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Research Article

Epinephelus Genus Groupers Population Structure and Length-Weight Relationships off Kenyan South Coast Indian Ocean Marine Waters

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Abstract

Groupers are apex predatory fishes playing important local economic roles and ecosystem functions worldwide. The Kenyan coast Indian Ocean waters have been a good landing centre for nearly 30% of the already identified 98 *Epinephelus* genus species groupers. However, of late, their natural populations have greatly decreased with the landed individuals mean length and weights showing drastic reductions. Most are therefore caught when either juveniles or sub adults. Information data is therefore needed to avert this alarming decline and initiate conservation measures for these prized premium fishes. This study elucidates the *Epinephelus* genus groupers population structures and length-weight relationship analyses for these highly sought fishes from Kenyan inshore marine waters. The study results indicated varying significant conditions ($p<0.001$) for these species having Length-Weight Relationship (LWR) regression coefficients (R^2) that appeared to be stronger ($R^2>0.6000$) for 23 species. Despite this apparently strong fit, Analysis of Covariance (ANCOVA) revealed no significant differences between (a) intercept and (b) slopes of the species regression lines ($p = 0.5552$). R^2 analyses also showed consistent non isometric patterns in the plotted power curved data suggesting that unless stringent management measures are implemented to restrict over-exploitation, it is likely that the species currently categorized as 'Near Threatened' under the International Union for Conservation of Nature (IUCN) Red list would soon become 'Endangered' while those 'Endangered' extinct. This can greatly alter the ecosystems' ecological health as they are apex predators in the demersal food web and their stock depletions would result in the alteration of the ecosystem.

Key words: *Epinepheline* fishes, endangered, length and weights, conditions, Indian Ocean marine waters

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INTRODUCTION

Marine biodiversity loss threat is increasing worldwide due to overfishing, climate change and habitat destruction. This vulnerability threat has been more apparent to fishes because of the changing fishing patterns; excessive fishing of unwanted by-catch; illegal fishing; excessive fishing of the fishes before attainment of first maturity lengths; use of fishing techniques that harm both the environment and fish stocks among other factors. Conservation of vulnerable and threatened fish species has thus gained great global ecological importance over recent years. As a result, the fish's life-history characteristic knowledge is of great importance for effective implementation of sound conservation management strategies[1-3].

The Kenyan Indian Ocean marine waters homes 30 species apposite for human utilization out of the 98 known *Epinephelus* genus grouper species[3-5]. These genus groupers belong to the Epinephelidae subfamily in the Serranidae family and are widely distributed in Hawaii waters, Indo-west Pacific, Red Sea, Philippines, Southern Japan and in Eastern Africa where they are popularly known as groupers or rock cods[5]. Majority are long lived, slow growers and have lower fecundities in addition to forming spawning aggregations which are heavily exploited by both small and large-scale fishers[6-9].

The fishes constitute important components of the demersal fishery resources that are main targets of commercial fishers in both tropical and sub-tropical waters worldwide. As a result, the genus fishes are important components of the inshore small-scale fisheries along the Eastern coast of Africa where they are locally known as "Tewa" or Rock cods. However, a recent[10] United Nations Environmental Programme (UNEP)-Nairobi Convention in conjunction with Western Indian Ocean Marine Science Association (WIOMSA), reported that an estimated 1,900 bony fish species including some *Epinephelus* genus groupers are threatened within the region[11]. Despite this threatened status, they are still target species of the rural fisher folks within the Western Indian Ocean (WIO) region for income, fish protein and micronutrients. This, in addition to various ecological and environmental degradation changes of the natural habitats within the region, has resulted in serious population declines with some almost being driven to the verge of extinction[11].

The current global rate of grouper exploitation and mortality is also arguably the highest under current management regimes that unless a renewed initiative is undertaken, some species will become effectively extinct[2] and creating shifts in the biological communities with resultant systemic biodiversity losses[12]. Thus, given the vulnerability of the fishes even to modest fishing efforts due to their slow growth rates, late maturity, low fecundity and long life spans, potential recovery of their populations to overharvesting can take decades and human decisions regarding them is a crucial element of marine-related social science[13].

A fish's Length-Weight Relationship (LWR) is an important fishery management tool in fisheries biology and stock assessments in all water bodies as it enables the determination of fish age, structure and health by providing various facts about its seasonal cycles and influential aspects of the biotic and abiotic factors[14]. This is because an average fish weight of a given length group can easily be estimated by establishing a mathematical relation between length and weight parameters[15]. They also show an indication of the fish's gonad development and are useful for regional comparisons and specific species histories[16]. In addition, the data also provides important clues on climate, environmental and human subsistence changes[16,17] that help in predicting the best suited time and length for harvesting particular fish species[18,19].

Therefore, with no information existing currently on the *Epinephelus* genus groupers' population structure and length-weight relationships off the 97 entire Kenyan Indian Ocean Marine Waters, the study presents the first study on population structure and length-weight relationships of these vulnerable fish species in Kenya using a one year collected length and weight morphometric data.

MATERIALS AND METHODS

The study was conducted within the inshore small-scale marine fishing areas of Msambweni (S04°30'31.26", E039°28'12.97") lying about 70 km south of Kenyan Mombasa city; Shimoni (S 04°38'52.67", E 039°22'50.55") of which part of its traditional fishing grounds has been hived off and gazetted as a marine protected area under the Kisite-Mpunguti Marine National Park and Reserve and Vanga (S04°40'16.11", E039°13'36.96") which its fishing grounds and village is situated on the southern tip of Kenya-Tanzanian border in the Kenyan south coast (Fig. 1). The study sites were selected based on the existence of previous grouper studies undertaken from there; their high grouper fishers and fisheries activity coefficient within south coast of Kenyan and lastly, for being the most pristine and sheltered reefs on the Kenyan coast making them key grouper fishing areas.

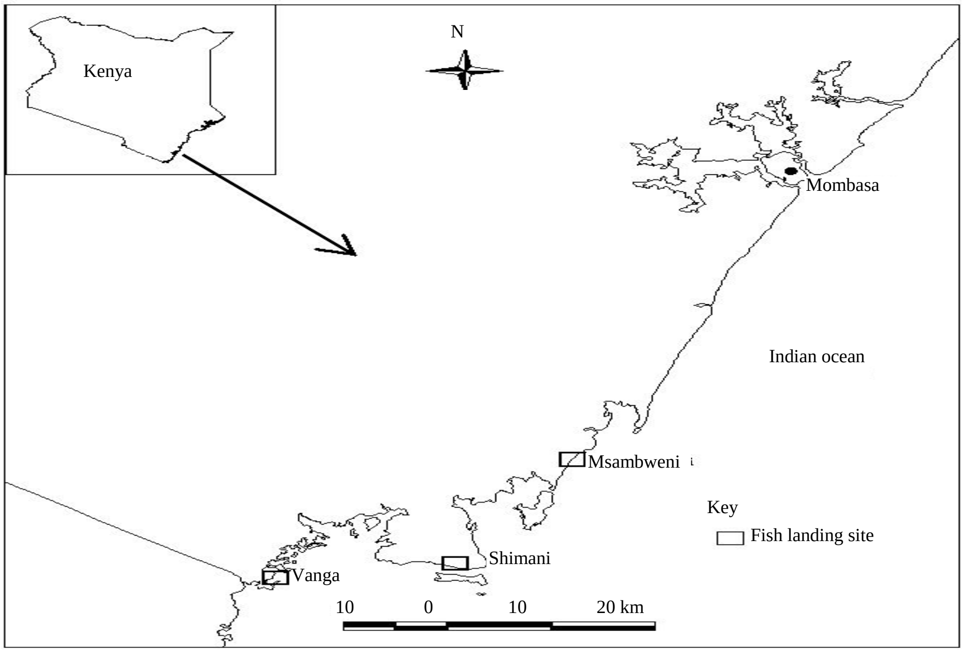

Fig. 1: Study landing sites map of Vanga, Shimoni and Msambweni

Field sampling and laboratory work was conducted from December, 2013 to November, 2014. The *Epinephelus* genus grouper specimens were purchased from the small-scale artisanal fishery catches landed at the sites. Purchased freshly landed catches were immediately chilled in ice on site and transported to Kenya Marine and Fisheries Research Institute (KMFRI) Mombasa Laboratory for analyses. At the laboratory, the specimens were sorted and identified to species level using keys and guides from Anam and Mostarda[4] and Heemstra and Randall[5]. The already identified specimens Total length and Weights were then individually measured and recorded. Total Length (TL) was measured to the nearest 0.01 cm using digital slide calipers (Mitutoyo, CD-15PS) and total body weight (W) was measured using an electronic balance (Shimadzu, EB-430DW) with 0.01 g accuracy. All morphometric measurements were conducted according to Froese and Pauly[20]. Length and sex-ratio distributions were also constructed separately for the species specimens and only those with more than one individual landing were used for sex-ratio determinations. Each species lengths were categorized from the smallest to the largest to determine the existing ranges. The isometric (b = 3) or allometric growth relationship between total length (TL, cm) and total body weight (W, g) was described for these fishes growing with their bodies becoming heavier using a plotted power function; $W = a*TL^b$ in which a is the power function coefficient (the regression intercept) and b the exponent (the regression slope). The relationships were estimated by linear regression analyses based on natural logarithms: ln (W) = ln (a)+b ln (TL). Prior to the analyses, ln-ln plots of length and weight values were performed for visual inspection of outliers in accordance to Froese[21]. Growths' were considered positively allometric if the estimate of b was approximately equal or greater than 3 and negative if less than 3. Fulton's condition factor (KF)[22] was calculated using the equation:

$$KF = 1000\times(W\times L^{-3})$$

where, W is the total body weight (W, g) and L the total length (TL, cm). The scaling factor of 1000 was used to bring the KF close to unit for all the species.

The non parametric Chi-square goodness-of-fit test was used to test for significant deviations from the expected 1:1 male to female ratio and also to compare the species numbers within the study sites using MINITAB release 14 software. In addition, the plotted LWRs were power tested using the coefficient of regression (R^2) to determine significant differences from the isometric value of b = 3 using Microsoft® Excel-add-in-Daniel's XL Toolbox spreadsheet computer package. The a and b parameters of the species LWRs were also compared by covariance (ANCOVA) analysis and all statistical significance tests determined at $\alpha = 0.05$.

RESULTS

The species population abundance of the encountered thirty *Epinephelus* genus groupers were generally lower and had skewed distribution patterns within the study sites. As a result, some species were not landed in certain sites and where landed, were less than 5 individuals. However, significant difference (p-value = 0.030) existed on the total distribution abundance of all pooled landed specimens at the sites (Table 1). Their lengths, weights and sexes were also as tabulated in Table 2. The obtained length and weight data for 25 species with more than two individual landings were plotted and power tested using regression coefficients of determination (R^2) to determine if their length-weight growth relationships were isometric (b = 3), or allometric (b<or>3). All twenty five of the species had negative allometric growth relationships where b<3 with only two species; one large bodied species, *E. fuscoguttatus* (with maximum adult growth length size of 120 cm) (Fig. 2a) and one small bodied species, *E. miliaris* (with maximum adult growth length size of 43 cm)

Table 1: Landed pooled genus species abundance and distribution patterns within sites

Pooled landed genus species according to their maximum growth characteristics	Msambweni	Shimoni	Vanga	N	χ^2	p-value
Small and medium sized genus species	45	162	76	283	2.055	0.416
Large sized mobile genus species	32	61	25	118	4.926	0.085
Total	77	223	101	401	6.981	0.030

[a]N: Numbers landed, p-value (probability of significance at α = 0.05)

Table 2: Landed genus species numbers, lengths (cm), weights (g) and sex data

		Lengths (cm)							
		TL		SL		Weights (g)		Sex	
Landed genus species	No.	Min.	Max.	Min.	Max.	Min.	Max.	F	M
Msambweni data sheet									
Epinephelus chabaudi	1	-	36.5	-	31.0	-	615	1	0
Epinephelus chlorostigma	3	14.0	17.6	12.1	14.9	265	295	2	1
Epinephelus coeruleopunctatus	5	14.0	36.5	9.0	29.6	260	682	4	1
Epinephelus diacanthus	2	10.0	14.0	7.5	11.5	199	250	2	0
Epinephelus epistictus	2	57.7	60.5	35.8	49.5	650	850	1	1
Epinephelus fasciatus	10	18.5	20.8	14.2	16.3	302	395	8	2
Epinephelus flavocaeruleus	8	20.5	30.5	16.8	26.8	299	359	6	2
Epinephelus fuscoguttatus	3	45.5	65.2	37.6	56.2	804	2804	2	1
Epinephelus hexagonatus	4	10.0	18.5	8.0	15.9	200	395	3	1
Epinephelus longispinis	6	10.0	12.4	7.9	10.1	199	262	4	2
Epinephelus malabaricus	4	35.8	70.6	29.5	65.0	480	985	3	1
Epinephelus melanostigma	2	15.0	28.1	12.8	23.2	299	369	2	0
Epinephelus merra	1	-	36.6	-	31.2	-	612	1	0
Epinephelus morrhua	1	-	57.5	-	49.6	-	650	1	0
Epinephelus multinotatus	5	18.0	29.0	14.9	24.6	386	760	3	2
Epinephelus socialis	1	-	16.0	-	13.4	-	304	1	0
Epinephelus spilotoceps	6	12.3	14.0	9.8	11.4	290	350	4	2
Epinephelus tauvina	4	22.5	25.2	16.9	20.4	299	304	3	1
Epinephelus tukula	8	25.0	55.0	22.2	47.2	600	656	6	2
Epinephelus undulosus	1	-	36.5	-	31.0	-	630	1	0
Total	77	-	-	-	-	-	-	58	19
Shimoni data sheet									
Epinephelus areolatus	20	11.5	28.1	9.4	23.2	240	369	16	4
Epinephelus bentoides	4	12.8	16.0	10.2	13.4	265	300	3	1
Epinephelus chlorostigma	10	14.0	17.6	12.1	14.9	265	295	8	2
Epinephelus coeruleopunctatus	18	15.9	36.5	12.7	29.6	285	682	14	4
Epinephelus coioides	12	18.0	22.8	15.0	18.2	298	502	8	4
Epinephelus diacanthus	4	10.0	14.0	7.5	11.5	199	250	3	1
Epinephelus fasciatus	26	12.8	22.4	10.2	18.4	288	489	16	10
Epinephelus fuscoguttatus	3	62.5	77.9	55.0	69.9	680	1350	2	1
Epinephelus hexagonatus	10	11.5	14.0	9.6	11.6	240	245	8	2

Table 2: Continue

		Lengths (cm)							
		TL		SL		Weights (g)		Sex	
Landed genus species	No.	Min.	Max.	Min.	Max.	Min.	Max.	F	M
Epinephelus lanceolatus	4	20.0	43.9	16.9	35.4	352	1210	3	1
Epinephelus longispinis	13	10.0	18.4	8.0	10.1	199	362	10	3
Epinephelus macrospilos	10	11.5	28.1	9.4	23.2	240	369	8	2
Epinephelus malabaricus	20	20.0	43.9	16.9	35.4	325	1110	16	4
Epinephelus melanostigma	3	15.0	28.1	12.8	23.2	299	369	2	1
Epinephelus merra	10	13.0	18.3	10.9	15.1	200	398	6	4
Epinephelus miliaris	4	18.2	23.0	14.9	19.8	299	535	3	1
Epinephelus multinotatus	17	17.4	22.9	13.9	16.9	445	508	15	2
Epinephelus poecilonatus	6	13.6	28.6	11.4	26.5	300	430	5	1
Epinephelus polyphekadion	1	-	49.5	-	42.4	-	659	1	0
Epinephelus rivulatus	6	10.0	14.0	7.5	11.5	199	250	4	2
Epinephelus spilotoceps	8	12.3	14.0	9.8	11.5	285	346	6	2
Epinephelus tauvina	10	12.0	17.5	9.9	14.5	235	299	8	2
Epinephelus tukula	4	25.0	55.0	22.2	47.2	600	656	3	1
Total	223	-	-	-	-	-	-	168	55
Vanga data sheet									
Epinephelus acanthistus	4	18.0	32.3	14.9	26.2	302	476	4	0
Epinephelus areolatus	6	17.5	41.4	14.5	34.1	412	996	4	2
Epinephelus chlorostigma	8	14.0	17.6	12.1	14.9	265	295	6	2
Epinephelus coeruleopunctatus	8	26.8	30.2	23.6	27.4	308	525	6	2
Epinephelus coioides	3	20.1	24.6	17.9	21.4	306	598	3	0
Epinephelus epistictus	3	41.4	66.7	34.1	57.7	996	1350	2	1
Epinephelus fasciatus	18	15.6	18.0	13.1	15.0	318	405	16	2
Epinephelus fuscoguttatus	1	-	66.2	-	57.7	-	1050	1	0
Epinephelus lanceolatus	2	25.0	45.5	22.9	37.6	685	1338	2	0
Epinephelus longispinis	9	10.0	18.4	8.0	10.1	199	362	8	1
Epinephelus macrospilos	4	12.0	28.9	7.9	23.2	245	375	3	1
Epinephelus malabaricus	12	30.0	43.9	27.9	35.4	600	1150	10	2
Epinephelus melanostigma	2	15.0	28.1	12.8	23.2	299	369	2	0
Epinephelus merra	6	13.0	36.6	10.0	31.2	200	612	4	2
Epinephelus miliaris	9	18.2	23.6	14.9	20.0	299	565	7	2
Epinephelus multinotatus	2	18.0	21.0	14.9	17.0	386	458	2	0
Epinephelus tauvina	2	24.8	26.5	20.9	22.8	301	430	1	1
Epinephelus tukula	2	23.9	25.0	22.0	23.2	300	600	2	0
Total	101	-	-	-	-	-	-	83	18

F: Female, M: Male, Min: Minimum, Max: Maximum, TL: Total length, SL: Small length

(Fig. 2b) having allometric growth relationships where b ≈ 3 (Table 3). The species calculated Fulton's condition (KF) factor values also showed significant variations ($p<0.01$) with the best and worst performers being *E. spilotoceps* with 127.551 and *E. epistictus* (2.856), respectively (Table 3).

The observed minimum total length among the 401 sampled specimens ranged from 13-31 cm for the small and medium sized species with majority being slightly above 22 cm. The mobile and larger bodied species on the other hand sizes ranging from 17.4-77.9 cm with most being slightly above 57 cm (Table 2). However, secondary maturity data obtained from published literature was used to determine if the landings comprised of immature fishes since the present study's data could not allow estimation of first maturity sizes.

DISCUSSION

The Kenyan IUCN red list threatened fishes biometric information has been quite insufficient despite a number of studies having been conducted within the Asian countries[9,18,19,23-28]. In this study, the size structures of 17 species (*E. areolatus*, *E. coeruleopunctatus*, *E. chlorostigma*, *E. coioides*, *E. fasciatus*, *E. hexagonatus*, *E. longispinis*, *E. macrospilos*, *E. malabaricus*, *E. melanostigma*, *E. merra*, *E. miliaris*, *E. multinotatus*, *E. poecilonatus*, *E. spilotoceps*, *E. tauvina* and *E. tukula*) demonstrated some marked length size class range differences (Table 3). The differences may be particularly attributed to environmental water temperature and food availability variations[29] thus signaling the need for urgent extensive studies on the entire genus species to provide more management and conservation information.

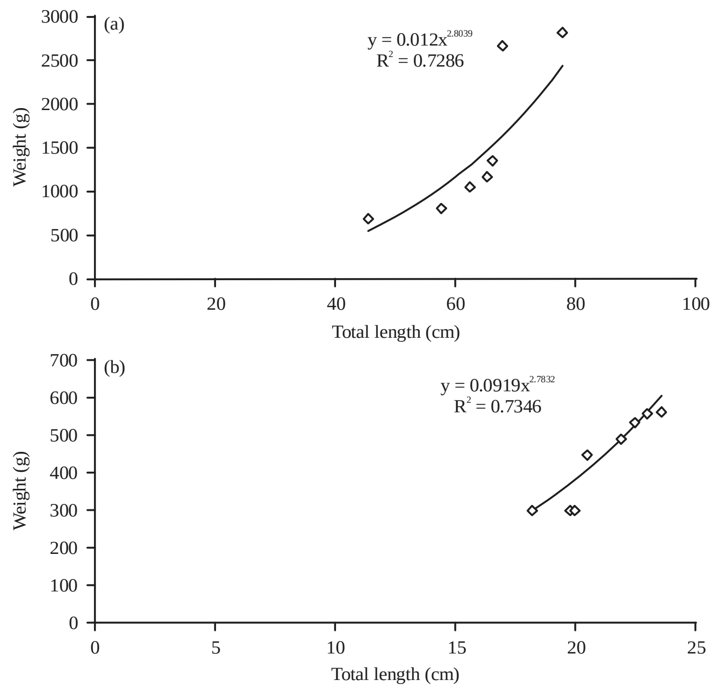

Fig. 2(a-b): Total length-Weight relationship for (a) *Epinephelus fuscoguttatus* and (b) *Epinephelus miliaris*

Table 3: General species length-weight relationship (LWR) and condition estimates

Landed genus species	N	Weight-length equation	R^2	Relationship	KF
E. acanthistus	4	$W= (3.19\times10^{1})\ L^{0.7798}$	0.9983	Allometric	14.257
E. areolatus	26	$W= (2.93\times10^{1})\ L^{0.8918}$	0.8521	Allometric	14.036
E. bentoides	4	$W= (6.55\times10^{1})\ L^{0.554}$	0.9002	Allometric	73.242
E. chlorostigma	21	$W= (8.22\times10^{1})\ L^{0.4428}$	0.9388	Allometric	54.111
E. coeruleopunctatus	31	$W= (1.56\times10^{1})\ L^{1.0453}$	0.9845	Allometric	14.025
E. coioides	15	$W= (0.02\times10^{1})\ L^{2.4721}$	0.7574	Allometric	40.663
E. diacanthus	6	$W= (3.85\times10^{1})\ L^{0.7067}$	0.9595	Allometric	91.108
E. epistictus	5	$W= (0.51\times10^{1})\ L^{1.2671}$	0.6137	Allometric	2.856
E. fasciatus	10	$W= (4.62\times10^{1})\ L^{0.696}$	0.7048	Allometric	43.508
E. flavocaeruleus	8	$W= (8.10\times10^{1})\ L^{0.4289}$	0.9593	Allometric	12.653
E. fuscoguttatus	5	$W= (0.001\times10^{1})\ L^{2.8039}$	0.7286	Allometric	5.932
E. hexagonatus	14	$W= (2.78\times10^{1})\ L^{0.83}$	0.8207	Allometric	62.385
E. lanceolatus	6	$W= (0.23\times10^{1})\ L^{1.71}$	0.8365	Allometric	14.204
E. longispinis	28	$W= (2.40\times10^{1})\ L^{0.961}$	0.8426	Allometric	58.111
E. macrospilos	14	$W= (1.05\times10^{2})\ L^{0.3797}$	0.8869	Allometric	15.536
E. malabaricus	36	$W= (0.93\times10^{1})\ L^{1.1826}$	0.8910	Allometric	3.268
E. melanostigma	7	$W= (1.33\times10^{2})\ L^{0.3021}$	0.9527	Allometric	16.631
E. merra	17	$W= (1.74\times10^{1})\ L^{0.0103}$	0.9439	Allometric	12.586
E. miliaris	13	$W= (0.01\times10^{1})\ L^{2.7832}$	0.7346	Allometric	42.985
E. multinotatus	24	$W= (1.09\times10^{1})\ L^{1.2377}$	0.8299	Allometric	31.162
E. poecilonatus	6	$W= (6.94\times10^{1})\ L^{0.5798}$	0.8796	Allometric	18.381
E. rivulatus	6	$W= (3.38\times10^{1})\ L^{0.7612}$	0.9658	Allometric	91.108
E. spilotoceps	14	$W= (1.39\times10^{1})\ L^{1.2}$	0.7688	Allometric	127.551
E. tauvina	16	$W= (1.08\times10^{2})\ L^{0.3352}$	0.4947	Allometric	23.106
E. tukula	14	$W= (1.59\times10^{2})\ L^{0.3754}$	0.2313	Allometric	3.943

N: Numbers of the landed individual species, R^2: Regression coefficients of determination, KF: Fulton's condition factor value

Overall, the species catches and abundance declines are suspected to have resulted from increases in fishing effects and effort due to increased demand for food. It could have been also a reflection of different species settlement histories as evidenced by their modal size class structure differences that were mostly below the reported most groupers first maturity sizes[30,31]. Conversely, the observed species dominance and distribution may have been also due to their ability differences to deal with extreme physical site conditions. This was evidenced by the non-significant distributions between the small and medium sized (χ^2 contribution = 2.055; 1 df; p-value = 0.416) and the larger sized mobile groupers (χ^2 contribution = 4.926; 1 df; p-value = 0.085) (Table 1).

Nearly all species of fish LWR is expressed by the equation: $W = a*L^b$ and the change in weight can be described by the relationship. Thus, in cases where the relationship regression slope b<3 or >3, growth is said to be allometric and the fish becomes less rotund when b<3 or more rotund when b>3 with increasing length. However, when b = 3, growth is said to be isometric and the fish grows with unchanged specific gravity and body proportions. It is however also possible for shape to change when b = 3 as a result of changes in the regression intercept "a"[22,32] making the estimated LWR parameters also to differ among seasons and years due to physicochemical characteristics of the environment, sex and maturity stages of a given fish species. This isometric relationship departure may however be minor for some early life history aspects but may become more important in the calculation of metabolic processes as was stated by Cone[22] and Laurence[33]. As a result, fish condition studies assume that heavier fishes are often of better conditions and condition indices have been frequently used by fish culturists as indicators of the general population 'well-being or fitness'.

This study's results therefore provide the much needed information required for future comparisons and urgent detection of any long-term declines in the conditions that may have occurred as a result of environmental degradation, key physiological components of the fish's life history and growth.

CONCLUSION

This study provides important baseline information for the Kenyan *Epinephelus* genus groupers LWR and conditions needed by fishery biologists, managers and conservationists' for initiating early management strategies and future studies for the remaining stocks of these endangered fishes within Kenyan Marine ecosystems. Moreover, the LWR and condition information for these genus species in Kenya are clearly lacking from literature and data bases including those of FishBase. The results therefore provide invaluable information for the online FishBase database.

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