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Egg production and shell relationship of the land hermit crab *Coenobita scaevola* (Anomura: Coenobitidae) from Wadi El-Gemal, Red Sea, Egypt

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Abstract The aim of the present study is to characterize the fecundity of the land hermit crab *Coenobita scaevola* as well as the influence of shell type on fecundity using morphometric relationships. Hermit crabs were collected monthly from January to December 2007 from the protected area of Wadi El-Gemal, at Marsa Alam on the Red Sea, and ovigerous females were selected. Hermit crab wet weight and the gastropod shell weight were recorded. The number of eggs carried by females of several sizes (CL, carapace length), stages of development and egg size were determined. Shells of eight gastropod species were occupied by ovigerous females of *C. scaevola*. Shells of *Nerita undata* was the most occupied (65.7%), particularly by individuals falling within the size range 5.0–7.0 mm CL. Only 35 berried females were recorded during May, July and September and the mean fecundity was 679.8 ± 140 eggs. Fecundity was found positively correlated with crab size and shell dimensions. The relationship between fecundity and the internal volume of the occupied shell was ranked as the most correlated. The impact of shell utilization on hermit crab fecundity is discussed.

Introduction

Hermit crabs are decapod crustaceans that have developed strategies to utilize empty gastropod shells and other types of cavities to shelter their uncalcified abdomen (Litulo, 2005). According to Martinelli et al. (2002), there are currently more than 800 species of hermit crabs worldwide, ranging from the deeper parts of the oceans to intertidal habitats. Despite their importance, the reproductive aspects of these organisms are still poorly known, principally in such tropical habitats.

Fecundity is defined as the number of eggs produced per clutch per spawn that are attached to the pleopods of the female (Mantelatto et al., 2002). It is an important parameter in crustaceans. Knowledge of the fecundity of a species determines its reproductive potential (Negreiros-Fransozo et al., 1992) and/or the stock size of the population (Mantelatto and Fransozo, 1997) and possibly explains its reproductive adaptations to environmental conditions (Sastry, 1983). Hermit crabs, in particular, because they inhabit gastropod shells, afford an opportunity to study the interaction between resources and reproductive strategy (Mantelatto et al., 2002). According to Wilber (1989), a female's shell may affect its

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reproduction by determining whether or not it becomes ovigerous and/or limiting the number of eggs produced.

Coenobita scaevola (Forskäl, 1775), is the only coenobitid species in the Red Sea area (Vine, 1986). This land hermit crab is very abundant above sea level on the beaches of the Red Sea and on the highly arid shores of the Sinai Peninsula. It is totally dependent on the sea for water and consequently limited to the near shore area (Achituv and Ziskind, 1985). It has been studied for its pattern of shell utilization (Sallam et al., 2008) as well as for its population features and breeding season (Sallam and Mantelatto, 2010). This species has been reported to be the first organism to disappear from any shore when a new tourist establishment is constructed (Sallam et al., 2008). The authors concluded that the rarity or abundance of this sensitive species on any shore could reflect the degree of healthiness of that shore.

Despite its ecological significance, nothing is known of the egg production of this species. The objective of this investigation is to characterize the fecundity of *C. scaevola* from Wadi El-Gemal at Marsa Alam as well as the role played by the shell type and size using morphometric relationships and to compare it to the fecundity of other species.

Materials and methods

Hermit crabs were obtained monthly from January to December 2007 from the protected area of Wadi El-Gemal at Marsa Alam, Red Sea (Fig. 1). A non-destructive sampling design was adopted in order to avoid a negative impact on this ecological reserve and the population. Collections were made on the last week of the month. It was carried out during daytime over an area 300 m long over a period of 30 min. Hermit crabs were captured by hand and fixed immediately in 10% formalin sea water solution and brought to the laboratory for analysis. Each ovigerous female was removed carefully from the shell in an anticlockwise fashion, weighed (female wet weight, FWW), and measured on the basis of carapace length (CL = from the tip of the rostrum to the V-shaped groove at the posterior edge of the shield). Measurements were made by means of a Vernier caliper (0.1 mm accuracy). Shell species were identified according to Sharabati (1984) and the following measurements were made: shell weight (SW), shell aperture width (SAW) and shell aperture length (SAL). Shell internal volume (SIV) was determined by the amount of water required to fill the empty shell by means of a measuring pipette. The eggs were carefully removed from the pleopods and classified into developmental stages according to the methodology of Turra and Leite (2001): initial stage: stages 1 and 2, without eyes and yolk partially consumed; intermediate stage: stages 3 and 4, eye formation started and yolk partially consumed; final stage: stage 5, eyes formed and yolk totally consumed. They were then counted under a light stereomicroscope.

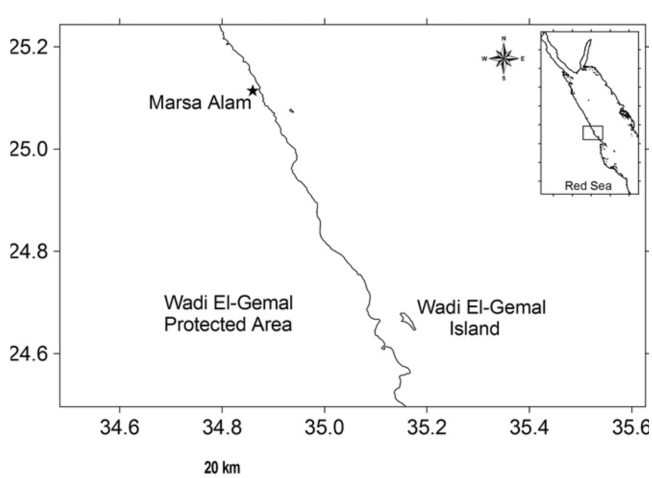

Figure 1 Map of indicating the area of sampling at Wadi El-Gemal, Marsa Alam, Red Sea.

Results

Shells of eight gastropod species were occupied by ovigerous females of *C. scaevola* (Plate 1). Shells of *Nerita undata* (Linnaeus, 1758) were the most occupied (65.7%). The other species with low percentage of occupation were *Nerita polita* (Linnaeus, 1758) (8.6%), *Cerithium caeruleum* (Sowerby, 1855) (5.7%), *Turbo radiatus* (Gmelin, 1791) (5.7%), *Nassarius arcularius plicatus* (Roding, 1798) (5.7%), *Modulus tectum* (Gmelin, 1791) (2.9%), *Nassarius coronatus* (Bruguière, 1789) (2.9%) and *Polinices tumidis* (Swainson, 1840) (2.8%). Shells of *N. undata* were the most inhabited by ovigerous females of the size range 5.0–7.0 mm CL (Fig. 2). Small-sized individuals (4.0–5.0 mm CL) occupied *N. coronatus* and *C. caeruleum*, while large-sized ones (6–7 mm) occupied the shells of *N. polita*, *M. tectum* and *T. radiatus*.

Out of 557 females collected, only 35 ovigerous females were found during the months: May ($n = 16$), July ($n = 15$) and September ($n = 4$) with 23.5%, 45.4% and 12.2%, respectively. The carapace length mean ± standard deviation of all ovigerous females was 5.84 ± 0.62 mm (range: 4.1–7.3 mm) and showed a unimodal pattern (Fig. 3). The mean fecundity was 679.8 ± 140 eggs with a range of 422 (CL = 4.1) to 945 eggs (CL = 7.3). Fecundity varied in function of the shell used by the females (Table 1). The occurrence of each of the three

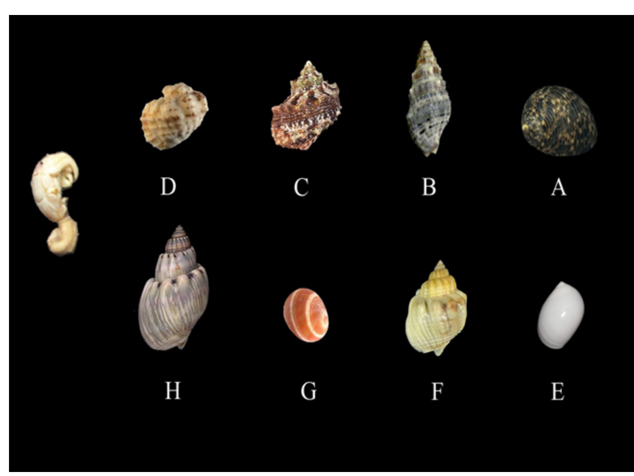

Plate 1 Ovigerous female *Coenobita scaevola* and the gastropod shells utilized. (A) *Nerita undata*; (B) *Cerithium caeruleum*; (C) *Turbo radiatus*; (D) *Modulus tectum*; (E) *Polinices tumidis*; (F) *Nassarius arcularius plicatus*; (G) *Nerita polita*; (H) *Nassarius coronatus*.

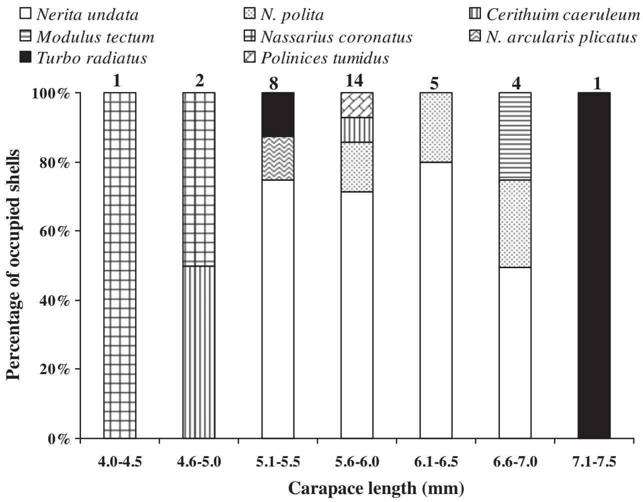

Figure 2 *Coenobita scaevola*. Percentage of occupation of gastropod shell species along the size frequency distribution of the ovigerous females (values above columns correspond to the number of individuals in each size class).

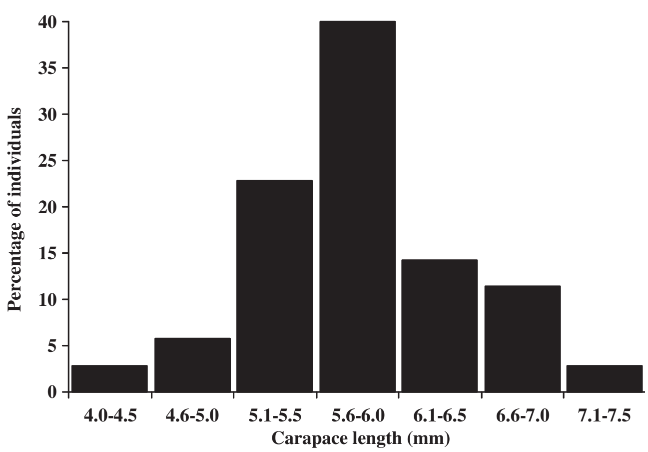

Figure 3 *Coenobita scaevola*. Size frequency distribution of ovigerous females collected from January to December 2007 ($n = 35$).

egg stages is shown in Fig. 4. Ovigerous females with eggs in the initial stage of development had perfect occurrence (100%) during May and September. Those in the intermediate stage were observed in July with a 20%, while individuals with

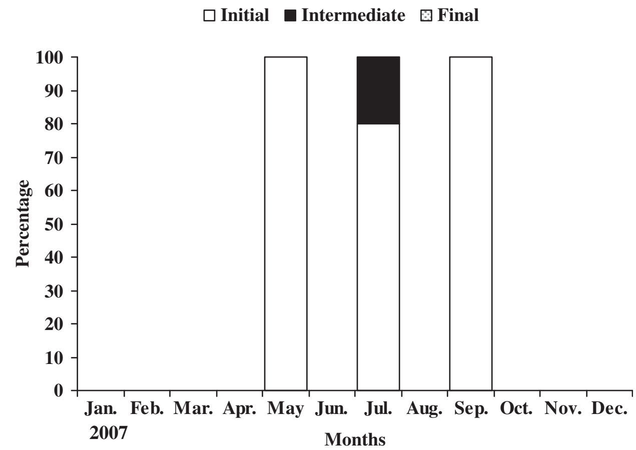

Figure 4 *Coenobita scaevola*. Percentage of ovigerous females with embryos in different developmental stages among the specimens collected on Wadi El-Gemal.

eggs in the final stage were totally absent. The egg number increased with increasing carapace length with a variation in the mean number of eggs in each size class (Fig. 5). No significant difference was found in the fecundity between seasons ($F = 1.29$, $P > 0.05$) (Fig. 6). However, the size of ovigerous females differed significantly between seasons ($H = 629.73$, df = 6, $P < 0.001$). Good relationships were observed between egg number and carapace length ($y = 0.8964x + 4.9153$, $r^2 = 0.7848$) (Fig. 7) and with crab weight ($y = 550.24x^{0.9912}$, $r^2 = 0.7845$) (Fig. 8).

Fecundity analysis carried out in relation to shell dimensions demonstrated positive correlations (Fig. 9). Regression equations for these relationships are as given in Table 2. The equations ranked the relationship between the fecundity and the internal volume of the occupied shell as recognized by the high correlation ($r^2 > 0.7$).

Discussion

The results presented in this paper bring new data to support previous findings on the reproductive aspects of *C. scaevola* of Wadi El-Gemal by Sallam and Mantelatto (2010). Females of this population achieve sexual *maturation early in their life cycle* and have a low reproductive rate when compared to other coenobitids. Mean fecundity of *C. scaevola* (679 eggs) is similar to that recorded for other pagurid hermit crabs from subtropical areas (Negreiros-Fransozo et al., 1992; Mantelatto

Table 1 Fecundity of females of *Coenobita scaevola* in the eight utilized shells in Wadi El-Gemal, Marsa Alam.

Gastropod shell	Number of individuals	Min. Max.	Mean fecundity ± standard deviation
Cerithium caeruleum	2	688 766	727 ± 55.2
Nerita polita	4	618 761	710.5 ± 63.4
Nerita undata	22	510 930	706 ± 142.6
Turbo radiatus	2	639 682	660.5 ± 30.4
Nassarius arcularis plicatus	2	422 747	584.5 ± 229.8
Modulus tectum	1	–	565
Nassarius coronatus	1	–	500
Polinices tumidis	1	–	393

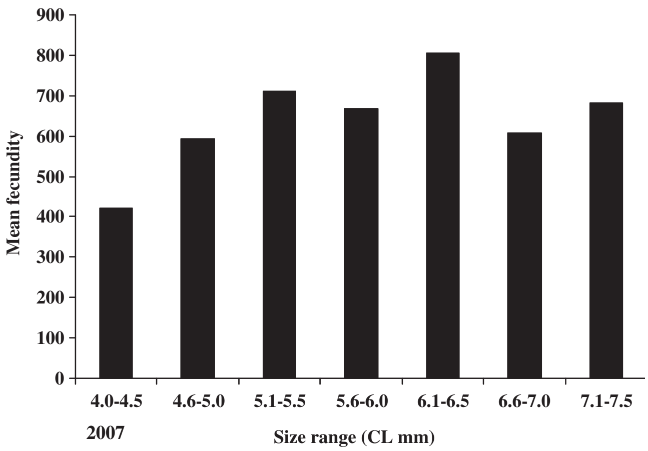

Figure 5 *Coenobita scaevola*. Mean fecundity per hermit crab size class ($n = 35$).

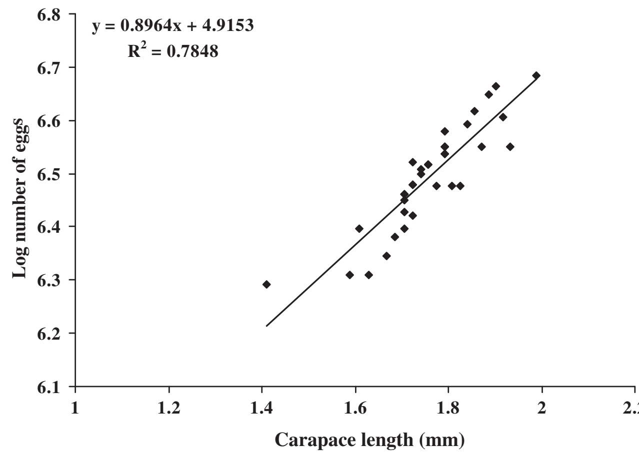

Figure 7 *Coenobita scaevola*. Linear regression between egg number and female size.

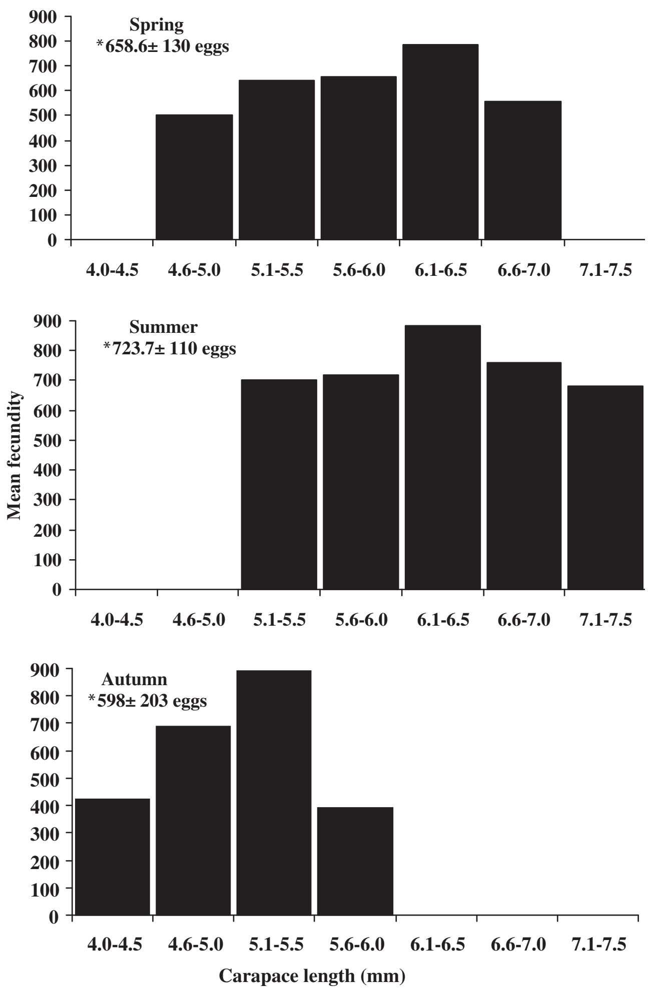

Figure 6 *Coenobita scaevola*. Mean seasonal fecundity per size class (* mean fecundity ± standard deviation).

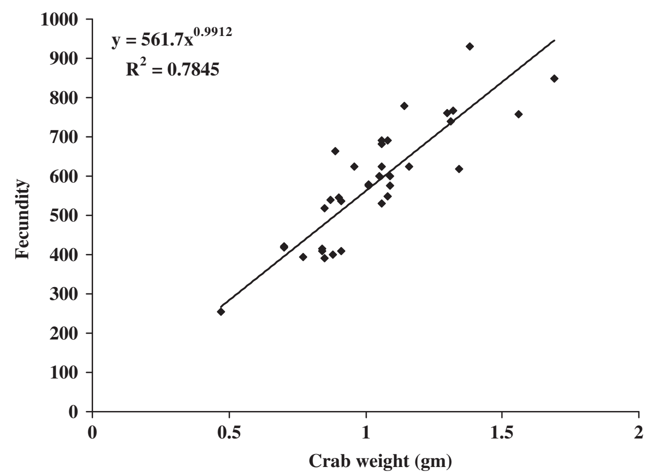

Figure 8 *Coenobita scaevola*. Relationship between egg number and female weight.

et al., 2002; Terossi et al., 2010). Fecundity increased in proportion with female shield length. The egg number of most hermit crabs increases in parallel with female size (Turra and Leite, 2001; Mantelatto et al., 2002; Macpherson and Raventos, 2004; Litulo, 2005). However, small variations in the number of eggs were observed within the same size class. According to Sastry (1983), Mantelatto et al. (2002) and Torati and Mantelatto (2008), this can be related to accidental eggs loss or incomplete fertilization.

On the other hand, fecundity showed no significant variations with seasons. In a previous study, Sallam and Mantelatto (2010) suggested that reproduction of this species is interrupted during some periods of the year. The authors concluded that this reproductive pattern could be explained as an adaptation to terrestrial habitats. Bertness (1981) stated that the reproductive pattern in hermit crabs can be continuous or seasonal and that the high reproductive activities and extended reproductive seasons are thought to be adaptations to shell limitation. Coddy (1966) reported that fecundity can be affected in different ways by particular conditions within each environment. Additionally, Yoshino et al. (2002) stated that future reproduction prospects determine the timing for reproduction of each individual, i.e., individuals with higher chances of survival would invest more energy into growth instead of

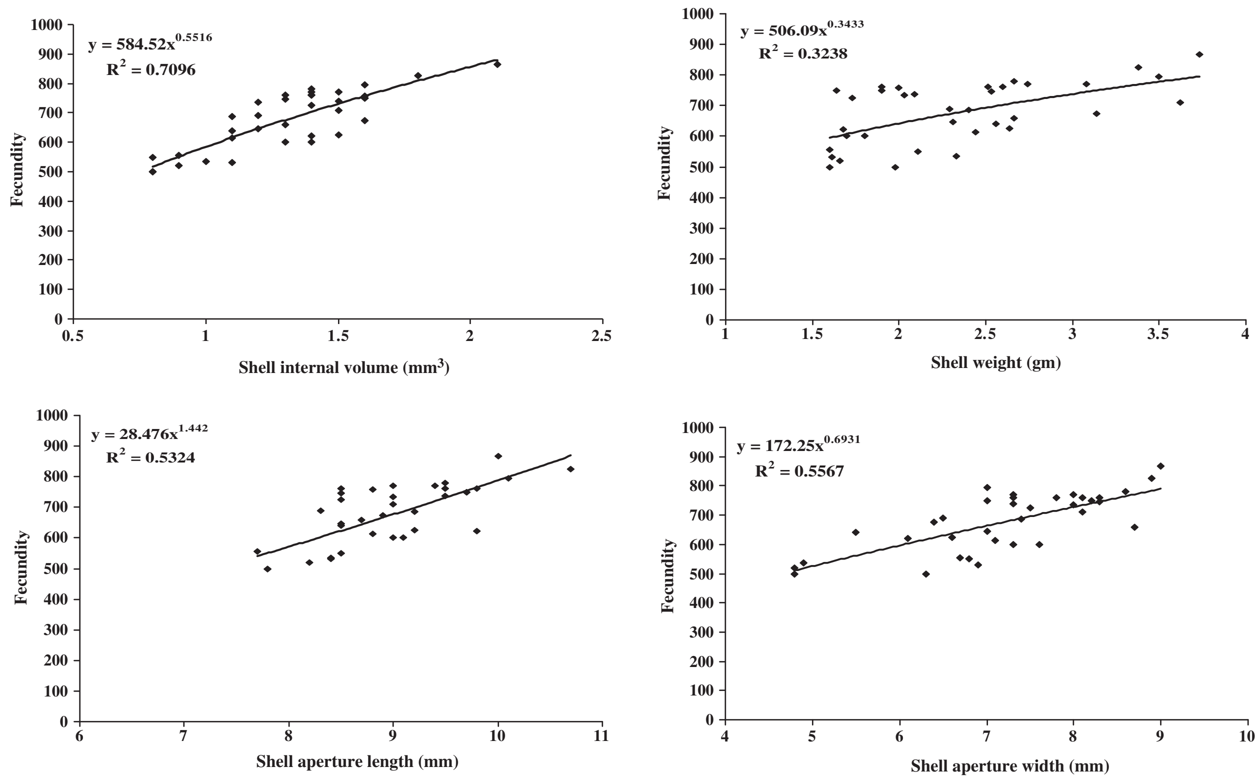

Figure 9 *Coenobita scaevola*. Regression analysis between fecundity and shell dimensions.

Table 2 *Coenobita scaevola*. Regression analysis of fecundity versus shell dimensions (r^2, correlation coefficient; Fe, fecundity; SWT, shell weight; SIV, shell internal volume; SAL, shell aperture length; SAW, shell aperture width).

Relationship	Power equation $Y = aX^b$	r^2
FE × SWT	$FE = 506.09SWT^{0.3433}$	0.3238
FE × SIV	$FE = 584.52SIV^{0.5516}$	0.7096
FE × SAL	$FE = 28.476SAL^{1.3442}$	0.5324
FE × SAW	$FE = 172.25SAW^{0.6931}$	0.5567

reproduction, whereas individuals with poorer prospects for survival would invest more energy into reproduction. Based on this scenario, it could be therefore inferred that the low/discontinuous reproductive strategy of *C. scaevola* females of Wadi El-Gemal is an adaptive response to the preserved non-stressful environment of this protected area in which energy is allocated toward growth rather than reproduction and *C. scaevola* population is not shell limited as indicated by the low frequency of ovigerous females in the different shell types.

Interestingly, ovigerous females showed a high plasticity of shell occupation, occupying shells of eight gastropod species, with *N. undata* being the most occupied. Sallam et al. (2008) reported *C. scaevola* to occupy 10 gastropod shell species with relative differences in shell occupation between sexes and a significant preference to *N. undata* by both sexes. The pattern presented by ovigerous females of *C. scaevola* may be associated with the availability of resources in the study area or that ovigerous females are more selective in the shell occupation due to their reproductive condition. Achituv and Ziskind (1985) reported *Polinices mammilla* as the most common shell used by *C. scaevola* at Shura-El-Gharqana on the western shores of the Sinai Peninsula. On the other hand, preference of *N. undata* may be due to the better adequacy provided by this shell for the females in terms of protection and space for egg storage. Sallam et al. (2008) concluded that *C. scaevola* preferred *N. undata* since it is the lightest shell available and that the energy saved by carrying lighter shells may be used to increase growth rate or egg production. According to Fotheringham (1976), shell weight directly affects the amount of energy used in reproduction, shifting it to activities such as locomotion and the search of food. In the present study, the number of eggs produced was larger among ovigerous females occupying lighter shells. The observation that *N. coronatus* and *C. caeruleum* were occupied by smaller ovigerous females while larger specimens occupied *M. tectum* and *T. radiatus*, reflects the influence of hermit crab size on shell species occupation and infers that ovigerous females occupy other shells when very small and very large shells of *N. undata* are not available. However, this assertion should be viewed with caution due to the limited number of individuals that occupied these shell species. The positive correlation between fecundity and the internal volume of shells noted in this study suggests that ovigerous females have a preference toward shells with enough volume to accommodate their swollen abdomens during egg carrying. Similar findings have been reported for several hermit crab species (Mantelatto et al., 2002; Iossi et al., 2005).

Despite the apparent ability of *C. scaevola* to adapt to the surrounding environment of Wadi El-Gemal, the low reproductive rate together with the non-continuous reproduction reflect the sensitivity of this species and emphasizes the need for constant monitoring of its population to ensure its sustainability in this preserved habitat.

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