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Growth Parameter indices, Mortality Variables and Levels of Exploitation of Red Claw Crayfish (*Cherax Quadricarinatus*, Von Martens, 1868) in the Kafue Floodplain Fishery and Lake Kariba, Zambia.

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ABSTRACT

This study was aimed at documenting the growth parameters, mortality variables and levels of exploitation of *Cherax quadricarinatus* in the Kafue Floodplain Fishery and Lake Kariba. *C. quadricarinatus* (n = 1, 129) were collected using traps, locally called Kamono. The results showed that *C. quadricarinatus* reaches its asymptotic length very fast owing to its high growth coefficient at both study sites (overall K = 0.875 yr^{-1} at Lake Kariba, K = 1.01 yr^{-1} at Kafue Floodplain Fishery). *C. quadricarinatus* showed longevity values of 3.0 years and 3.2 years from the Kafue Floodplain Fishery and Lake Kariba. *C. quadricarinatus* was under-exploited at Lake Kariba (E = 0.16) but it was over-exploited in the Kafue Floodplain Fishery (E = 0.61). The feral populations of Crayfish are well-adapted to their alien habitat as evidenced by the optimal growth rates.

Key words: *Cherax quadricarinatus*, Kafue Floodplain Fishery, Lake Kariba, Growth, exploitation.

1. Introduction

The Red Claw Crayfish (*Cherax quadricarinatus*) also called Tropical Blue Crayfish is an arthropod which is classified in family Parastacidae of order Decapoda. Just like all Decapods, *C. quadricarinatus* has five pairs of thoracic legs (pereiopods) which are enlarged pincers (claws called chelae). The chelae are smooth, straight with flat inner and narrow cutting edges; in mature males and forming a bright red-orange patch (hence common English name) (Grandall and De Grave, 2017). Like all arthropods, *C. quadricarinatus* has a pair of antennae with a distinct prominent spine which may be longer than the total body length in adult males (Haubrock *et al*., 2021). Total body length reaches up to 25 cm of total length while body weight reaches up to 600 g but typical size in natural populations is less than 100 g, with 200 g considered large (Austin *et al*., 2010).

C. quadricarinatus has a robust nature with broad tolerances to environmental extremes (can survive temperature ranges of 4°C- 40°C) combined with its rapid growth rate, high fecundity, ability to spawn multiple times per year (Mudenda *et al*., 2024) has contributed to its invasiveness (Nunes *et al*., 2017a). Aquaculture and ornamental aquarium trade are notably the main pathways behind the rapid spread of crayfish across the globe. Its relatively large potential body size and bluish colouration, which gives it good aesthetic values, makes it an ideal species for aquaculture (Belle *et al*. 2011; Mukuka, 2019).

The initial introductions of *C. quadricarinatus* in Africa were in the 1960s and 1970s and South Africa was the first (Makwelele, 2017). Red claw was introduced in Zambia from South Africa in 1992 for aquaculture purposes (Audenaerde and Dirk, 1994). Recorded evidence of *C. quadricarinatus* establishment in the wild was reported in 2005 in the Kafue River and in 2008 at Siavonga on the Zambian shore of the Sanyati Basin on Lake Kariba (Nakayama *et al*., 2010). In 2013, *C. quadricarinatus* was found in the Upper Zambezi River (Mukuka, 2019). In Zambia, Crayfish are usually caught as a by catch by artisanal fishers. Crayfish is now commercially reared for consumption in Zambia (Makwelele, 2017).

Computations of growth parameters and exploitation levels of fish stocks are very important in documenting various aspects of Biology such as longevity, Length-at-First Maturity, age at recruitment and growth. These population parameters are very important in fisheries management (Abdul *et al*., 2019; Mudenda *et al*., 2024).

Estimation of natural mortality (N), fishing mortality (F) and total mortality (Z) parameters are essential to the execution of sustainable management practices for improved conservation of biodiversity (Ahmed *et al*., 2020; Saha *et al*., 2021; Mudenda *et al*., 2024). These parameters are used to estimate exploitation ratios of a fish stock in an aquatic habitat. An exploitation ratio which is less than 0.5 denotes under-exploitation while an exploitation ratio value above 0.5 depicts over-exploitation (Gulland, 1982). A natural aquatic habitat is optimally exploited if its exploitation ratio is 0.5. In a natural water body, if the natural mortality is higher than the fishing mortality, the fishery is dominated by small sized-individuals (juveniles) which are very susceptible to adverse environmental conditions, or the fish stock is not well-adapted to its environment (Ahmed *et al*., 2020; Makeche *et al*., 2020). A high fishing mortality relative to natural mortality denotes that a fishery has a mature fish stock which is vulnerable to the fishing gear which fishers are using. Such a fish stock is in danger of being extinct because it may be exploited beyond the maximum sustainable yield (Apegyah *et al*., 2008; Ahmed *et al*., 2020).

2. Materials and Methods

2.1. Study area and sampling

Crayfish were collected using baited traps, locally called Kamono. The research was conducted from the Kafue Floodplain Fishery because it is a World-recognized Ramsar site which is rich in biodiversity (Makeche *et al*., 2020).

Crayfish were sampled from Chanyanya and Kafue Road Bridge (Fig. 1). Chanyanya lies along latitude -15°42'S and longitude 28°00'E. Kafue Road Bridge study site was located along latitude -15°84'S and longitude 28°24'E. A total of 462 *C. quadricarinatus* samples were collected from the Kafue Floodplain Fishery between November and December, 2022.

The research was conducted from Lake Kariba because Lake Kariba is the largest man-made Lake in Zambia that has diverse ecological habitats that are rich in fish biodiversity (Mudenda *et al*., 2012; Lake Kariba Research Unit, 2015).

Crayfish were sampled from Kabbyobbyo and Mundulundulu in Siavonga (Fig. 1). Kabbyobbyo lies along latitude -16°53'S and longitude 28°57'E. Mundulundulu study site was located along latitude -16°54'S and longitude 28°71'E. A total of 667 *C. quadricarinatus* samples were collected from Lake Kariba between November and December, 2022.

Fig. 1- Map showing the location of study sites in the Kafue Floodplains and Lake Kariba.

2.2 Data analysis

2.2.1 Growth parameters

The growth coefficient (K) was estimated using the formular: $K = -\frac{1}{\Delta t}$ x ln b (Sparre and Venema, 1998); where b is a constant obtained by regression analysis of L(t) values of the sample size and Δt is change in time. The asymptotic length (L_∞) was estimated from the formular: $L_\infty = \frac{L\ max}{0.95}$ (Sparre and Venema, 1998); where L_{max} is the maximum total length measurement recorded. Growth performance indices (Φ′) were then estimated using the equation by Pauly and Munro (1984) expressed as: $\Phi' = \log_{10}(k) + 2\log_{10}(L\infty)$, where;

k = Von Bertalanffy growth coefficient and L_∞ = Von Bertalanffy asymptotic length. L_{max} is the largest length among the measured total lengths of the fish species. The longevity index (t_{max}) was estimated from the equation of (Pauly, 1984): $T_{max} = 3/K$; where K = growth coefficient. The Length-at-optimum yield (Lopt) was estimated using the formula (Pauly, 1984): $L_{opt} = L_\infty (3/(3+M/K)$; where M is the natural mortality. The Length-at-first maturity (L_{50}) was computed using the equation: Log L_{50} = 0.8776 Log ($L\infty$)- 0.38 (Froese and Binohlam, 2000).

2.2.2 Growth forms

Length-weight relationships were estimated from the allometric formula: $W = aL^b$ which was then log-transformed as: log W = log a +b log L. Where W is weight (g), L is the total length (mm), a is a constant and b is the growth form (Makeche *et al.*, 2023). If b = 3 the fish grows isometrically, then small fish in the sample under consideration have the same form and condition as large fish. If b > 3, the fish shows positive allometric growth, then large fish have increased in height or width more than in length, either as a result of a notable ontogenetic change in body shape with size (which is rare) or most large fish in the sample were thicker than small fish (which is common). Conversely, if b < 3 the fish shows negative allometric growth, then large fish have changed their body shape to become more elongated or small fish are in better nutritional condition at the time of sampling (Froese, 2006; Dalu *et al*., 2013).

2.2.3 Mortality variables

The total mortality (Z) of *P. wesselsi* was computed using the Beverton-Holt equation method. The Beverton and Holt equation (1957) is based on the mean lengths of a fish species and it is given below:

$$Z= \frac{k(L\infty - Lm)}{Lm - Lc}$$

Where: k is the growth coefficient, L_∞ is the asymptotic length, L_m is the mean length of the catch samples, L_c is the smallest length among the measured total lengths of the fish specimens and Z is the total mortality.

Total mortality (Z) is made up of two components: the fishing mortality (F) and the natural mortality (M) (Gulland, 1982) and it is expressed as follows: Z = M + F.

The natural mortality (M_w) of *P. wesselsi* was determined from the equation: $M_w = 1.92\ year^{-1} *(W)^{(-0.25})$ (Peterson and Wroblewski (1984); where, M_w = natural mortality at mass W; and $W = a*L^b$, a and b are the regression variables of length and weight (total length against body weight).

The fishing mortality (F) was calculated using the equation: F = Z-M.

2.24 Levels of Exploitation

Using the estimated values of total mortality and natural mortality above, the level of exploitation (E) was then determined from the formula of Gulland (1982) as given below:

$$E = \frac{Z - M}{Z}$$

Where Z is the total mortality coefficient and M is the natural mortality coefficient.

Values of exploitation ratios were used to determine whether or not the fish stocks in the Kafue Floodplain fishery are over-exploited. An exploitation value of 0.5 denotes optimal exploitation; an exploitation value above 0.5 denotes over-exploitation while an exploitation value below 0.5 signifies under-exploitation.

3. Results

3.1 Growth parameters

In the Kafue Floodplain Fishery, the growth coefficient (K) which was determined among *C. quadricarinatus* ranged from a low of 0.975 to a high of 1.03 (Table 1). In Lake Kariba, the growth coefficient ranged from a low of 0.875 to 0.931. In the Kafue Floodplain Fishery, Male *C. quadricarinatus* showed a higher growth coefficient value (1.03) than Female *C. quadricarinatus* (0.975). In Lake Kariba, Male *C. quadricarinatus* growth exponent coefficients were almost at par with Males (0.931) showing slightly larger values than Females (0.93) (Table 1).

The growth performance index was higher in Males (Φ′ = 4.5) than in Females (Φ′ = 4.4) in the Kafue Floodplain Fishery. Growth performance indices were the same in Males and Females in Lake Kariba (Φ′ = 4.6).

Length-at-First-sexual Maturity (L_{50}) values ranged from a low of 37 mm among Females to a high of 38 mm in Males in the Kafue Floodplain Fishery (Table 1). The combined data showed an L_{50} of 38 mm. In Lake Kariba, (L_{50}) values ranged from a low of 44 mm among Males to a high of 47 mm among Females.

In the Kafue Floodplain Fishery, the longevity index (T_{max}) which was determined among *C. quadricarinatus* ranged from a low of 2.9 years among Males to a high of 3.1 years (Table 1). In Lake Kariba, longevity indices were the same (3.2) in both sexes (Table 1).

The Length at maximum yield (L_{opt}) (Table 1) ranged from 146 mm among Females to 149 mm among Males in the Kafue Floodplain Fishery. In Lake Kariba L_{opt} values ranged from a low of 164 mm among Male samples to 176 mm among Female samples. The combined data showed a L_{opt} value of 147 mm in the Kafue Floodplain Fishery and 171 mm in Lake Kariba.

Asymptotic length (L_∞) (Table 1) ranged from 161 mm among Females to 171 mm among Males in the Kafue Floodplain Fishery. In Lake Kariba L_∞) values ranged from a low of 204 mm among Male samples to 216 mm among Female samples. The combined data showed a L_{opt} value of 171 mm in the Kafue Floodplain Fishery and 216 mm in Lake Kariba.

3.2 Growth forms

The overall growth form (b value) of *C. quadricarinatus* in the Kafue Floodplain Fishery was 2.74. Since the determined growth form of the sampled *C. quadricarinatus* specimens in the Kafue Floodplain Fishery was less than 3, this depicts negative allometry. The growth form and the logarithmic equation which shows the length-weight relationship among *C. quadricarinatus* in the Kafue Floodplain Fishery is shown in Fig. 2.

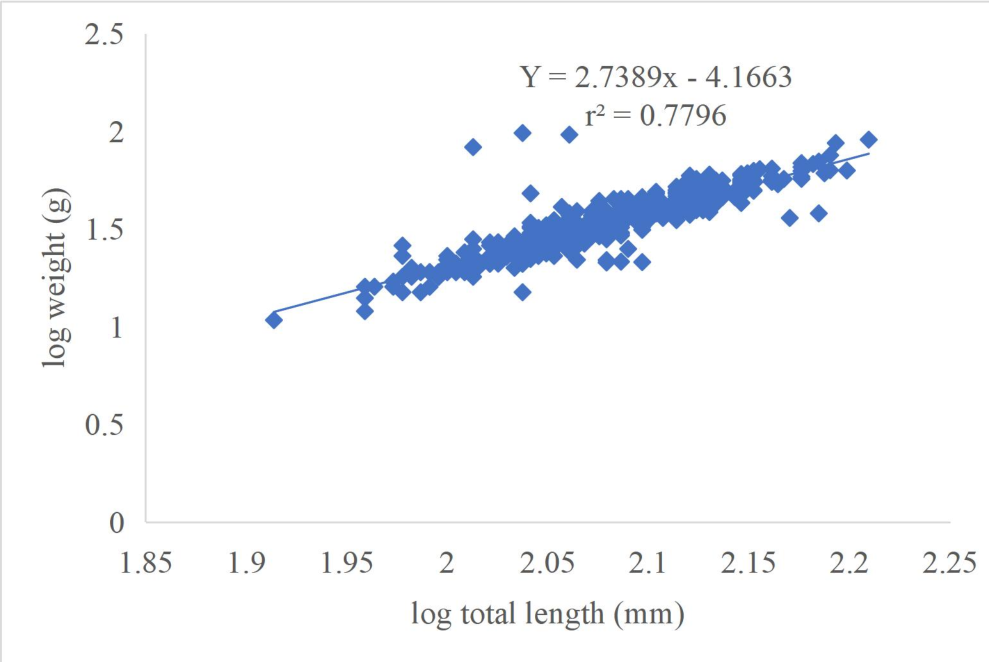


Fig. 2- Length-weight relationship of *C. quadricarinatus* in the Kafue Floodplain Fishery.

There was significant regression of length on weight ($r^2 = 0.780$) (Fig. 2).

The overall growth form (b value) of *C. quadricarinatus* in Lake Kariba was 2.49. Since the determined growth form of the sampled *C. quadricarinatus* specimens in Lake Kariba was less than 3, this depicts negative allometry. The growth form and the logarithmic equation which shows the length-weight relationship among *C. quadricarinatus* in Lake Kariba is shown in Fig. 3.

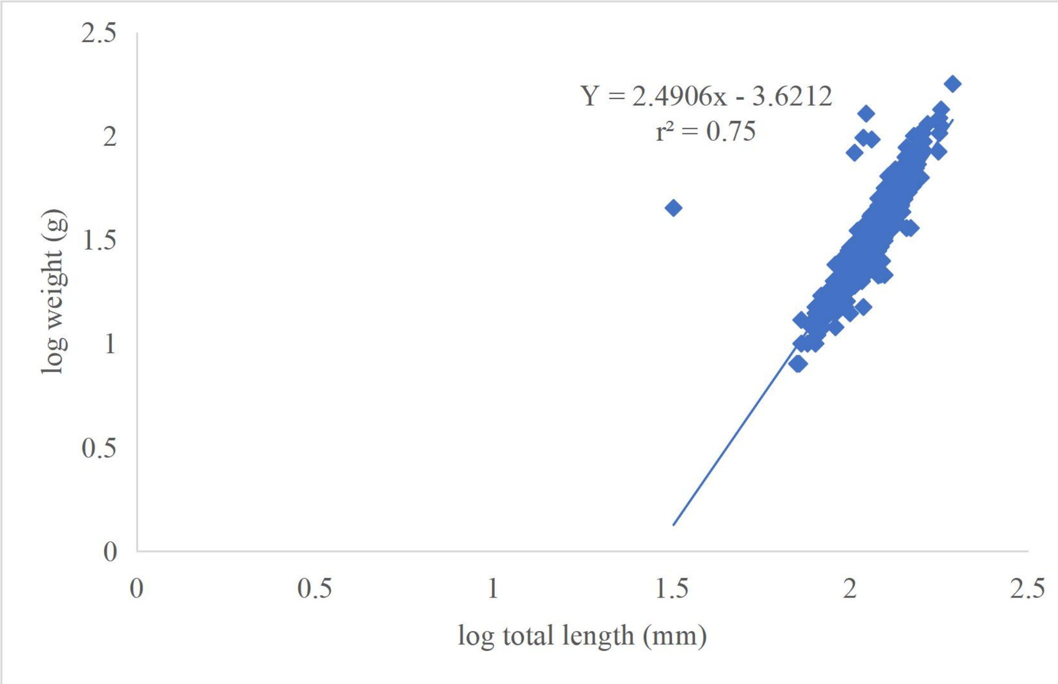


Fig. 3- Length-weight relationship of *C. quadricarinatus* in Lake Kariba.

There was significant regression of length on weight ($r^2 = 0.750$) (Fig. 3).

3.2 Mortality variables

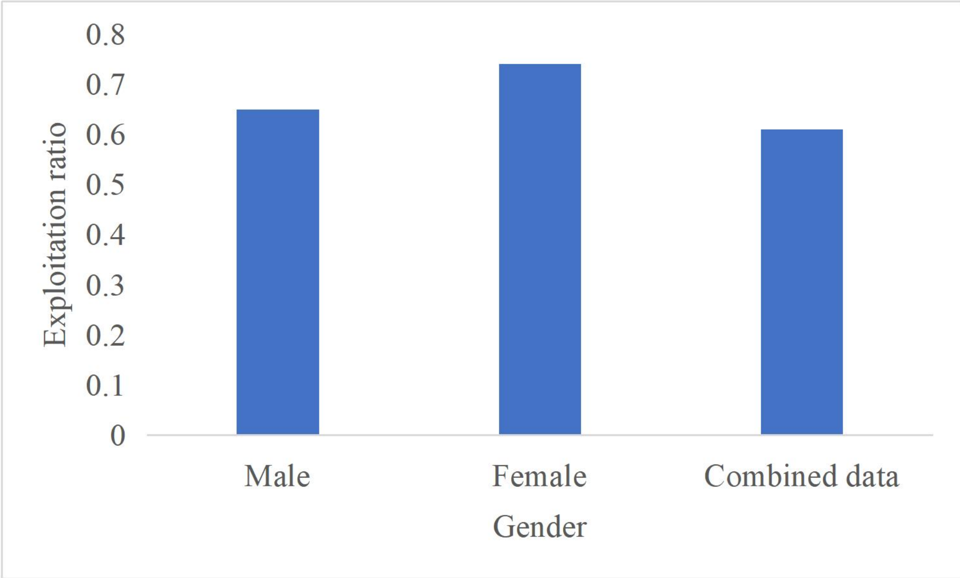
In the Kafue Floodplain Fishery, natural mortality (M) variables ranged from a low of 0.397 among Females to 0.459 among Males. In Lake Kariba, M values ranged from 0.642 in Females to 0.674 in Males. Combined values showed that natural mortality values ranged from 0.503 in the Kafue Floodplain Fishery to 0.7 in Lake Kariba (Table 1).

In the Kafue Floodplain Fishery, fishing mortality (F) variables ranged from a low of 0.861 among Male *C. quadricarinatus* to a high of 1.15 among Females. In Lake Kariba, F values ranged from a low of 0.301 among Males to a high of 0.368 among Female *C. quadricarinatus*. Combined values showed that natural mortality values ranged from 0.138 in Lake Kariba to 0.787 in the Kafue Floodplain Fishery (Table 1).

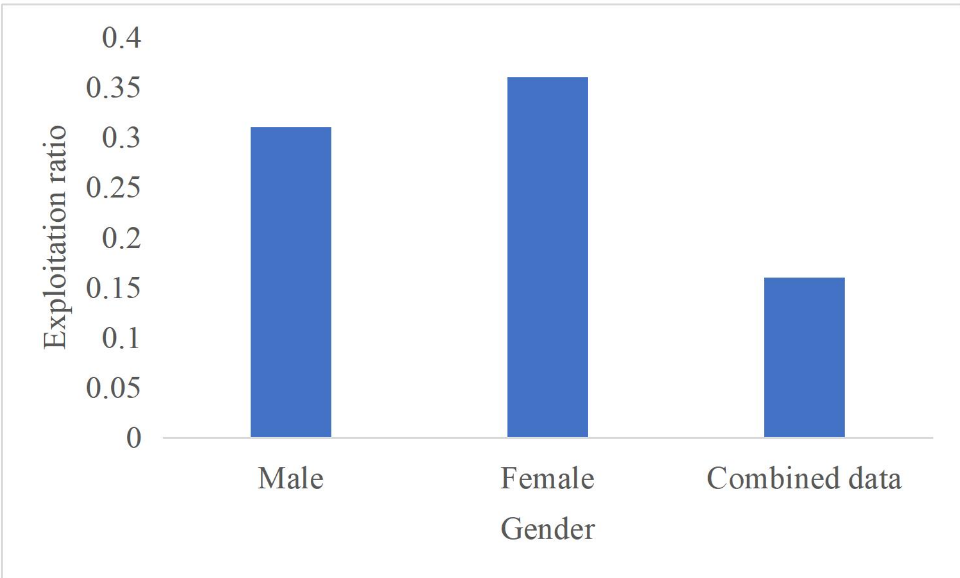
In the Kafue Floodplain Fishery, fishing mortality (Z) variables ranged from a low of 1.32 among Male *C. quadricarinatus* to a high of 1.55 among Females. In Lake Kariba, Z values ranged from a low of 0.975 among Males to a high of 1.01 among Female *C. quadricarinatus*. Combined values showed that total mortality values ranged from 0.838 in Lake Kariba to 1.27 in the Kafue Floodplain Fishery (Table 1).

3.3 Levels of Exploitation

In the Kafue Floodplain Fishery, levels of exploitation (E) variables ranged from a low of 0.65 among Male *C. quadricarinatus* to a high of 0.74 among Females (Fig. 4). In Lake Kariba, E values ranged from a low of 0.31 among Males to a high of 0.36 among Female *C. quadricarinatus*. Combined values showed that total mortality values ranged from 0.16 in Lake Kariba to a high of 0.61 in the Kafue Floodplain Fishery (Table 1).



(a)



(b)

Fig. 4 - Histograms showing levels of exploitation in the Kafue Floodplain Fishery (a) and Lake Kariba (b).

Table 1: Growth parameter indices, mortality variables and exploitation ratios of *Cherax quadricarinatus* in the Kafue Floodplain Fishery and Lake Kariba.

	Kafue														Kariba													
	L_c	L_m	L_{max}	L_∞	L_{50}	T_{max}	L_{opt}	b	Φ′	K	M	F	Z	E	L_c	L_m	L_{max}	L_∞	L_{50}	T_{max}	L_{opt}	b	Φ′	K	M	F	Z	E
Male	82	121	162	171	38	2.9	149	2.81	4.5	1.03	0.459	0.861	1.32	0.65	32	116	194	204	44	3.2	164	2.54	4.6	0.931	0.674	0.301	0.975	0.31
Female	91	120	158	166	37	3.1	146	2.66	4.4	0.975	0.397	1.15	1.55	0.74	43	126	205	216	47	3.2	176	2.54	4.6	0.93	0.642	0.368	1.01	0.36
Total	82	121	162	171	38	3.0	147	2.74	4.5	1.01	0.503	0.787	1.29	0.61	32	126	205	216	47	3.2	171	2.49	4.6	0.875	0.7	0.138	0.838	0.16

L_c = smallest length in the sample (mm), L_m = sample mean length (mm), L_{max} = Maximum length in the sample (mm), L_∞ = asymptotic length, L_{50} = Length-at-First sexual maturity (mm), T_{max} = longevity index in years, L_{opt} = Length at maximum yield (mm), b = exponent of the arithmetic form of the weight-length relationship (growth form), Φ′ = Growth performance index, K = Growth coefficient, M = natural mortality, F = fishing mortality, Z = total mortality and E = exploitation ratio.

5. Discussion

Growth coefficients (K) are very useful in knowing how fast fish approaches its asymptotic length (L_∞) because there is a strong correlation between the growth coefficient (K) and asymptotic length (L_∞) (Abdul *et al*., 2019; Mukuka, 2019). Zhang and Megrey (2006) generalized that long-lived fish species approaches their limiting sizes earlier than short-lived fish species. Spare *et al*. (1989) stated that K values greater than or equal to 1 are for short-lived species. Henceforth, the K values of this research (Kafue Floodplain Fishery = 1.01 yr^{-1}, Lake Kariba = 0.875 yr^{-1}) indicate that *C. quadricarinatus* is a long-lived species. The results of the current research are in conformity with previous research on Lake Kariba by Marufu *et al*. (2018) (K = 0.72 yr^{-1}) and Mukuka (2019) (K = 0.65 yr^{-1}) from the Zambezi River. The results of the current research are also within the range of results found on different fish species. Hotos and Katselis (2011) found similar growth coefficients (K = 0.8) among *C. planiceps* in Greece just like Panda *et al*. (2018) found above-average values (K = 0.98) among Mullets in Lake Chilika, India. Furthermore, Murugan *et al*. (2014) established that Male *Mugil cephalus* grow faster than Female species (Male K = 0.95yr^{-1}; Female K = 0.82yr^{-1}). This study has also shown that Males (K = 1.03 $yr^{-1}$from Kafue and K = 0.931 yr^{-1} from Kariba) grow faster than Females (K = 0.975 $yr^{-1}$from Kafue and K = 0.93 yr^{-1} from Kariba).

The growth performance index (Ø) is a function of both the growth coefficient (K) and asymptotic length (L_∞). The growth performance index is directly proportional to the growth coefficient but inversely proportional to the asymptotic length (Yongo and Outa, 2016). It is very important to determine the growth performance index in order to validate other growth parameters because the value of the growth performance index gives a good indication of the reliability of the estimated growth parameters (Sparre & Venema, 1998; Panda *et al*., 2018). The results of the current research are similar to those obtained by Mudenda *et al*. (2024) among *Cherax qudricarinatus* (Ø ranged between 4.3 to 4.4) and Nyirenda *et al*. (2024) among tilapiines (Ø ranged between 4.36 to 4.98). Makwelele (2017) (Ø = 2.7 to 2.85), Marufu *et al*. (2018) (Ø = 3.96) and Mukuka (2019) (Ø = 4.11) all obtained smaller growth performance values among *C. quadricarinatus* from the Kafue Floodplain Fishery, Lake Kariba and Zambezi River. The difference between the current results and those obtained by other researchers can be attributed to the difference in the study areas and the time of sampling.

The size at first sexual maturity (L_{50}) is very important for fish stock assessment because it gives an indication of the minimum permissible capture size (Hossain *et al*., 2019; Saha *et al*., 2021). It is affected by at least three factors: demographic structure, resource availability, and size selective predation (Belk, 1995). Different species have different L_{50} values (Nyirenda, 2017). L_{50} results of the current research from the Kafue Floodplain Fishery, agree with results found by Nyirenda (2017) in Zambia which showed that Females attain sexual maturity earlier than Males. The current results from Lake Kariba agree with Abujam (2011), who found that Male Spiny eels (L_{50} = 10.1cm) attain sexual maturity earlier than Females (L_{50} = 14-18 cm). The size at first sexual maturity (L_{50} = 38 mm in the Kafue Floodplain Fishery and 47 mm in Lake Kariba) results of this study are within the range of results found by Marufu *et al*. (2018) (L_{50} = 44.5 mm) but they are smaller than those found by Mukuka (2019).

This study showed that the Length-at-optimum yield (L_{opt}) for *C. quadricarinatus* was 147 mm in the Kafue Floodplain Fishery and 171 mm in Lake Kariba. This study is thus the first effort to document the Length-at-optimum of *C. quadricarinatus* in Zambian aquatic ecosystems. Consequently, it provides baseline information for additional research for fisheries biologists. Saha *et al*. (2021) found a smaller Length-at-optimum (L_{opt} = 60 mm) value among *Trichogaster ladius* while Abdul *et al*. (2019) (L_{opt} = 250 mm) found a larger value among *Sarotherodon galilaeus*, implying that L_{opt} values are species-dependent because the Length-at-optimum yield depends on the growth rate of species (Saha *et al*., 2021).

The longevity index results (T_{max}) of the current study (T_{max} = 3.0 years to 3.2 years) are smaller than results obtained by Marufu *et al*. (2018) (T_{max} = 4.17 years) and Mukuka (2019) (T_{max} = 4.11 years). These differences can be attributed to differences in habitat productivity. The current results are similar to those obtained by Abdul *et al*. (2019) (T_{max} = 3.70 years among *Sarotherodon galilaeus*. Nyirenda (2017) (T_{max} ranged from 1.23 years to 3.01 years) obtained smaller longevity values. These differences are expected because various species have different growth coefficients. Growth coefficients are also determined by nutrient availability (Abdul *et al*., 2019).

The natural mortality (M) results of the current study (M = 0.5 yr^{-1} in the Kafue Floodplain Fishery and 0.7 yr^{-1} in Lake Kariba) are within the range of values found by Makwelele (2017) (M = 0.05 yr^{-1} to 0.8 y-1). The current natural mortality results are however, smaller than natural mortality results obtained by Marufu *et al*. (2018) (M = 0.99 yr^{-1}) and Mukuka (2019) (M = 1.45 yr^{-1}). The fishing mortality (F) results of this study are smaller than results obtained by Makwelele (2017) (F = 2.5 to 4.0), Marufu *et al*. (2018) (F = 1.07 yr-*1*) and Mukuka (2019) (F = 3.35 yr^{-1}). The exploitation ratios obtained from the Kafue Floodplain Fishery are within the range of results obtained by Marufu *et al*. (2018) (E = 0.52 yr^{-1}) and Mukuka (2019) (E = 0.7yr^{-1}). The exploitation ratios are however, smaller than those obtained by Makwelele (2017) (E = 0.972 to 0.934). The difference in results between the current study and those of Marufu *et al*. (2018) and Mukuka (2019) is mainly attributed to the method of determination used. Mukuka (2019) used the length-frequency (Pauly, 1979) method while the current study used the length-weight method (Peterson and Wroblewski (1984). The length-frequency method tends to over-estimate values of natural mortality because it is difficult to capture a representative length-frequency sample (real size distribution of the population) even with a large sample size due to gear selectivity (Mukuka, 2019). This has a compounding effect on von Bertalanffy growth parameter estimations, and consequently on natural mortality (M) and total mortality (Z) estimations. The length-frequency method also over-estimates total mortality variables (Z) when seasonal growth is considered (Pauly, 1990). The difference between the current results and results obtained by Makwelele (2017) is attributed to the time of study. The two studies were conducted during different times of the year.

5. Conclusion

Cherax quadricarinatus exhibited optimal growth, typical of an invasive species. The above-average growth coefficients, coupled with the below-average to marginally above-average natural mortality variables suggest not only good adaptation to the environment, but potential increase in population size.

6. Recommendations

Similar studies should be conducted in other aquatic habitats in order to have a wide basis for comparisons.

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