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Analysis of mortality and exploitation of a stock of shrimp *Xiphopenaeus kroyeri* in the Southwestern Atlantic Ocean

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Abstract
The aim of this study was to estimate the rates of mortality and exploitation of Atlantic seabob shrimp, *Xiphopenaeus kroyeri*, caught in the southwestern Atlantic Ocean. Monthly samples of species were obtained over five years from the artisanal fishing carried out in the State of Rio de Janeiro, Brazil. We analyzed 25,574 specimens with the total length varying from 32.0 to 134.0 mm for males and 33.0 to 148.0 mm for females. Two software programs were used to estimate rates of growth, mortality and exploitation: FiSAT II and Solver assessment tools. The asymptotic total length varied from 126.0 to 141.8 mm (males) and 143.9 to 154.4 mm (females). The growth rate (year^{-1}) ranged from 0.62 to 2.23 for males and 0.27 to 1.73 for females. Both assessment tools indicated that the exploitation rate of Atlantic seabob shrimp was above the maximum acceptable, requiring the reduction of the local fishing effort.

Keywords: mortality, exploitation, shrimp fishery, Atlantic Ocean, FiSAT II, Solver.

1. Introduction

The species *Xiphopenaeus kroyeri* (Heller, 1862), known as Atlantic seabob shrimp, is distributed in the western Atlantic Ocean, from the United States (~36° N, 75° W), extending through the Caribbean (~15° N, 75° W) to the south of Brazil (~30° S, 53' W). It occurs exclusively in the coastal marine area, up to 70 m depth, with clear preference for waters of up to 30 m depth and sandy and muddy bottom [1, 2].

The Atlantic seabob shrimp has economic importance throughout its distribution: in the United States, it is the most commercially important shrimp from Florida to Texas; in the Gulf of Mexico, it represents more than 30% of commercial shrimp catches; in Colombia and Trinidad and Tobago, it is the main species of shrimp caught in coastal fisheries; in Guyana, Suriname and French Guiana, it is mainly caught for export purposes [3, 4, 5, 6]. In Brazil, the annual catch of crustaceans by extractive marine fisheries is about 50,000 t, and the Atlantic seabob is the shrimp species with greater volume of catches, representing 80% of the production [7].

Species considered as fishery resources can have their sustainability affected by commercial fishing as a result of the population size reduction [8, 9]. The calculation of mortality and exploitation rates is important in fisheries management and in the assessment of sustainability of stocks caught for commercial purposes. Several authors have used those rates to infer about the situation of the stocks exploited in order to plan management actions [10, 11, 12].

In this study, we used two software programs as tools (FAO-ICLARM Stock Assessment Tools - FiSAT II and the Microsoft Excel Solver routine) in order to analyze the length frequency of the Atlantic seabob shrimp, resulting in the model of the length-converted catch curve. This template is used in the estimation of population parameters, such as mortality and exploitation, especially in organisms such as crustaceans, which have no indication of hard structures like otoliths, scales, vertebrae, and spines [13].

The assumptions of the model are that total mortality and recruitment are constant in all length classes (and age), and that all age groups are equally vulnerable to fishing gears [14, 15]. For using the model, all age groups should be included in the sample, so that the structure of the population studied is well represented during the time interval considered [14].

The program FiSAT II is the result of using two programs together: LFSA (Length-based Fish Stock Assessment) and ELEFAN (Electronic Length Frequency Analysis), incorporating several analysis routines for tropical fish stocks assessment, based on the analysis of length frequency distribution and modal progression and size per age [16, 17]. The Solver routine is a non-linear interactive tool that applies the method of least squares, which is the use of the function of the sum of the squares of the residues to estimate the parameters of the length-converted catch curve model [18].

The aim of this study was to estimate for the first time the rates of mortality and exploitation of a fishing stock of Atlantic seabob shrimp distributed in the southwestern Atlantic Ocean, from a five years sample series, comparing the estimates generated through FiSAT II and Solver assessment tools. The implications in the use of these tools for the management of this stock will be compared and discussed.

2. Materials and methods

2.1 Sampling

Samples of Atlantic seabob shrimps were taken monthly during five years (2005-06, 2006-07, 2008-09, 2009-10, and 2011-12) from artisanal fisheries landed at the port of Atafona (21°37' S; 041°00' W), which is located in the north of the State of Rio de Janeiro, southeastern Brazil. The fishing area is between 21°35' S and 21°55' S, at 6 to 20 m depth and one to three nautical miles away from the coast line, representing around 100 to 200 km^2 of coastal waters (Fig 1). Vessels use bottom trawl nets with doors as fishing gear. The length of the trawl nets varies from eight to ten meters, with a six-meter opening and a mesh (measured between non-adjacent nodes) of four centimeters in the body and three centimeters in the cod end.

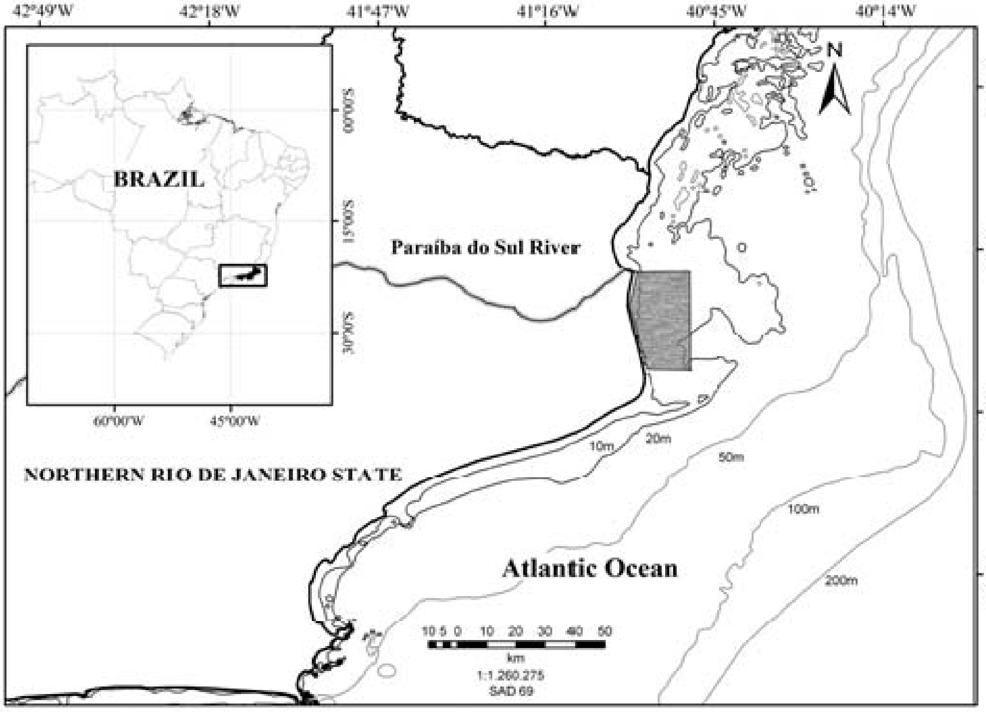


Fig 1: The northern coast of the State of Rio de Janeiro, southeastern Brazil, with details of the shrimp fishing area (21°35' S to 21°55' S).

Samples were taken from different vessels, totaling two to three kilograms of the species every month. The individuals surveyed were randomly selected on board the vessels, from the total volume caught during the fishing operation, representing the stock of the species available for the local fisheries. The specimens collected were macroscopically classified as to sex and stage of maturity [19, 20]. The total body length was measured with a vernier caliper (to 0.1 mm), in rectilinear projection, from the tip of the rostrum to the end of the telson.

2.2 Data analysis

The total mortality rates (Z) were estimated from the model of length-converted catch curve [14] using FiSAT II and Solver assessment tools. The estimates were made annually and separately for males and females due to sexual dimorphism of the species in relation to body size and growth rate [21].

Through FiSAT II, frequency distributions–with individuals grouped at intervals of 5 mm of total length–and growth parameters (L∞: asymptotic total length in mm; and k: growth rate per year^{-1}) were used for mortality estimates. The parameters were calculated through growth analysis of ELEFAN I routine (Electronic Length-Frequency Analysis) [22], which identifies those that better fit to the data set based on modal shift of temporal sequences of length samples. The growth curve was obtained through von Bertalanffy's model, without seasonality: $L_t = L\infty\ (1 - e^{-k\ (t-to)})$, in which L_t is the length at age t and t_0 is the theoretical age at zero length [23].

Total mortality (year^{-1}) was estimated through the model of length-converted catch curve, according to the equation: $In\ (N_i/dt_i) = a + Z\ t_i$; in which, N_i is the number of individuals in the class of length i; dt_i is the time required for the individual to grow in class i; a is a constant, t_i is the age corresponding to the midpoint of the class i (being $t_0 = 0$); and Z is the total mortality [17].

Natural mortality (year^{-1}) was estimated by Pauly's empirical model: $In\ M = -0.0152 – 0.279 * In\ (L\infty) + 0.6543 * In\ (k) + 0.463\ In\ (T)$; in which T is the average temperature of the water (°C), which in the area of study was considered as 25 ºC. Natural mortality was also estimated by Taylor's method, according to the equation: $M\ (day^{-1}) = 4.60/Ap_{0.99}$; in which $Ap_{0.99}$ is the age at which individuals reach 99% of the asymptotic total length ($Ap_{0.99} = t_0 + (4.60/k)$. The values of

L∞, k, and t_0 were obtained from growth analysis using FiSAT II. In this case, we considered $t_0 = 0$, because the estimated values for this parameter were negative. This occurs due to the negligible size of the crustaceans at birth.

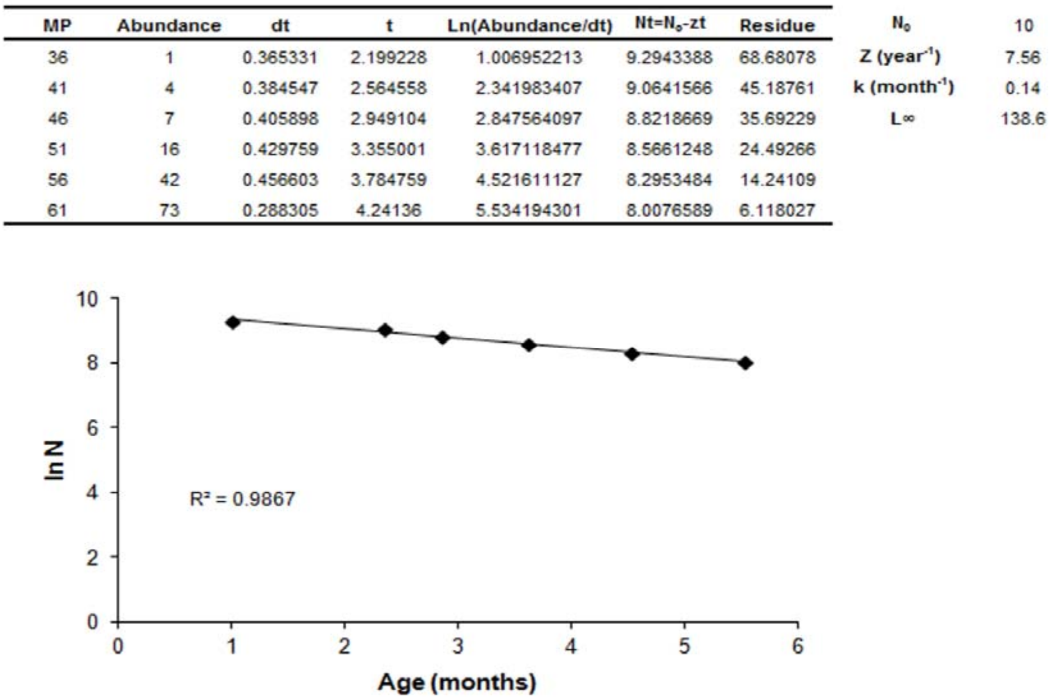
Regarding Solver assessment tool, the growth parameter L∞ was set to the same value generated by FiSAT II, because the results for males and females were consistent with the biology of the species and with the maximum lengths recorded from the samples. This consideration was also given by other authors who applied Solver in studies on fish stocks [24, 25, 26].

Through the PeakFit program, version 4.06, we selected monthly modal peaks of frequency distribution of individuals (grouped at 5-mm intervals) for growth analysis. The selection of modals was based on R^2 and F critical values, always below the F value calculated. The overlapping modal peaks were eliminated from the analysis because they did not represent true age groups. PeakFit has the advantage of not rejecting modal peaks with low number of individuals.

The parameters k (growth rate per day^{-1}) and t_0 were estimated by minimizing the sum of the squared differences between the observed and expected age length for each cohort, through adjusting von Bertalanffy growth curve to length data at age t using Solver [27]. The cohorts which best represented the growth of the species–with greater consistency between estimates of growth and longevity constants–were selected for the final calculation of growth constant and final adjustment of the growth curve.

The length-converted catch curve was obtained by regression of the natural logarithms of the number of individuals in each age class by the interval of time an individual takes to grow from a certain class of size to the next, depending on the relative age (Fig 2). The interval of time needed for growth through the size classes is represented by dt and estimated by the equation: $dt = (-1/k) \text{In} (L\infty - MP_2)/ (L\infty - MP_1)$. The dt value is necessary for applying the equation $y = \ln (\text{abundance}/dt)$, whose result is applied to the sum of residues at the end of the mortality estimate and when obtaining the length-converted catch curve. The estimate of relative age (t) was accomplished through von Bertalanffy equation: $t = (-1/k) \ln (1 - MP/L\infty)$, in which k is the growth rate (month^{-1}) and MP is the midpoint of the length class in mm (MP_1: midpoint of previous class and MP_2: midpoint of the next class).

In order to complete the calculation of the total mortality rate, we used the equation: $Nt = N_0 - Zt$; in which Nt is the number of individuals at time t; N_0 is the initial number of individuals; Z is the total mortality rate (month^{-1}); and t is the relative age described above. The parameters N_0 and Z were estimated using the method of least squares in Solver. The residue was calculated from: $(\text{In} - Nt)^2$. For the calculation of natural mortality (year^{-1}), we used Pauly's empirical model and Taylor's method, in the same way as applied in FiSAT II, considering the L∞ and k values obtained from Solver.



MP	Abundance	dt	t	Ln(Abundance/dt)	$Nt=N_0-zt$	Residue
36	1	0.365331	2.199228	1.006952213	9.2943388	68.68078
41	4	0.384547	2.564558	2.341983407	9.0641566	45.18761
46	7	0.405898	2.949104	2.847564097	8.8218669	35.69229
51	16	0.429759	3.355001	3.617118477	8.5661248	24.49266
56	42	0.456603	3.784759	4.521611127	8.2953484	14.24109
61	73	0.288305	4.24136	5.534194301	8.0076589	6.118027

N_0	10
Z (year^{-1})	7.56
k (month^{-1})	0.14
L∞	138.6

Fig 2: Example of total mortality rate estimate and the model of length-converted catch curve through Solver assessment tool. MP = midpoint of class length (mm); dt = time interval required for growth through size classes; t = relative age; Nt = number of individuals at time t; N_0 = initial number of individuals; Z = Total mortality rate.

We estimated fishing mortality (F) from the total and natural mortality rate in both assessment tools, which is the difference between them ($F = Z - M$). The exploitation rate (E) is the result of the division between fishing mortality and total mortality ($E = F/Z$) [23]. The stock is considered overexploited when its exploitation rate exceeds 0.5 ($F > M$) [28].

3. Results

This study analyzed 25,574 specimens of Atlantic seabob shrimp, *Xiphopenaeus kroyeri,* over five-years sampling: 12,582 males (49.2%) and 12,992 females (50.8%), and 11,536 immature (45.1%) and 14,038 mature (54.9%). The total length of all specimens analyzed ranged from 32.0 to 134.0 mm (average: 85.8 ± 13.7 mm) for males and from 33.0 to 148.0 mm (average: 90.3 ± 18.4 mm) for females.

The asymptotic total length ranged from 126.0 to 141.8 mm (males) and 143.9 to 154.4 mm (females). The growth rate (year^{-1}) ranged from 0.62 to 1.40 (males) and from 0.27 to 0.61 (females) according to FiSAT; while according to Solver, values ranged from 1.56 to 2.23 (males) and from 1.55 to 1.73 (females) (Table 1). Mortality rate estimates generated from the two assessment tools varied over the years and between the sexes, with the higher rates calculated by Solver. In general, males showed higher values than females. The exceptions were Solver estimates regarding natural mortality rates through Taylor's method in 2011-12 with equal values between the sexes, and in 2008-09 with slightly higher values for females (Table 2)

Table 1: Maturity classes and estimates of growth parameters: L∞ = asymptotic total length (mm); k = growth rate (year^{-1}) of male and female Atlantic seabob shrimps, *Xiphopenaeus kroyeri*, through FiSAT II and Solver assessment tools.

Males						
Tool				FiSAT II	Solver	
Year	**n**	**Immature**	**Mature**	**L∞**	**k**	**k**
2005-06	2,558	306	2,252	138.6	0.85	1.64
2006-07	2,855	560	2,295	131.3	0.78	2.23
2008-09	2,215	181	2,034	141.8	0.81	1.71
2009-10	2,749	369	2,380	126.0	0.62	2.18
2011-12	2,205	275	1,930	128.1	1.40	1.56
Females						
Tool				**FiSAT II**	**Solver**	
Year	**n**	**Immature**	**Mature**	**L∞**	**k**	**k**
2005-06	2,772	2,091	681	143.9	0.27	1.57
2006-07	3,029	2,561	468	152.3	0.37	1.61
2008-09	2,267	1,694	573	152.3	0.40	1.73
2009-10	2,608	2,010	598	147.0	0.61	1.68
2011-12	2,316	1,545	771	154.4	0.35	1.55

Table 2: Estimates of total (Z), natural (M), fishing (F), and exploitation (E) mortality rates of males and female Atlantic seabob shrimps, *Xiphopenaeus kroyeri*, through FiSAT II and Solver assessment tools, using Pauly and Taylor's methods.

Males							
		Tool			**FiSAT II**		
	Method		**Pauly**		**Taylor**		
Year	**Z**	**M**	**F**	**E**	**M**	**F**	**E**
2005-06	3.72	0.99	2.73	0.73	0.85	2.87	0.77
2006-07	2.62	0.95	1.67	0.64	0.78	1.84	0.70
2008-09	3.44	0.96	2.48	0.72	0.81	2.63	0.76
2009-10	2.14	0.83	1.31	0.61	0.62	1.52	0.71
2011-12	5.19	1.42	3.78	0.73	1.40	3.81	0.73
		Tool			**Solver**		
	Method		**Pauly**		**Taylor**		
Year	**Z**	**M**	**F**	**E**	**M**	**F**	**E**
2005-06	7.56	0.42	7.14	0.94	1.65	5.91	0.78
2006-07	7.35	0.64	6.71	0.91	2.24	5.11	0.70
2008-09	6.38	0.45	5.93	0.93	1.72	4.66	0.73
2009-10	7.09	0.64	6.45	0.91	2.19	4.90	0.69
2011-12	6.46	0.41	6.05	0.94	1.57	4.89	0.76
Females							
		Tool			**FiSAT II**		
	Method		**Pauly**		**Taylor**		
Year	**Z**	**M**	**F**	**E**	**M**	**F**	**E**
2005-06	0.89	0.46	0.43	0.48	0.27	0.62	0.70
2006-07	1.24	0.57	0.67	0.54	0.37	0.86	0.70
2008-09	1.53	0.59	0.94	0.61	0.40	1.13	0.74
2009-10	1.95	0.79	1.16	0.60	0.61	1.34	0.69
2011-12	1.39	0.52	0.87	0.63	0.35	1.04	0.75
		Tool			**Solver**		
	Method		**Pauly**		**Taylor**		
Year	**Z**	**M**	**F**	**E**	**M**	**F**	**E**
2005-06	4.53	0.38	4.15	0.92	1.57	2.96	0.65
2006-07	5.44	0.39	5.05	0.93	1.62	3.82	0.70
2008-09	6.13	0.43	5.70	0.93	1.74	4.39	0.72
2009-10	5.67	0.42	5.25	0.93	1.68	3.99	0.70
2011-12	6.07	0.36	5.71	0.94	1.57	4.50	0.74

The exploitation rates were higher than the value considered optimal (E = 0.5) for both sexes, except for females in 2005-06 (FiSAT II, Pauly's empirical model). However, the value for this period was close to the maximum sustainable limit of exploitation (E = 0.48) (Table 2).

4. Discussion

4.1 Mortality and exploitation of Atlantic seabob shrimp

Annual variations of population parameters–such as mortality rates–are expected in penaeid shrimps due to their short life cycle [29, 30]. The short longevity of these organisms, which can range from 1.5 to 3 years [31, 26, 21], makes variations in environmental conditions (e.g., temperature, salinity, availability of food resources) have a strong influence in the development and/or survival of specimens [9].

Male Atlantic seabob shrimps have higher natural mortality rate in comparison to females. Taking into consideration that natural mortality in penaeid shrimps is directly related to growth rate and inversely related to longevity [28], the difference between the sexes can be explained by the greater growth rate and lower longevity of males in the region studied [21]. Only one study conducted in southeastern Brazil has recorded the natural mortality rate for this species [32]. The authors considered males and females as a single sample and the value (M = 0.60) was in general lower than mortality rates estimated by our study (Table II). However, the variation among results may be related to methodological differences between the studies.

The use of natural mortality estimation as a single value representing all size classes (and age) can be questionable. Throughout the life cycle, individuals are subject to different natural mortality factors, such as predation and diseases, which have different intensity of action according to age groups [9]. Variation of natural mortality rates throughout the life cycle and the inability to associate them with the main causes hinder the acceptance of this parameter as a real estimation of mortality. However, this parameter has been used in studies assessing fisheries stocks, including crustaceans [33, 34, 35, 36, 37].

For both sexes, the rate of fishing mortality was the one that most contributed to the increase of the total mortality rate over the years of sampling, with higher values recorded for males compared to females. Males have larger growth rates, resulting in faster development and attainment of maturity with smaller body sizes with respect to females. This explains the largest catches of mature males by the mesh of the fishing gears (Table II).

Mature females, in turn, migrate to deeper areas at the time of spawning and only return to the regions near the coast when they are recovered from sequels left by spawning [38]. Therefore, during this period, females are more protected from fishing activities, considering that in the area of study the vessels use bottom trawl nets up to 20 m depth. This may have influenced the representativeness of mature females with respect to immature females, which were more frequent throughout the sampling years (Table II).

Once a cohort is formed, natural mortality begins to remove individuals from the population through abiotic (salinity, temperature) and biotic factors (predation, diseases). Subsequently, the effects of fishing mortalities are incorporated and they are determined by the exploitation of the individuals through commercial fishing. Fishing mortality varies in function of the total length of individuals and is directly related to fishing effort and the choice of the gear used [9]. Although the sex ratio in the region has been about 1:1, males had the highest fishing mortality rates. This can be explained by the fact that the asymptotic total length and growth rate parameters had lower and higher values in males compared to females, respectively. The rate of fishing mortality is estimated as a result of the total mortality rate, for which these parameters are used for calculation. Despite the economic importance and the commercial exploitation of the species throughout its distribution, the literature has no records of fishing mortality rate estimates in other areas for comparison purposes.

In the region studied, the exploitation rates of both sexes were above the maximum sustainable level (E = 0.50) [28], indicating the pressure that fishing activities have been exerting on this stock over the years. In the Brazilian coast, the commercial production of the species can be considered as overexploited due to the reduction of the total volume that is landed in the fishing ports [39]. Penaeid shrimps are traditional targets of commercial fisheries around the world [40] and studies show the decline of fishing activities directed at these shrimps in recent years [41, 42, 11, 43].

For the maintenance of fish stocks at sustainable levels of commercial exploitation the adoption of management measures is required. The main management measure for shrimp fishing is the establishment of closed fishing seasons, which are based on the time of recruitment of the target species of fisheries. Regarding the Atlantic seabob shrimp, closed fishing seasons for the species in the southeastern and southern regions of Brazil are regulated through Normative Instruction No. 189/2008, which prohibits the exercise of trawling by motor vessels in the marine area between 2°18' S and 33°40' S, from March 1st to May 31st [44]. Juveniles of the species are more common in the area of study between January and May and from June to August [21]. Even though the closed fishing season is in accordance with the peaks of recruitment in the region, the exploitation rates indicate that this measure is not being effective for the maintenance of this stock. Given this, the current fishing effort should be revised so as to reduce overexploitation.

4.2 Comparison between FiSAT II and Solver assessment tools

Mortality rates and exploitation estimated for the Atlantic seabob shrimp through FiSAT II and Solver assessment tools varied between sampling years and sex of individuals, with the highest values recorded through Solver (Table 2). For total mortality rates of males, the annual values calculated through Solver were two times higher than results obtained through FiSAT II. In the case of females, these values were about four times higher. The variations reflect differences in mathematical assumptions by both tools.

In FiSAT II, the base of calculations of the catch curve model are the parameters of asymptotic total length and the growth rate (year^{-1}), calculated through ELEFAN I routine (Electronic Length Frequency Analysis). This routine tends to exclude individuals with greater lengths from the analysis, leading to overestimation of growth rate and, consequently, of the natural mortality rate [22], as observed for natural mortality estimates through Pauly's method.

The PeakFit 4.06 program was used for the detection of modal peaks related to the length frequency distribution of individuals to estimate growth rate (day^{-1}) using Solver assessment tool. This parameter is required for subsequent estimates of mortality rates and exploitation with the same tool. This procedure has the advantage of considering up to the length classes with low frequency of occurrence in the sample. The estimation of mortality rates through Solver was held from higher growth rates compared to those of FiSAT II, generating higher natural mortality rates.

FiSAT II is available for free use at the Food and Agriculture Organization of the United Nations (FAO). However, the tool was developed for being used in Windows operating system, whose license is purchased through payment of a fee. On the other hand, Solver is available in both Windows and

Linux operating systems, the last being a free software. Despite this, the first tool has been widely used in the assessment of fishery stocks of various species targeted by fisheries worldwide [45, 46, 47, 48, 49, 50]. The use of Solver for this purpose is more recent and limited [27, 25, 15, 51], probably due to the increased time spent in carrying out the analyses.

Despite the numerical differences between mortality rates and exploitation, the results obtained from the two tools converged with respect to the level of sustainability of this fishing stock. Both indicated that the rate of exploitation of the Atlantic seabob shrimp is above the maximum acceptable ($E > 0.5$). In case the estimates of exploitation rate of a given stock indicate different conditions, the precautionary principle must be adopted and the highest rate of exploitation for the purpose of fisheries management must be taken into consideration.

5. Conclusion

The fishing stock of the Atlantic seabob shrimp on the northern coast of the State of Rio de Janeiro is overexploited by artisanal fisheries. Given this, there is a need for the reduction of the local fishing effort in order to maintain it at sustainable levels of long-term exploitation. There is also a need for adopting fisheries management measures–associated with the closed fishing season already in effect in the region–such as changing fishing net meshes in order to allow the escapement of smaller individuals from the nets. For monitoring mortality rates and exploitation of this stock, the use of Solver assessment tool is suggested, because it is an interactive method, in which all size classes sampled are regarded in the estimation of the parameters considered.

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