alkalinity (Eqn. 15) with the latter accounting for 42.2% of the variance in catch abundance. This explanation also holds for the inverse linear between total hardness and catch abundance of *A. gardneri*. Thus the fish exhibits an affinity for increase in $CaCO_3$ anions (ie. alkalinization). The power conductivity – catch abundance function (Eqn. 18) may be interpreted as implying a strong affinity of the fish to highly productive periods of the year. This is because conductivity is an important index of primary and secondary productivities of freshwater ecosystems (Welcomme, 1976).

Partly like in the present study, Clausen (1964), Driver (1977), Townsend *et al*. (1983), Sutcliffe (1983) and Collier and Winterbourn (1987) have demonstrated the interacting influences of hydro-physical and hydro-chemical parameters on the occurrence, abundance and diversity of aquatic fauna. However, the exact operational biomechanism of these relationships is obscure. It may be conjectured here that the pond physicochemical variables individually or synergistically influence the physiology and etiology of the *A. gardneri* in subtle ways that in turn affect catchability and hence, the abundance dynamics (*cf*. Pizl and Josens, 1995; Smith and Haines, 1995).

The physicochemical and phytoplankton characteristics of Mfangmfang pond (King and Nkanta, 1991; Akpan and Akpan, 1989) suggest that Mfangmfang pond is oligotrophic. The influence of this pond trophic status is probably reflected in the observed slow growth rate of *A. gardneri*. Slow growth rate may also be linked to the inherent diminutive anatomical configuration of the fish which limits the amount of visceral energy storage for growth. The very slow growth rate estimate of *A. gardneri* in Mfangmfang pond is probably responsible for the high longevity estimate of T_{max} = 14 years which appears to be odd for a small –sized cyprinodont as *A. garderi*. The overall slow growth rate and high longevity estimates are probably the products of the highly parsimonious methods applied in this study.

To the knowledge of the authors, this is probably the first time that the biotic potential of a West African tropical cyprinodontid species has been evaluated. The relatively high mean estimates of the monthly and yearly biotic potentials (i.e. r_{max} 1 and r_{max} 2) suggest that this fish may produce more than one generation annually. A critical examination of Table 2 indicates the possible production of at least two generations, in May and September. These were counterbalanced by two major mortalities, in February and November.

In this study, each r^{max} estimate may be interpreted as the difference between the Instantaneous specific natality rate (i.e birth rate per unit time/per individual)
(b) and the instantaneous specific mortality rate(i.e death rate per unit time per individual) (d) (Odum, 1971; Dajoz, 1977). Hence r_{max} may be simplified as in eqn (28):

$$r_{max} = b - d \qquad (28)$$

Therefore, the positive r_{max} estimates represent the dominance of natality over mortality and *vice versa* for the negative r_{max} estimates. In this regard,

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Table 2 shows that natality dominated in seven months and mortality in five months. The overall dominance of natality ensures population resilience and persistence under strongly fluctuating environmental conditions.

Dajoz (1977) noted that biotic potential is closely related to temperature. An extension of this concept in the present study revealed that other parameters are also significantly correlated. These include body size, dissolved oxygen concentration and pond water level.

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