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Estimation of the weight-length relationship and condition factor of three main fish species in the coastal region of the southern zone of São Tomé and Principe Island

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Abstract
This study was developed with the objective to estimate the Length-Weight Relationship (LWR) and condition factor of three main fish species collected by artisanal fishermen in the coastal region and in the mangroves of the South zone of São Tomé Island. This study focused on species of greater economic value and importance; these species are: *Dentex macrophthalmus*, *Lethrinus atlanticus*, and *Lutjanus fulgens*. The sampling duration was between March and October, 2019, using hand line, bottom longline, and vertical longline gears. Potential regression analysis was performed to study the length-weight relationship $W = a.FL^b$; and the respective exponential equations for the LWR relationship are *Dentex macrophthalmus* (Wt = 0,0152 (FL)^{2,9801} *Lethrinus atlanticus* (Wt = 0,0159 (FL)^{2,9778}, *Lutjanus fulgens* (Wt 0,0115 (FL)^{3,0581}. In the present study, the results revealed that *Lutjanus fulgens* showed an isometric growth pattern (b = 3); *Dentex macrophthalmus* and *Lethrinus atlanticus* showed a negative allometric growth pattern (b = 2.9 and b = 2.9). Studies on the condition factor revealed that variations in K values can be attributed to the spawning cycle, the intensity of feeding, and seasonality. The condition factor ranged from 0.013 (*Lutjanus fulgens*) to 0.015 (*Lethrinus atlanticus*). This study provides new records of maximum fork length in Fish Base for the three species: *Dentex macrophthalmus* (32 cm), *Lutjanus fulgens* (39.5 cm) and for *Lethrinus atlanticus* (37 cm). It is recommended to review the legislation considering the length at first capture (FL_{50}) values of the present study as a measure of protection for this resource in the coastal regions of the South of São Tomé Island.

Keywords: condition factor, weight-length relationship, fisheries management

Introduction

The order of Perciforms, also called *Percomorpha* or *Acanthopteri*, includes about 40% of all bone fish and constitute the largest order of fish. In this order, about 7000 different species are classified, present in almost all aquatic ecosystems. The order covers about 160 families, which include several species of commercial interest (Carpenter *et al*.; 1989) [8]. Most families in many subordinates today are not definable in terms of shared derived characters and, therefore, may not be monophyletic [1]. Most perciforms are marine fish from the coast, while about 2,000 species (for example, cichlids) normally occur only in freshwater. (Nelson, 1994, 2006) [22].

In the present study, we selected three species belonging to this order, the Sparidae family being represented by *Dentex macrophthalmus* (Bloch, 1791); Lutjanidae family, mainly *Lutjanus fulgens* (Valenciennes, 1830), and Lethrinidae family highlighted by *Lethrinus atlanticus* (Valenciennes, 1830).

However, fish are an extremely diverse group and subject to several changes in the aquatic environment, which is why they are excellent models for physiological studies, especially regarding reproduction, as it is a high energy cost process and occurs only when individuals are in their environmental and metabolic comfort, and can serve as a study model for understanding the influence of environmental factors, natural or anthropogenic, on biological systems (Ribeiro & Moreira 2012) [27].

To understand the adaptive mechanisms and the environmental factors that regulate them, it is of great importance for the elaboration of conservation actions, management and exploitation of fisheries resources. Fisheries management and research often require the use of biometric relationships to transform the data collected in the field into appropriate indexes (Patiyal *et al*., 2013) [24]. The weight-length relationship (LWR) of fish is an important tool in the studies of fish biology, physiology and ecology, as this relationship is useful for determining and estimating the average weight and biomass of fish, when measures of length are evaluated, indicating conditions and allowing comparisons between the growth of different populations (Gomeiro et Braga, 2003) [16], establishing a mathematical

[1] Group of organisms that form a clade or branch, that is, that consists exclusively of an ancestral species and all its descendants.

relationship between fish length and weight, it is an adequate practical index to understand their survival, growth, maturity, reproduction and well-being (Le Cren, 1951) [19]. Like any other morphometric characters, the LWR can be used as a character for the differentiation of taxonomic units and changes in the relationship with the various developmental events in life, such as metamorphosis, growth and early maturity (Gomeiro et Braga, 2003)) [16]..

In addition, the weight-length relationship can also be used as a quantitative indicator of the degree of health status or well-being of the species in its habitat, known in fisheries biology as the condition factor, which has been used to evaluate different feeding conditions in different species, as well as the interference of population density, climate and other environmental conditions. Thus, the condition factor can be considered a body index that reflects the interactions between fish and biotic and abiotic factors (Kindong *et al*., 2017) [17].

Different K values for a fish indicate the state of sexual maturity, the degree of availability of food sources, the age and sex of some species (Castiglioni *et al*., 2011) [6]. These relationships are also an important component of Fish Base (Froese and Pauly, 2013). The fish condition factor can be affected by several factors, such as stress, sex, local seasonality, food availability and other water quality parameters (Le Cren, 1951) [19].

Studies of weight-length relationship and determination of sexual maturity in continental and freshwater fish are extensive; notable among these are in several studies and reports, Castiglioni & Coelho (2011) [6] determining the sexual maturity of cordatus in mangroves on the south coast of Pernambuco, Brazil; Gomiero (2003) [16] weight-length relationship and condition factor for (Perciformes, Cichlidae) in the Volta Grande Reservoir, Rio Grande/Minas Gerais; Carpenter, K.E. and G.R. Allen, 1989 [8]. FAO Species Catalog. Emperor fish and big eyes of the world (family Lethrinidae), Kindong *et al*., 2017 [17]. Estimation of Length-weight Relationship and Condition Factor of Five Cultrinae Fish Species from Dianshan Lake, Shanghai, China; Santos *et al*,.(2014) [29] the first maturation size as a parameter for establishing the minimum capture size for Corvina in the fishing gear Southeast of São Paulo. Our study estimates the LWRs of 3 species of coastal water fish, *Dentex macrophthalmus* (Bloch, 1791); *Lutjanus fulgens* (Valenciennes, 1830) and *Lethrinus atlanticus* (Valenciennes, 1830). As far as we know there are no studies and reports on weight-length and the condition factor of these fish species in the coastal regions of southern São Tomé. Therefore, this study provides basic information on these commercially important fish species, which can serve as a tool for management and conservation practices.

Materials and Methods

Description of the Study Area

Geographically, the south region of São Tomé is within the limits of latitude 0 ° 5 'N and longitude 6 ° 36' E, the fishing activity was carried out mainly in two regions, Angolares in the Mangrove Zone (A0) (00007.888'N and 006038.752'E), in the Bay (A1) between 10-13 meters deep (00007.608'N and 006039.029'E), Stone Zone (A2) of the 15-30 meters deep (00006.468'N and 006039.588'E), Largo (A3) between 40-80 meters deep (00005.054'N and 006039.765'E), and in the region of Porto Alegre Zona in the Mangrove (P0) from 00002.761'N and 006031.825'E, Baía (P1) between 7-10 meters depth of 00002.468'N and 006032.454'E, Stone Zone (P2) 15-30 meters deep between 00000.886'N and 006030.374'E, Largo (P3) but 100 meters deep between 00001.621'N and 006029.927'E (Fig.1 and Fig.2). Numerous beaches interposed by rocky shores make up the landscape of the bay, which receives input from continental drainage through small rivers and streams, forming a system with mixopoly-hyaline characteristics, with low hydrodynamism and presence of fine and very fine sediment (Mantelatto et. Fransozo, 1999).

Fig 1: Points chosen for carrying out the scientific fishing studies distributed in two Sites in the South-Southeast of São Tomé Island.

Sampling Program

Specimens were collected by the Project "KIKE da MUNGU" (fish for the future) together with Oikos - Cooperation and development and the NGO MARAPA (Sea Environment and Artisanal Fishing), in partnership with the Fisheries Directorate.

Live samples were captured randomly directly from the selected sampling stations, with the help of local artisanal

fishermen who mainly explore the inner part of the country's South Zone Bay, using fishing gear as hand line, bottom longline, vertical longline. The sampling of landed catches was carried out every two weeks (between late March, April, July and October 2019), with a total of 409 species caught of commercial interest, the study was focused mainly on three species of fish that had greater ambiguity and with better socioeconomic importance in this region, *Dentex macrophtalmus, Lethrinus atlanticus, Lutjanus goreensis* and *Lutjanus fulgens*. All individuals collected were placed on ice and transported to the laboratory where biological identification was confirmed (Santos *et al*., 2014) [29]. All captured specimens were selected at random, identified and measured morphometrically. For each specimen, data on the total fork length (Lt; cm) up to 0.1 cm were recorded and the total weight in grams (Wt; g) was measured on the digital scale with precision of 0.1 g for each individual male and female separately, and by macroscopic analysis from an abdominal incision to expose the gonads, gender identification was performed (Ferreira, 1998; Santos, 2006; Casatti, 2013) [10]. Therefore, some species were much more abundant than others, the sample size varied according to the number of specimens.

Data Analysis

The collected data were stored in electronic spreadsheets and Excel sheets and analyzed. The significance level of 5% was adopted.

Weight-Length Ratio

The weight-length relationship is an important parameter of fish populations and its applications vary from the estimation of an individual's weight, known its length, to the indication of the condition's condition factor fish (K).

The relationship between total weight and total length of the fish was established through non-linear regression. This relationship was analyzed by measuring the length and weight of fish specimens collected in the study areas, based on the distribution of the relative frequencies monthly in the laboratory. The statistical relationship between these fish parameters was established using the parabolic equation of Froese (2006) [13].

$$W = a.L^b$$

Where:

W = weight of the fish in grams;

L = length of fish in centimeters;

a = Constant (linear regression coefficient)

b = an exponential relationship that expresses between weight-length.

The parameters of this relationship $W = a.L^b$, when converted to the logarithmic form of the total weight and total length values, provide a graphical linear relationship:

Log W = Log a + b Log L (Patiyal *et al*., 2013) [24].

Where:

b = represents the slope of the line,

Log a = is a constant.

The (r^2) coefficient of determination was used as an indicator of the quality of linear regression.

To detect unpredictable differences in the value of b coefficient between males and females, the t-Student test was used (Zar, 1996) [38]. This test was also used to determine the type of allometry. The classification of the type of growth in the total length x total weight ratio was made according to the values of the slope b, as follows: (i) b <3, negative allometric, that is, the dependent variable (Y) grows to a relatively lower rate than the independent (X); (ii) b > 3, positive allometric the independent variable (Y) grows at a relatively higher rate than the independent (X) and (iii) b = 3, isometric growth, the morphometric parts (X and Y) grow evenly.

Condition Factor

The condition factor is used to compare the condition, fat or well-being (Patiyal *et al*., 2013) [24] of the fish, based on the assumption that heavier fish of a given length are better off. The difference in the condition factor was demonstrated as a measure of histological events such as fat reserve, adaptation to the environment and gonadal development (Le Cren, 1951)[19]. The coefficient of the condition, K was calculated using (Fulton, 1904) [11].

$$K = W^* \frac{100}{L^3}$$

Where:

W = weight in grams,

L = length in cm and 100 is a factor that approximates the value of K unit. All statistical analysis was done in Excel 2010.

Determination of the Period of Sexual Maturity

In agreement with Nunes (2015) [23], the maturity stages were macroscopically classified of the gonads in the laboratory based and grouped into the following stages: Stage A (Immature), Stage B (Maturing), Stage C (Mature), Stage D (Empty or sold off).

Maturity occurs in the largest FL in which the individual is classified as sexually mature, according to the criteria adopted for our definition of maturity (B-C stages for both families and males). The corresponding population parameter FL_{50} (FL in which 50% of the individuals are mature) is the FL in which a model adjusted to the maturity proportions of the FL classes predicts the maturity ratio of 0.50. The proportion of mature individuals per FL size class of 10 cm is generally used to adjust maturity warheads based on length and estimate size at FL_{50} maturity. The average size of first sexual maturation describes the length or length class at which 50% of the population starts the reproductive period and the knowledge of this estimate can help in defining the minimum size of the catch and consequently factors such as the minimum size of different fishing gear as mesh of fishing nets or in the minimum size of hooks for fishing (Shephard & Jackson, 2005) [33]. Therefore, in this work it was not possible to elaborate the graph of the maturation warhead because the data were insufficient, as a recommendation, the need for a study but extended to collect more data.

Results and Discussion

Results

A total of 409 specimens were captured and 179 specimens of three species of fish belonging to three families were

sampled: *D. macrophthalmus*, *L. atlanticus* and *L. fulgens*, in which they were measured and weighed at random. The calculated linear regression indicated significant differences between the LWR slopes between species. In the present study, the sample size varied with fish species. The descriptive statistics of LWRs of these three species of fish caught in the inner part of the coastal bay of the South Region of São Tomé are provided in tables 1 to 2 and the potential regression equations are provided in Fig. 2,3,4,5. On the table 1 to 3 shows Length characteristics the, sample size (N), minimum, maximum and average lengths; standard deviation of the average length (S.D), the coefficient of determination (r2), (a) constant, slope regression (b), growth type and condition factor (K).

Table 1: Length characteristics of the three species including their sample size, median and standard deviations

	Length Characteristics (cm)				
Fish species	**N**	**Min**	**Max**	**Med**	**S.D**
Dentex macrophthalmus	65	12,5	1364,5	41,34	± 5,411
Lethrinus atlanticus	79	11,5	37	24,42	±4,451
Lutjanus fulgens	35	6,4	39,5	17,03	±8,007

Table 2: Length-weight ratio for the three fish species

Parameters of the relation					
Fish species	***a***	***b***	**r^2**	**Growth type**	**Condition Factor K**
Dentexmacrophthalmus	*0,0152*	*2,9801*	*0,96*	*NA*	2,999
Lethrinus atlanticus	*0,0159*	*2,9778*	*0,931*	*NA*	0,015
Lutjanus fulgens	0,0115	3,055	*0,81*	IS	0,013

Table 3: Minimum, maximum, average values and linear regression for the three species

Weight characteristics (gram)				
Fish species	**weight-length potential equation**	**Min**	**Max**	**Med**
Dentex macrophthalmus	Wt = 0,0152 (FL)^{2,9801}	30	494	159,53
Lethrinus atlanticus	Wt = 0,0159 (FL) ^{2,9778}	22	804	241,46
Lutjanus fulgens	Wt 0,0115 (FL) ^{3,0581}	1	4382	236,89

The species *Dentex macrophthalmus* and *Lethrinus atlanticus* were negatively allometric in their growth, while *Lutjanus fulgens* was isometric in their growth. For Le Cren (1951) [19], environmental factors, food and parasitism have a great influence on fish health. The graphical representation of individuals by condition factors (K) related to capture by studied species are shown in Fig. 2.

Length-Weight Relationship

Studies on the weight-length relationship of fish are an important tool in fishery biology and help to understand whether variations in the expected weight for the known groups are the indicators of fat, well-being and gonadal development in relation to the environment (Kindong *et al.*, 2017; Le Cren, 1951) [17, 19]. Fisheries management and research often require the use of biometric relationships in order to transform field data collection into appropriate indexes. The weight-length ratio can be used to estimate the weight of the fish when its length is known and vice versa. The weight-length equation that provides important information about the weight and biomass of fish and allows comparisons between the growth of different species (Kindong *et al.*, 2017; Wootton, 1990) [17, 37]

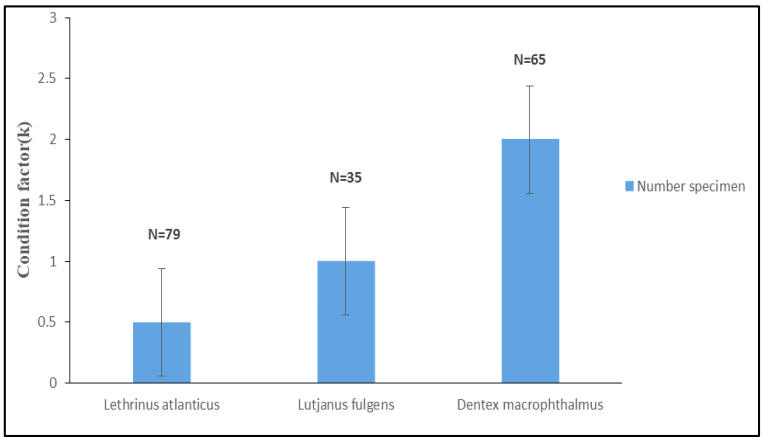

Fig 2: Representation by capture structure by condition factor (K) in three species of fish but commercialized in the south of São Tomé and Principe.

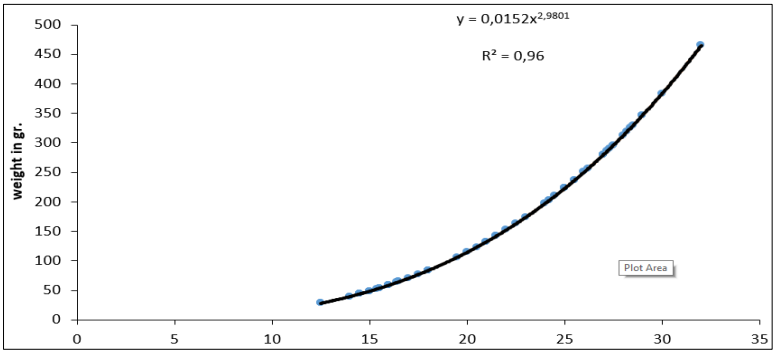

Fig 3: Potential regression graphs showing the weight-length relationship of grouped sex of species *Dentex macrophtalmus*

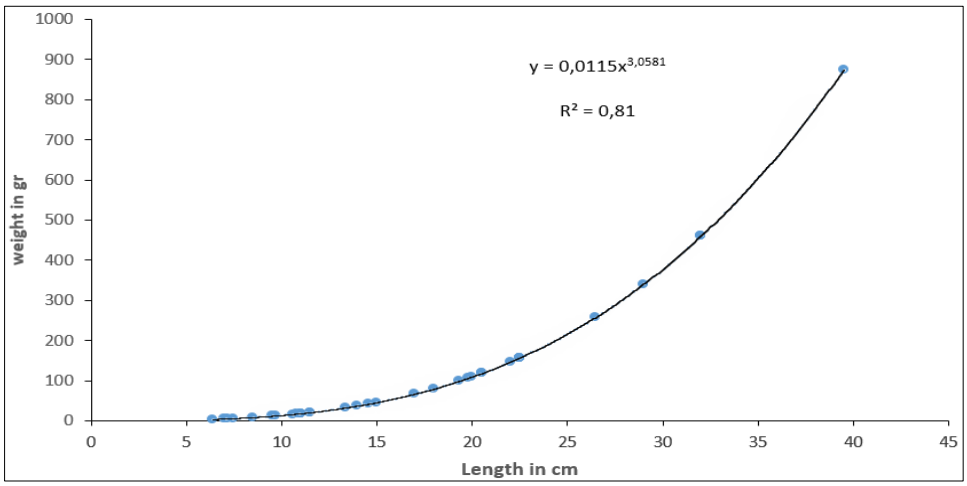

Fig 4: Potential regression graphs showing the weight-length relationship of grouped sex of *species Lethrinus atlanticus*

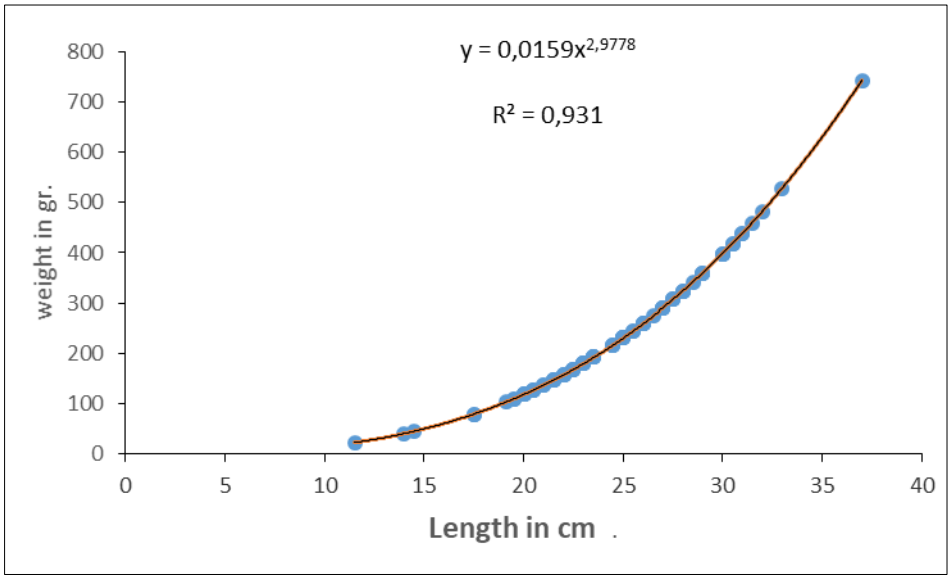

Fig 5: Potential regression graphs showing the weight-length relationship of grouped sex of *species Lutjanus fulgens*

Condition Factor

Condition indices have been widely used as indicators of relative health (Brown and Murphy, 1991). The condition factor (K) reflects, through its variations, information about the psychological state of the fish in relation to an individual's degree of well-being or health and its value reflects recent nutritional conditions and / or expenditure on reserves in cyclical activities, making possible the relations with the environmental conditions and the behavioral aspects of the species (Vazzoler, 1996) [34].

In the present study, the condition factor ranged from 0.013 (*Lutjanus fulgens*) to 2.999 (*Dentex macrophthalmus*), as shown above in Table 2. In addition, the graphical representation by capture structure by condition factor (K) of the three species of fish but marketed in the south of São Tomé and Principe are also provided in Fig.2.

The differences in condition factors even when it comes to the same area, factors such as structure in size and seasonality can be attributed to low feeding intensity and degeneration of the ovaries during winter and high feeding intensity and full development of the gonads during the months of summer. These values can be influenced by local conditions, therefore, the time interval between studies must also be considered. Considering the 49-year interval between the study by Vazzoler (1996) [34] and the present work, many changes may have occurred in the Coastal Zone of the south region of São Tomé, since it is an environment that has been greatly altered by anthropogenic actions.

The present study, as far as we know, is the first attempt to provide information on the growth condition of *Dentex macrophthalmus*, *Lethrinus atlanticus*, *Lutjanus fulgens* in the coastal regions of southern São Tomé. This study will inform biologists about the state and conditions growth of these fish species in natural waters, will be useful for fishing biologists and conservation agencies, for successful future development. In terms of reproduction, the highest K value is achieved in some species if the fish is fully mature and has greater reproductive potential (Kindong *et al*., 2017) [17].

From the nutritional point of view, an increase in the K value indicates the accumulation of fat and gonadal development, and the lowest K value normally occurs at the beginning of the reproductive period and the highest at the end (Le Cren, 1951) [19].

Discussion

Knowledge about the weight-length relationship of fishes is an important tool to describe the aspects related to the biology and ecology of fish resources, as they help to characterize whether variations in the expected weight for known groups

are indicators of fat, well-being and development gonad in relation to the environment (Kindong *et al*., 2017, Le Cren, 1951) [17, 19], also help to understand stock management and fisheries research that allows establishing standards for the management of halieutic resources that frequently require the use of biometric relationships to transform field data collection into appropriate indexes (Vazzoler, 1996 & Kingdong *et al*., 2017) [34, 17]. This relationship has been shown to be the easiest and fastest way to describe growth without taking into account the age of the fish, so this estimate has an important application in fishery biology Lima *et al*., (2017) [20].

For Wootton (1990) [37], the weight-length relationship can be obtained from measurements of length and weight of the same fish over their lives or from a sample of fish obtained at a given time. Looking at the weight-length ratio (Table 1 to 3), the values obtained for b showed growth variations for the three species. Therefore, the value of b equal to 3 indicates that the fish grows isometrically; values other than 3 indicate allometric growth. In the present study, the results revealed that *Lutjanus fulgens* showed an isometric pattern of growth (b = 3) indicating that, small specimens have the same shape and probably the same condition as large specimens, *Dentex macrophthalmus* and *Lethrinus atlanticus* presented a pattern of negative allometric growth (b <3) implying that the increase in length is not in line with the increase in weight. The value of b generally remains constant at 3.0 for an ideal fish (Kindong *et al*., 2017) [17].

In the present study, we recorded a negative allometric growth pattern for *Dentex macrophthalmus* (Bloch, 1791) and *Lethrinus atlanticus* (Valenciennes, 1830). Similar results to this study were also found by Smith *et al*., (1986) [32] for sea fish, Berlin; Zeller *et al*., (2017) [39] reconstruction of marine fisheries catches for key countries and regions, Columbia for *Dentex macrophthalmus*; Kromer (1994) [18], bio-ecology and environmental parameters, Guinea-Bissau; Carpenter *et al*., (1989) [8] emperor and goldfish, Rome for *Lethrinus atlanticus*. These researchers, when investigating the weight-length relationship, both also reported negative allometric growth for the same species.

The growth of the negative allometric type indicates that the species in the course of its development, is having an increase in its body greater in length than in weight (Lima *et al*.; 2017) [20].

However, the reports for the same species from Santos *et al*., (2014) [29], Silva *et al*., (2017) [31], Pinto *et al*., (2004) [26] are not in agreement with the report of this study; they reported a positive allometric growth pattern for these species.

As for *Lutjanus fulgens*, Afonso *et al*., (1999) [1], also reported isometric growth as reported in this study, while Dias et al., (2010) [9] reported positive isometric growth for the same species. Therefore, our study also corroborated the study of LWRs reported by them.

The differences in b values in this study can be attributed to the combination of several factors such as the number of specimens examined, the inclusion in the parameters between juveniles and adults of the weight-length ratio in fish can be affected by factors such as environmental conditions, gonadal maturity, sex, health and general state of the fish, seasonal effect, habitat, zone and population (Patiyal, 2013) [24]. In a weight-length relationship, the most important parameters to be observed are b and r^2. The allometry coefficient b indicates the rate of inflection of the curve to reach asymptotic values, that is, when growth starts to show an irrelevant widening in relation to weight. The determination coefficient (r^2) is a parameter that indicates how much variation of the dependent variable is associated with the variation of the independent variable (Lecren, 1951) [19].

Conclusion

This study presents the parameters of weight-length relationship and condition factor of the three most abundant species in the coastal regions of southern São Tomé. Such research was carried out due to the ecological and economic importance of these species for the region. It can be suggested that most of the growth coefficients of the populations studied and compared with the literature vary from one region to another, mainly due to the different environmental conditions, availability of food or stage of the life cycle that these are in. This was the case for many juvenile species that inhabit coastal areas and have negative allometric growth.

However, in population dynamics studies, high condition factor values indicate favorable environmental conditions (such as habitat and prey availability) and low values indicate less favorable environmental conditions (Blackwell *et al*., 2017)[5], we could say that, perhaps the environmental conditions were not favorable for the species (*Lethrinus atlanticus* and *Lutjanus fulgens*), as they registered the lowest K value and favorable environmental conditions for *Dentex macrophthalmus* that registered the highest K values.

This study provides new records of maximum fork length in Fish Base (Froese and Pauly, 2018) [14] for three species: *Dentex macrophthalmus* (32 cm), *Lutjanus fulgens* (39.5 cm) and for *Lethrinus atlanticus* (37 cm) and also provides basic data on the weight-length relationship and condition factor (K) which would be unpublished and could assist fisheries biologists and conservationists to impose appropriate regulations for stock assessment and fisheries management and management the sustainability of these species in this region.

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