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Population Dynamics and Stock Assessment of Deep-Water Red Shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus* in the Southeastern Mediterranean Waters

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ABSTRACT

The stock status of the two deep-water red shrimps (DWRS), *Aristaeomorpha foliacea* (ARS) and *Aristeus antennatus* (ARA) in the Southeastern Mediterranean (the Egyptian Mediterranean waters) was assessed. The length-based spawning potential ratio (LB-SPR) model was used for the assessment. The input data depended on a scheme of data collection for two years after identifying the fishing grounds of the DWRS. The von Bertalanffy growth parameters were estimated by analyzing the length frequency distributions, where the growth coefficient (K) = 0.41 year^{-1}, the asymptote carapace length (L_∞)=65.01 mm, and the theoretical age at length 0 (t_0)= -0.12 year for ARS, while they were K= 0.35 year^{-1}, L_∞= 57.51 mm, and t_0= -0.50 year for ARA. The average of natural mortality vector (M) was 0.8 for ARS, and 0.77 for ARA. Carapace length at 50% sexual maturity (L_{50}) was 32.85 and 26.31mm for females of ARS and ARA, respectively. The mean spawning potential ratios SPR (0.062 and 0.17) and the mean ratios of fishing mortality to natural mortality F/M (2.91 and 1.47) for ARS and ARA, respectively, revealed that the two stocks are overexploited. In the context of fisheries sustainable exploitation, a management plan is therefore needed to regulate the fisheries of the two studied species in the Egyptian Mediterranean waters.

INTRODUCTION

Deep-water red shrimps (DWRS) are the most important deep-sea fishery resources within the Mediterranean region. Over the past few decades, the fishing activity for these species has expanded from the western-central basin to encompass the entire Mediterranean area. Together, the giant red shrimp *Aristaeomorpha foliacea* (Risso, 1827) and the blue and red shrimp *Aristeus antennatus* (Risso, 1816) constitute the main target species for the demersal deep-water fishery in the Mediterranean **(Kapiris & Thessalou-Legaki, 2009)**.

In the Southeastern Mediterranean waters of Egypt, the DWRS fisheries potential was first explored in 2009, which contributes 12% of the total Egyptian fisheries production **(Ibrahim *et al.*, 2011)**. The total landings of the DWRS started to appear in the statistical yearbook of the General Authority for Fish Resources Development (GAFRD) from 2015 to date. According to **GAFRD (2020)**, the total landings commenced at 504 tonnes in 2015, experiencing subsequent increments to 757 and 979 tonnes in 2016 and 2017, respectively. However, there was a decline in production to 475 tonnes in 2019. Then, a further increase occurred in 2020, resulting in a total of 605 tonnes. In the context of fisheries management, the scientific basis for formulating decisions is provided by stock assessment. Nevertheless, a very little attention was paid to assessing the stock status of the two DWRS in the Egyptian Mediterranean waters, probably due to the data-limited nature of the area. In response to the growing need for science-based fisheries management in situations where data and resources are limited, numerous approaches for handling data-limited scenarios have recently been developed **(Dowling *et al.*, 2015, 2016; Rosenberg *et al.*, 2018)**. The length-based spawning potential ratio (LB-SPR) **(Hordyk *et al.*, 2015)** is one of the methods that builds on the estimation of SPR as a well-established biological reference point which could be used to inform management decisions for data-poor fisheries. The LB-SPR technique is a method based on equilibrium, where it assesses the observed length composition of the catch by comparing it with the anticipated length composition under equilibrium conditions.

Given the importance of the DWRS and the data-limited situation of their fisheries, this study presents the first attempt to analyze and assess the stock status of the most two-dominant DWRS: *Aristaeomorpha foliacea* (ARS) and *Aristeus antennatus* (ARA) using the data-limited approach (LB-SPR), to help manage and sustainably exploit their fishery in the Southeastern Mediterranean waters (General Fisheries Commission for the Mediterranean – GFCM, Geographical Sub-Area – GSA 26 "South Levant- Egypt").

MATERIALS AND METHODS

1. Study area

The coastline in the northern part of Egypt extends for about 1050km, extending from Rafah in the East, located on the Sinai Peninsula, to Sallum in the West, situated at the border between Egypt and Libya. To set a sampling scheme, it was important to identify the fishing grounds of the DWRS in the Egyptian Mediterranean waters (Fig. 1). Therefore, a pilot study was performed through an onboard observation program conducted in 2020.

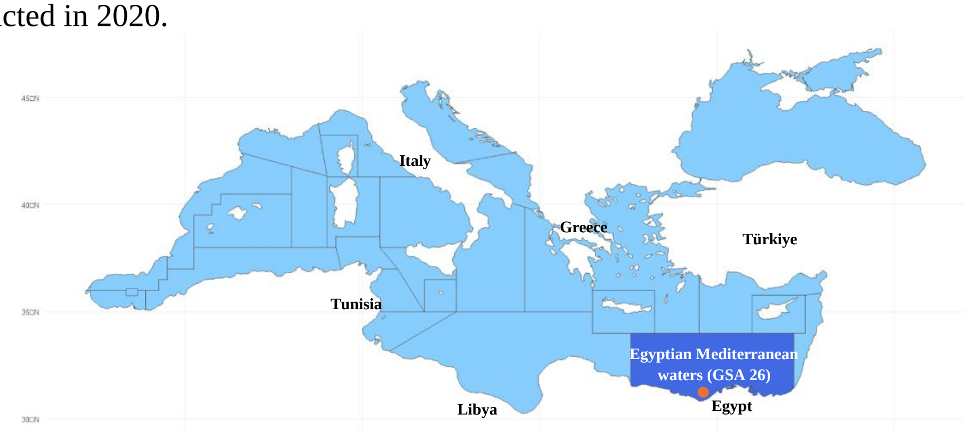

Fig. 1. Geographical sub-area – GSA 26 (South Levant "Egyptian Mediterranean waters"). Orange circle indicates the main fishing ground of DWRS.

2. Data collection

A framework of data collection on monthly basis was carried out over the period from January 2021 to December 2022. A total number of 2854 individuals of ARS and 2417 of ARA were collected through onboard bottom trawlers operating in the Egyptian Mediterranean. Moreover, in instances where onboard observations were not carried out, a sampling procedure was employed to collect specimens from the Damietta fish landing site, which is the only fishing harbor receiving the landings of such species in the Egyptian Mediterranean. Species composition of deep-water shrimps was calculated monthly from onboard observations.

3. Estimation of parameters used in the LB-SPR model

The length-based spawning potential ratio (LB-SPR) **(Hordyk *et al.*, 2015)** was used for the stock assessment. The ELEFAN (Electronic length frequency analysis) method, which is embedded in the TropFishR package in the R statistical computing software, was used to estimate growth parameter (L_∞, K, and t_0) , with new optimization techniques **(Taylor & Mildenberger, 2017)**. Length-weight relationship **(Le Cren, 1951)** and length at 50 and 95% maturity (L_{50} & L_{95}) **(King, 1995)** were estimated. The natural mortality (M) vector was calculated from Caddy (1991) equation using the PRODBIOM Excel spreadsheet **(Abella *et al.*, 1997)**.

RESULTS

1. Species composition

The illustration in Fig. (2) displays the typical seasonal species composition of deep-water shrimp in GSA 26. It was evident from the data that ARS constituted most of the catches at 69.92%, followed by ARA at 21.09%. *Plesionika edwardsii* and *Parapenaeus longirostris* accounted for 5.45 and 3.54% of the landings, respectively.

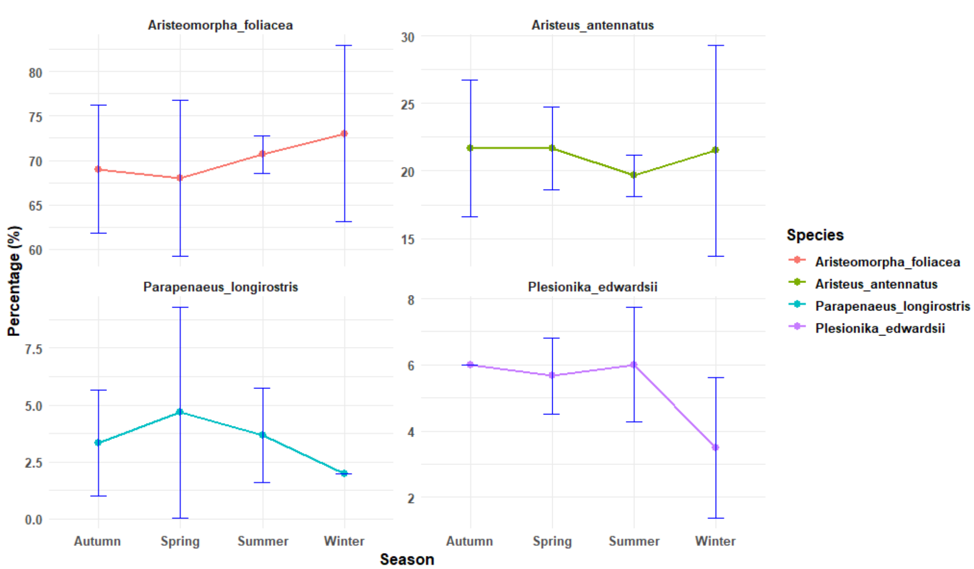

Fig. 2. Seasonal species composition of the four deep-water shrimps in GSA 26 as expressed by Mean (%) ± SD

2. Length-weight relationship

The observed total weight (W) in the present study ranged from 1.36 to 54.85g. Moreover, the carapace length (CL) ranged from 14 to 58mm for ARS. In case of ARA; the range of total weight was from 1.77 to 33.5g, while the total carapace length ranged from 12 to 51mm. The length-weight relationships for the sexes combined of the two studied species, which are graphically presented in Fig. (3), were determined by the following power equations: ARS, $W=0.00119*CL^{2.625}$; and ARA, $W=0.00115*CL^{2.633}$.

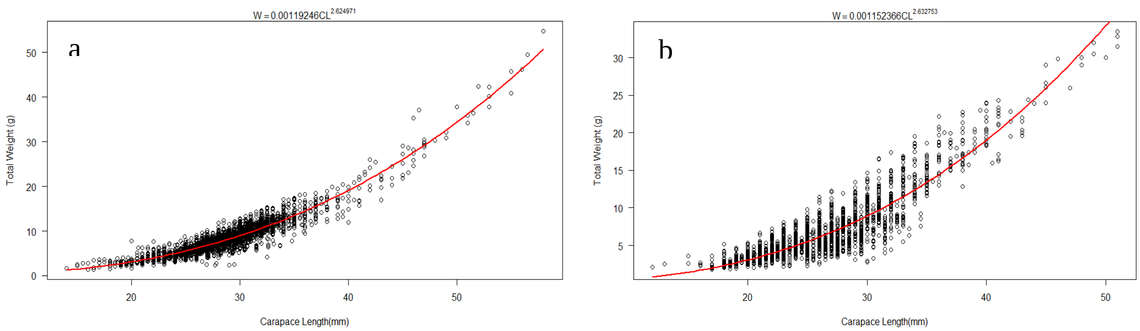

Fig. 3. Length-weight relationship of the two DWRS in GSA 26 showing: a) *Aristaeomorpha foliacea*, and b) *Aristeus antennatus*

3. Carapace length at first sexual maturity (CL_{50})

CL_{50} estimates were found to be 26.91 and 17.48mm for males, while it was 32.85 and 26.31mm for females of ARS and ARA, respectively (Fig. 4).

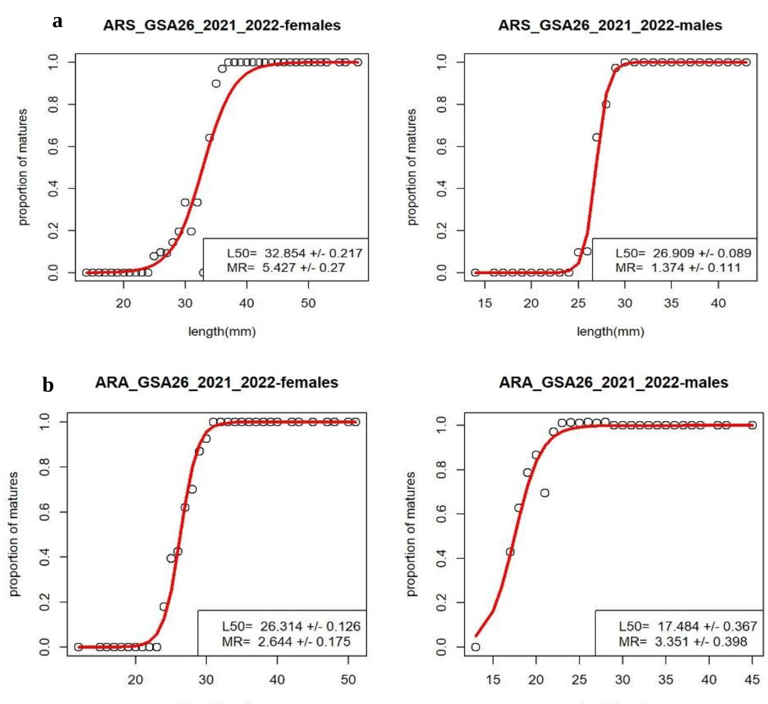

Fig. 4. Carapace length at first sexual maturity (CL_{50}) of (a) ARS and (b) ARA in GSA (26)

4. Growth parameters and natural mortality (M)

The growth parameters ($L\infty$, K and t0) were estimated using the length frequency distribution of the sexes combined for the two species. The growth parameter estimates were K= 0.41 year^{-1}, $L\infty$= 65.01mm, and t_0= -0.12 year, for ARS, while they were determined ARA as: K= 0.35 year^{-1}, $L\infty$= 57.51mm, and t_0= -0.50 year. Depending on the estimated growth parameters, the average of natural mortality vector (M) was 0.8 for ARS, and 0.77 for ARA.

5. LB-SPR model fitting

The length composition histograms for ARS and ARA species in GSA 26 with curves fitted by the LB-SPR model are shown in Fig. (5). It is clear that the model is able to fit the length frequency of the two species in the two years of data collection.

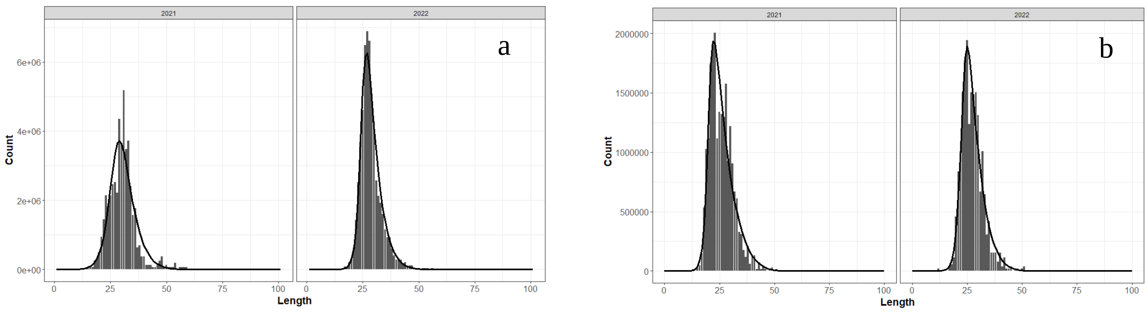

Fig. 5. LBSPR model fitting to the length composition of (a) ARS and (b) ARA in GSA (26)

6. Selectivity and maturity curves

The mean estimates of 50% selectivity ($SL_{50\%}$) and 95% selectivity ($SL_{95\%}$) for ARS were 25.6 and 31.02mm, respectively, while the mean estimates for ARA were 21.44 and 25.06mm. Selectivity curves for both species are drawn in Fig. (6).

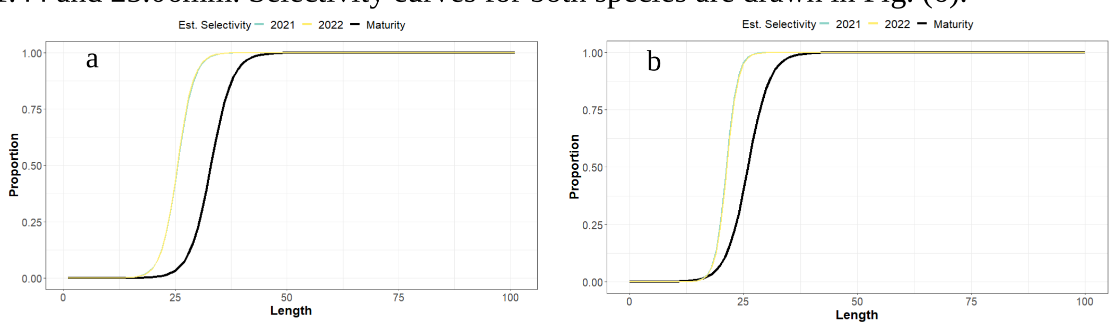

Fig. 6. Curves of maturity-at-length and selectivity-at-length of (a) ARS and (b) ARA in GSA (26)

7. Stock status indicators

The estimated F/M, selectivity-at-length, and the SPR of ARS and ARA stocks based on length frequency data are shown in Fig. (7). The estimated averages of F/M were 2.91 and 1.47 for ARS and ARA, respectively, indicating that both are higher than the threshold of F/M=1. In addition, the estimated averages of SPR were 0.062 and 0.17 for ARS and ARA, respectively. The calculated SPRs are below the desired reference point (0.40). Both F/M and SPR reveal that the stocks of ARS and ARA in GSA 26 are overexploited. The use of a lower-meshed trawl net in the fishery is demonstrated by other metrics too, such as mean length at 50% selectivity that was smaller than the length at maturity (25.6mm< 32.8m for ARS, and 21.44mm< 26.31mm for ARA).

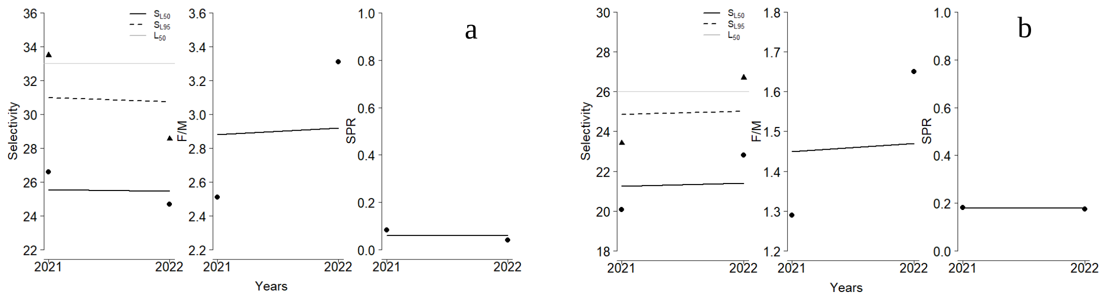

Fig. 7. Estimated SL_{50}, SL_{95}, F/M and SPR of (a) ARS and (b) ARA in GSA (26)

DISCUSSION

The length-based approaches are one of the methods commonly used in data-limited situations, where age determination has not been achievable **(Morgan, 1985; Parsamanesh *et al.*, 1998)**. In addition, the spawning potential ratio (SPR) is one of the known biological reference points that provides an indicator about the stock status since it refers to the proportion of natural, or unfished, reproductive production left in a population under fishing pressure **(Hordyk *et al.*, 2015)**.

The length-based spawning potential ratio (LB-SPR) model is based on the fact that the size structure of an exploited stock and its SPR are functions of relative fishing pressure (F/M), which is the ratio of fishing (F) to natural mortality (M), and the two life history ratios: M/K and L_{50}/ L_{∞} **(Beverton, 1963; Hordyk *et al.*, 2015)**. In the present study. The LB-SPR model was applied to estimate the spawning potential ratio (SPR) based on the length-frequency distribution of combined sex of the two deep-water red shrimps (DWRS), *A. foliacea* (ARS) and *A. antennatus* (ARA).

According to the estimated growth parameters, ARS revealed a slow growth and a long-life cycle, in accordance with the estimated life span recorded in other studies **(Politou *et al.*, 2004; Ragonese *et al.*, 2012)** at 7- 9 years for females. Similar to these results, the ARA seems to indicate a slow growth and long-life span (8- 10 years) for females **(D'Onghia *et al.*, 2005)**. These findings are in line with that reported in the present study.

Throughout the period of two-year data collection, the increase of F/M ratio along with the decrease of SPR support what was reported as the SPR for a species sharply decreases if the levels of F/M exceed the threshold of 1 **(Hordyk *et al.*, 2014)**. In the present study, the relatively high F/M ratio (2.91) for ARS and (1.47) for ARA are indications of the high fishing pressure on the two stocks. The SPR, which was estimated at 0.062 and 0.17 for ARS and ARA, respectively, did not exceed the target reference point (0.40) **(Mace & Sissenwine, 1993)**. Both indicators reveal that the stocks of DWRS (*A. foliacea* and *A. antennatus*) in the Egyptian Mediterranean waters are overexploited. According to the stock status, it is necessary to perform robust fisheries management options to maintain the exploitation level in line with the agreed reference points. This entails implementing measures, such as spatial and temporal restrictions, adjusting fishing gear, and conducting periodic evaluations of stock status. Additionally, recognizing the transboundary characteristics of the Mediterranean Sea, emphasizing regional and sub-regional collaboration and coordination becomes pivotal to provide an efficient approach for the conservation and sustainable management of DWRS stocks.

CONCLUSION

In conclusion, the findings of performing length-based assessment for the stocks of deep-water red shrimps, *Aristaeomorpha foliacea* and *Aristeus antennatus* reveals that the two stocks are overexploited depending on the spawning potential ratio (SPR), the ratio of fishing mortality (F), the natural mortality (M), and the carapace length at 50 and 95% selectivity (SL_{50} and SL_{95}). Management options that take into account the multispecies nature of the fishery are of prime importance to sustainably exploit these important fisheries in the Southeastern Mediterranean.

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