Egyptian Journal of Aquatic Research (2016) 42, 111–119

HOSTED BY

ELSEVIER

National Institute of Oceanography and Fisheries

Egyptian Journal of Aquatic Research

http://ees.elsevier.com/ejar
www.sciencedirect.com

FULL LENGTH ARTICLE

Basic assessment of *Portunus segnis* (Forskål, 1775) – A baseline for stock management in the Western Arabian Gulf

Bruno Welter Giraldes *, Ibrahim Al-Maslamani, Aisha Al-Ashwel, Mark Chatting, David Smyth**

Environment Science Centre (ESC) at Qatar University (QU), Doha, Qatar

Received 3 January 2016; revised 7 February 2016; accepted 14 February 2016
Available online 4 March 2016

KEYWORDS

Blue swimming crab;
Coastal zone;
Marine biology;
Qatar;
Portunoidea;
Harsh environmental condition

Abstract *Portunus segnis* (Forskål, 1775) is the representative species of the *Portunus pelagicus* (Linnaeus, 1758) complex described as inhabiting the Arabian Gulf. It represents one of the most important decapod resources within this semi-enclosed hyper-saline and hyper-thermal marine eco-region. Previous biological and ecological descriptions for *P. pelagicus* (*latu sensus*) have focused on other *Portunus* species while *P. segnis* from the Arabian Gulf has remained undescribed. This is a matter of concern as without taxonomic and ecological descriptions a scientific baseline for standing stock management cannot be created. In order to collate comprehensive baseline data for *P. segnis* vital biological, ecological and taxonomic information was examined and those results can be used to form the basis of a management strategy for this species within the Arabian Gulf. The research combines an overview of local unpublished works and new information about morphometric relations, body size ratios, size maturity, mortality, fecundity, spawning, recruitment, growth, sex ratio, sex dimorphism, colour pattern, habitat, taxonomy and discussion about the effects of temperature and salinity on this species.

Introduction

Qatar in the western Arabian Gulf, presents a unique amalgamation of extreme environmental conditions within a shallow marine basin, with water temperatures reaching almost 40 °C in summer and salinity measurements as high as 70 ppt (Kämpf and Sadrinasab, 2006; Le Vay and Falamarzi, 2009; Riegl and Purkis, 2012). Qatar's marine environment is one of the least described regions within the Arabian Gulf in relation to its biodiversity and ecology. A literature overview of the relevant scientific journals associated with the Arabian Gulf reveals a lack of research into baseline ecological and biological aspects of its marine organisms. Therefore it is vital that these matters be addressed if an understanding of the current stock status of a primary fishery resource within the region is fully understood.

* Corresponding author. Tel.: +974 4403 6859; fax: +974 4403 3940.
E-mail address: bweltergiraldes@qu.eu.qa (B.W. Giraldes).

Peer review under responsibility of National Institute of Oceanography and Fisheries.

http://dx.doi.org/10.1016/j.ejar.2016.02.001
1687-4285 © 2016 National Institute of Oceanography and Fisheries. Hosting by Elsevier B.V.

The swimming crab previously identified as *Portunus pelagicus* (Linnaeus, 1758) is a major component of the decapod fishery in the Western Arabian Gulf. Despite its economic and regional importance within the fishery, no biological or ecological description exists of the species in the relevant scientific literature. The most comprehensive description is currently in an unpublished technical report (Le Vay and Falamarzi, 2009), which has been used in this study for some biological descriptive references. Lai et al. (2010) recently undertook a revision of the *P. pelagicus* species complex which recognises four individual species: *P. pelagicus* (Linnaeus, 1758), *Portunus segnis* (Forskål, 1775), *Portunus reticulatus* (Herbst, 1799) and *Portunus armatus* (A. Milne-Edwards, 1861). The authors identified the species in the Arabian Gulf as being *P. segnis* based on morphological and DNA characteristics. Prior to the research by Lai et al. (2010) *P. pelagicus* was considered to have worldwide distribution with the main ecological and biological information for the species based on studies performed in Australia (Wassenberg and Hill, 1987; Shields and Wood, 1993; Potter and de Lestang, 2000; de Lestang et al., 2003; Kumar et al., 2003; Sumpton et al., 2003). Therefore *P. segnis* in the Arabian Gulf still remains without ecological and biological descriptions. The absence of this baseline information represents a fundamental missing component to the creation of any worthwhile stock management strategy which would be specific to the fishery within the region.

Recent analysis of *P. segnis* (Forskål, 1775) specimens from Qatar and further unpublished information found in literature overview highlights some biological and ecological differences comparing previous descriptions for this species (Lai et al., 2010). In addition, the semi-enclosed hyper-saline and hyperthermal marine eco-region of the Gulf has been shown to stimulate allopatric speciation, meta-population conservation and hybridisations (Riegl and Purkis, 2012) emphasising the need for a better understanding of the adaptations within the biodiversity which allows species to survive these harsh conditions.

In order to present comprehensive baseline data related to *P. segnis* management in the Arabian Gulf, this study collected important biological, ecological and taxonomic information about *P. segnis* (Forskål, 1775) in the western Arabian Gulf.

Material and methods

Study area

Four inshore sites were selected on the North and East coast of Qatar (Doha, Ras Rakan, Al-Khor and Al-Wakrah). All sample sites were located in shallow water between 0.5 and 10 metres deep with variations in substrate types ranging from bedrock to sand and sea grass (Fig. 1).

Sampling methods

Biological material was collected by local fisherman in November 2014, using anchored gillnets fished on the seabed positioned at depths between 0.5 and 10 m. Personal communication with local fishermen confirmed that the shallow coastal waters are the most abundant habitat for this species. Only large mature specimens were used to describe taxonomic characteristics, morphological proportions, sexual dimorphism, and colour pattern. The sample species were caught and transported live to the biological laboratory at Qatar University. The morphological characteristics for each specimen were measured to the nearest 0.1 mm using electronic Vernier© callipers. Each individual crab was then photographed and deposited in the marine taxonomic collection at Environmental Science Centre at Qatar University (ESCQU). Terms and definitions used in this study are as

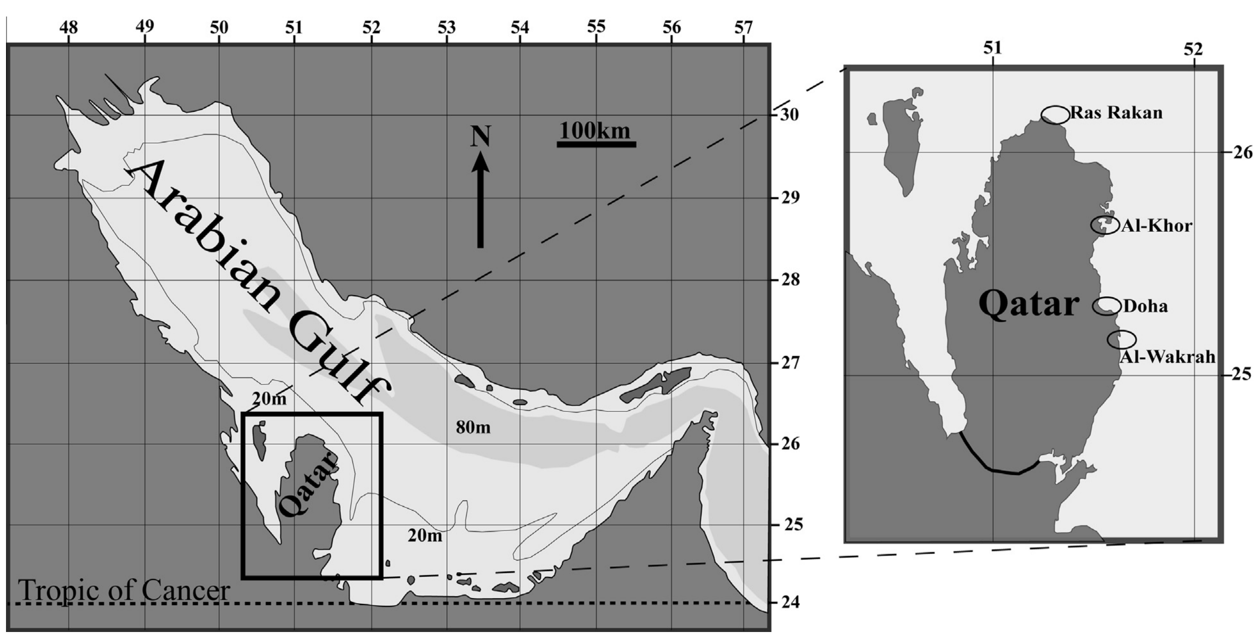

Figure 1 Map with geographic coordinates showing the position of Qatar in Arabian Gulf, the shallow area limits (20 m) and the sample sites in Qatar.

described by Lai et al. (2010). Survey dives were performed to describe in-situ species specific ecological and biological characteristics.

Data collection

Information for the sampled specimens on morphometric, taxonomic, behaviour, colouration and substrate background was obtained through in-situ field studies and collections. Further species specific information was obtained using a report published locally by the ministry of environment in Qatar (Le Vay and Falamarzi, 2009) and in a relevant thesis from Bahrain (Al-Rumaidh, 2002). Morphological and sexual dimorphism data were collected using, twenty measurements taken from each individual (Fig. 2A–F). Measurement specifics consisted of: Carapace Length (CL), Width (excluding 9th anterior-lateral tooth – CW1/and including 9th anterior-lateral tooth – CW2), Posterior Margin (PM), Antero-Lateral Border (ALB) and Frontal Margin (FM). For right and left cheliped were obtained the Merus Length (MEL), Merus Width (MEW), Manus Length (MAL), Manus Width (MAW), Dactylus Length (DAL). In the 4th pereiopod merus were obtained the Length (4PL) and the Width (4PW). As well as in the dactylus at natatory leg were obtained the Length (NDL) and the Width (NDW). In the abdomen were the Penultimate segment Length (PL) and width (PW), and Telson Length (TL) and Width (TW).

The measurements were standardised using derived ratios such as: CW1/CL, CW2/CL, CW1/CW2, PM/CL, ALB/CL FM/CL, MEL/MEW, MAL/MAW, MAL/DAL, 4PL/4PW, NDL/NDW, PL/PW, PL/TW, TL/TW, CW1/MEL, CW1/4PL, CW2/MEL, CW2/4PL. Statistical analysis was undertaken using Past© statistical software. Morphometric ratio comparisons between male and female were carried out using a one-way ANOVA. Missing values were not substituted. Morphological characteristics for each sampled specimen were obtained, based on taxonomic characteristics to distinguish the species in the *P. pelagicus* complex (Lai et al., 2010), this included: the Median frontal teeth; branchial region of carapace; carapace granulation; cheliped meri; spines on the anterior margin of cheliped merus; dactylus of fifth pereiopod; sixth segment of male abdomen and Carapace colour.

Results

Literature overview – specimens from West Arabian Gulf

Most information about *P. segnis* such as diagnosis, global distribution, habitat, colour pattern and genetic differentiation amongst other species in the complex are registered in Lai et al., 2010. However several information reported to species in the *P. pelagicus* complex is not addressed to *P. segnis* and this species from West Arabian Gulf still remain without description about specific habitat (for male, female and juveniles) maximum deep and further ecological and fishing stock information. According to local fishermen, personal observation and some local references unpublished in peer review articles (Al-Rumaidh, 2002; Le Vay and Falamarzi, 2009), in West

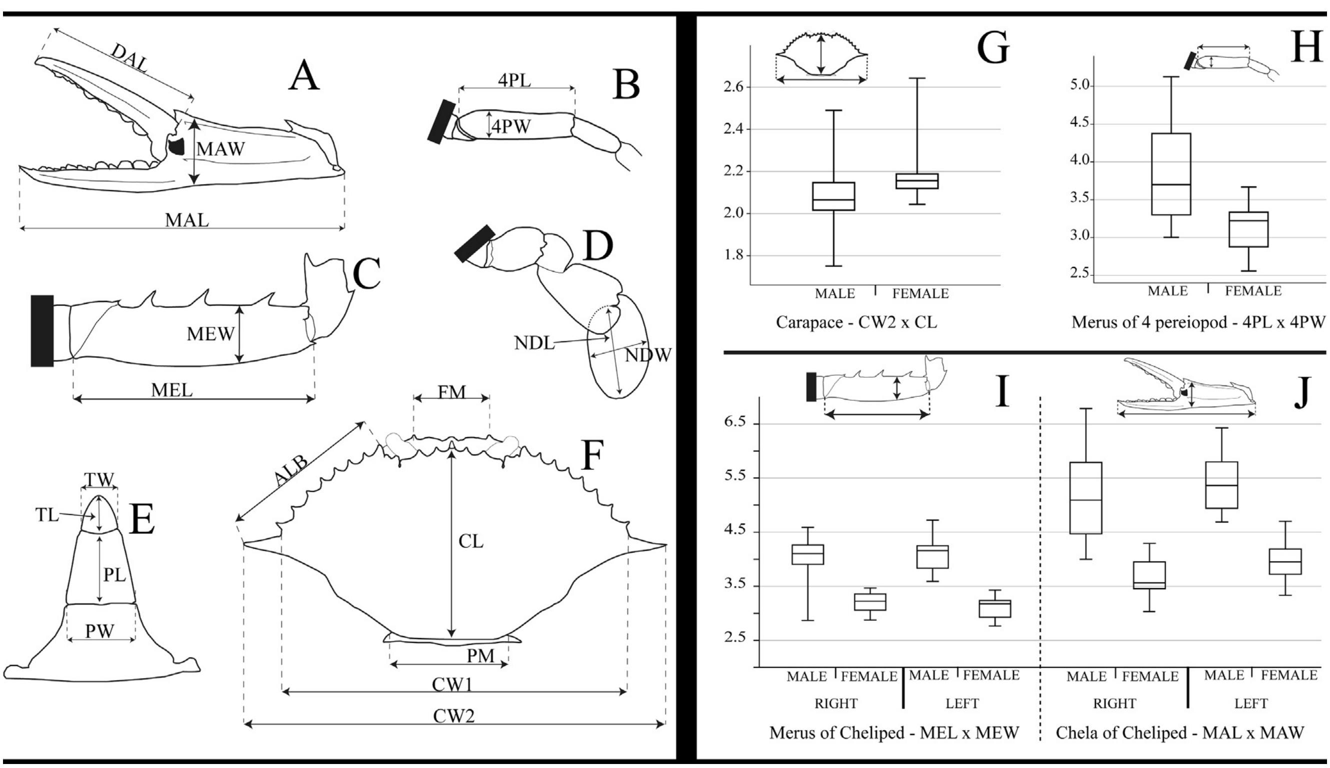

Figure 2 Schematic drawings highlighting morphological measurements and abbreviation, (A) chela or manus of chelipeds, (B) fourth pereiopod, (C) merus of chelipeds, (D) modified fifth pereiopod, (E) abdomen, (F) carapace; and box plot highlighting the rates with significant differences between males and females, (G) carapace, (H) merus of fourth pereiopod, (I) merus of right and left chelipeds and (J) chela/manus of right and left chelipeds.

Arabian Gulf this species inhabit mainly coastal waters in ecosystems like seagrass beds and mangrove, presenting larger biomass in water between 2 and 15 m deep, with small juveniles in very shallow waters (less than 1 m) and females occupying deep-water zones during spawning.

Regarding the feeding habits and diet *P. segnis* stomach analysis at Western Arabian Gulf has revealed a diet that includes fish, crustacean, molluscs, polychaetes and highly digested animal matter; including a considerable amount of algae both brown and green and inorganic material including sand, mud, synthetic fibres and plastics form pollutants (Zainal, 2013). The swimming crabs at *P. pelagicus* complex are prolific predators of bivalves (Lee, 1996) however they are also opportunist omnivore/detritivore (necrophagy) feeding on carrion especially fishing-discards (Wassenberg and Hill, 1987) and are an efficient nighttime forager with a large displacement during foraging forays. It uses a zigzag search pattern to find food moving towards its prey at a mean point-to-point speed of 290 m h^{-1} (8 cm s^{-1}) (Wassenberg and Hill, 1987).

The following biological information is based on Le Vay and Falamarzi (2009). The biometric relation between weight (Wt in g), carapace width and length (CW and CL in cm) is $Wt = 0.36 * CW^{2.567}$ with $r^2 = 0.946$ and $CL = 0.593 * CL + 0.208$ with $r^2 = 0.946$ for males; and $Wt = 0.26 * CW^{2.665}$ with $r^2 = 0.933$ and $CL = 0.619 * CL + 0.091$ with $r^2 = 0.939$ for females. The overall sex ratio is 1:3 with the majority of the month close to 1:1 only in August 2007 and May 2008 did the proportion of male's increase, probably as a result of the influx of small male recruits in August (2007) and the offshore migration of egg-bearing females in May (2008).

The size of maturity was recorded as 75–80 mm in accordance with the abdominal changes; 70–75 mm in relation to the unlocked abdominal flaps; and 80–89 mm for females with egg-mass. Larger females were shown to be more fecund producing more eggs in direct proportion to weight; females with 110–115 mm produced up to 450,000 eggs and with 85–90 mm producing 150–200,000 eggs, resulting in two equations – (1) egg n° = 1846.6 * weight-108 and (2) egg n° = $0.782 * CW^{2.78}$. Therefore females that measure 110–120 in carapace width will produce 2–3 times more eggs than females of 80–90 mm; in addition smaller females produced smaller eggs, which might be less viable.

The rate of growth (carapace width) oscillates between 16 and 26 mm $year^{-1}$ in small animals at shallow waters and 13–20 mm $year^{-1}$ for adults in deeper water zones. There are two seasonal periods for maturity and spawning in females, the most important is between December and March and the other between August and October. The length-frequency of species captured using traps, (which target larger animals), demonstrated that females of this faster growing species, presented young mature females (90–110 mm) starting to appear in March–April, (spring times), and in October–November they were in larger sizes of up to 110–120 mm. Small males started to appear in August–September with the mature sizes (80–110 mm) dominant between November and March.

Recruitment – the greatest peak in the abundance of juveniles was recorded in August and started in June with a small amount recorded in March. The length-frequency of species captured in trawls also demonstrated a recruitment of small specimens (20–60) during the summer months of June to August and in the winter from December to March. The maximum carapace width estimated in the growth study ($L\infty$) ranged from 150 to 159 mm; the growth values of (k) were 2.37 and 2.63. Mortality estimation – life span between 1.5 and 3 years and that mortality of 38–80%. Sex ratio present similar concentration between males and females (1.1–1.0 and 1.3–1.0); higher proportion of males occur in the spawning period probably due to the reproductive spawning migration of the females when they migrate to deeper waters.

New samples

Examined material

Total of 67 adults: (40 males and 27 females), 10 at Doha (5 male and 5 female/4Nov2014/ESCMC 00011); 20 at Ras Rakan (4 male and 6 female/5Nov2014/ESCMC 00012), (5 male/7Nov2014/ESCMC 00014) (1 male and 4 female/10Nov2014/ESCMC 00017).; 10 at Al-Khor (5 male and 5 female) 6Nov2014 (ESCMC 00013); 27 at Al-Wakrah (3 male and 5 female/8Nov2014/ESCMC 00015), (17 male and 2 female/9Nov2014/ESCMC 00016).

Divergences in morphology

Several characteristics reported for *P. segnis* (Lai et al., 2010) were observed in some sample specimens in Qatar such as: the median frontal teeth absent, inconspicuous and almost obsolete (38 specimens absent or obsolete – 29 male and 9 female); branchial region of carapace swollen convex (48 specimens – 20 male and 18 female); 3 spines on anterior margin of cheliped merus (30 specimens – 13 males and 17 females); three spines on anterior margin of cheliped merus (30 specimens – 13 males and 17 females); natatorial paddle elongated oval (37 specimens – 17 males and 15 female) with a ratio between 1.5 and 1.8; shorter and broader sixth segment of male abdomen, (36 males) with a ratio from 1.0 to 1.5; all males did not present distinguishable carapace granulation.

However, several specimens sampled in Qatar presented different characteristics to those described for *P. segnis* by (Lai et al., 2010) and presented confusing characteristics similar to other species within the complex, such as: median frontal teeth strong and sharp characteristics of *P. armatus* 7 (1 male and 6 female); branchial region of carapace not swollen (19 specimens – 10 male and 9 female) characteristics to *P. reticulatus* and *P. armatus*; four spines at least in one merus (10 specimens – 6 males and 4 females) characteristics of *P. armatus* and 1 male presented five spines; a rounded dactylus of P5 (25 specimens – 15 male and 10 female) with a ratio from 1.0 to 1.4, characteristic of *P. reticulatus* and *P. armatus*; narrower and more elongate sixth segment of male abdomen, (only 2 males) with a ratio of 0.9, characteristics of *P. reticulatus* and *P. armatus*; females present marked granulation on the carapace supposedly a characteristic to *P. armatus* however Lai et al. (2010) used males for taxonomic differentiation this character fits with the *P. segnis* description.

Divergences in morphometric relations

Due to some confusing measurements of carapace width on Portunidean crabs especially due to damages in the lateral spines the accurate measurement of individuals, presented in relation to Carapace widths of *P. segnis* in Arabian Gulf is as follows: The CW2 is 20% bigger than the CW1; therefore it is possible to insert a correction factor of approximately 20% (20 ± 4%) of the CW1 to obtain the total CW2 size for comparisons in further studies. The largest known recorded specimen (CW2) for *P. segnis* is a female from Syria, 158.4 × 75.4 mm (Lai et al., 2010); in this study the largest female was 162 mm from an Al-Khor sample and 159 mm for a male in Doha; in Bahrain waters the largest male was 160 mm (Al-Rumaidh, 2002); and in Iran in the east side of Gulf was 173 mm (Kamrani et al., 2010). All specimens were slightly below the maximum growth estimation for CW2 with 180–190 mm (L∞) (Le Vay and Falamarzi, 2009).

According to Lai et al. (2010) in the diagnosis for *P. segnis* the morphometric ratios were: carapace width (CW2) 2.2–2.3 times wider than long; chelipeds merus of adult males maximum 4.5 times longer than wide; ambulatory legs with merus of 4th pereiopod 3.3–4.4 (median 3.6) longer than wide; and natatorial paddle similar with *P. pelagicus* with about 1.7 times longer than wide. Comparing those ratios with the specimens sampled here in the Arabian Gulf (Table 1): for carapace fits with females (2.170.11) while males are under the reported diagnosis (2.08 ± 0.11); at chelipeds merus females are far from maximum (right 3.2 ± 0.17 and left 3.11 ± 0.18) and males a bit inferior (right 4.08 ± 0.37 and left 4.08 ± 0.29); in 4th pereiopod ratios females are inferior (3.13 ± 0.3) and males fits perfectly (3.86 ± 0.54); and the natatorial paddle ratio was inferior in females (1.48 ± 0.15) and males (1.45 ± 0.1).

Table 1 Studied rates comparing structures of *P.* cf *segnis* in western Arabian Gulf in females and males; presenting the rates average and standard variation according with sexes and the statistical *p* (bold significant difference).

Rates	Female	Male	(*p*)
Carapace			
CW1/CW2	1.21 ± 0.03	1.2 ± 0.04	0.1879
CW1/CL	1.79 ± 0.09	1.74 ± 0.11	0.08589
CW2/CL	2.17 ± 0.11	2.08 ± 0.11	**0.002518**
ALB/CL	0.9 ± 0.05	0.88 ± 0.04	0.06655
FM/CL	0.41 ± 0.03	0.4 ± 0.02	0.08027
PM/CL	0.63 ± 0.04	0.59 ± 0.03	**0.0002146**
Right cheliped			
MAL/MAW	3.64 ± 0.37	5.15 ± 0.76	**0.0001447**
MAL/DAL	2.25 ± 0.24	2.31 ± 0.08	0.6194
MEL/MEW	3.2 ± 0.17	4.08 ± 0.37	**0.0001442**
Left cheliped			
MAL/MAW	3.94 ± 0.34	5.36 ± 0.5	**0.0001447**
MAL/DAL	2.13 ± 0.17	2.23 ± 0.08	0.1326
MEL/MEW	3.11 ± 0.18	4.08 ± 0.29	**0.0001442**
Pereiopod			
4PL/4PW	3.13 ± 0.3	3.86 ± 0.54	**0.0001132**
NDL/NDW	1.48 ± 0.15	1.45 ± 0.1	0.5347
Abdomen			
PW/PL	2.52 ± 0.23	1.01 ± 0.06	**0.0001079**
TW/TL	1.27 ± 0.11	1.06 ± 0.09	**0.0001082**
PL/TW	1.41 ± 0.11	1.88 ± 0.15	**0.0001082**
Carapace x appendage			
CW2/MEL	1.68 ± 0.2	1.29 ± 0.15	**0.0001469**
CW2/4PL	4.58 ± 0.66	3.82 ± 0.54	**0.0001379**
CW1/MEL	1.38 ± 0.17	1.07 ± 0.12	**0.0004243**
CW1/4PL	3.77 ± 0.53	3.17 ± 0.44	**0.0001079**

Additional colour pattern information

Sexual dimorphism was recorded in colour patterns with two standard colours for males and two standard colours for females (Fig. 3), including subtle variations in those two standard colours. The males and especially females presented the dark green colours (*obscure-viridis, nebulosus*) first described by Forskål, (1775, as *Cancer segnis*) and Savigny (1826, Crabes-nageurs) which has not been reported for other species in the *P. pelagicus* complex (Lai et al., 2010). During the diving survey, it was noticeable that those colours work as mimicry, a cryptic colour pattern camouflaging the animal in its associated substrate. When specimens were observed within a bleached seagrass habitat the species, (particularly females) presented a yellow brownish colour (Fig. 3F, H); when observed in live green seagrass or in green microbial mats they were predominantly greenish (Fig. 3A, C, E, G). It was observed that the cryptic colouration was employed in conjunction with defence behaviour. The crab remained in crypsis, squatted down with the chelipeds folded and fitted into the cephalothorax, and when under threat it would abruptly change the behaviour to an aposematic position raising its body from the bottom and opening its chelipeds to lateral, thereby increasing the apparent size of the body and exposing a conspicuous colour in an aposematic position and colour pattern (Fig. 3I) which included one eyespot (ocelli) in the palm of the chelas. Males presenting an aposematic position and colour in a more aggressive manner than females were observed. Young mature males presenting a similar colour to that of females; their main male expression (the chelipeds) being smaller than larger mature males. This may suggest different patterns between males due to possible competition for a mate.

Discussion

Taxonomical features and morphometric patterns

We support that morphologically the species in the west Arabian gulf is *P. segins* as described (Lai et al., 2010) but it is necessary to use more than only one taxonomic feature to confirm the diagnosis and for some specimens the description and identification key drives for a different species in the complex. It is possible that the similarities between *P. segnis* found in the Arabian Gulf and other species in the *P. pelagicus* complex such as *P. reticulatus* and *P. armatus* are revealing a hybrid population in the western Arabian Gulf; similar hybridism between species in the *P. pelagicus* complex has previously been reported in Australia (Lai et al., 2010). The extreme environmental conditions in the West Arabian Gulf represent a strong biogeographic barrier that can stimulate allopatric speciation and vicariance. Therefore we do not dismiss the possibility of the Arabian *P. segnis* being a different hybrid species or meta-population and only more specific genetic analysis can identify this issue. This study is presenting for the first time morphological differences for *P. segnis* identification in the Arabian Gulf and morphological characteristics for female identification.

Comparisons in morphometric ratios highlight some important differences between the described *P. segnis* and the specimens sampled during this study. Once again, this species in the Western Arabian Gulf seems to be the *P. segins*

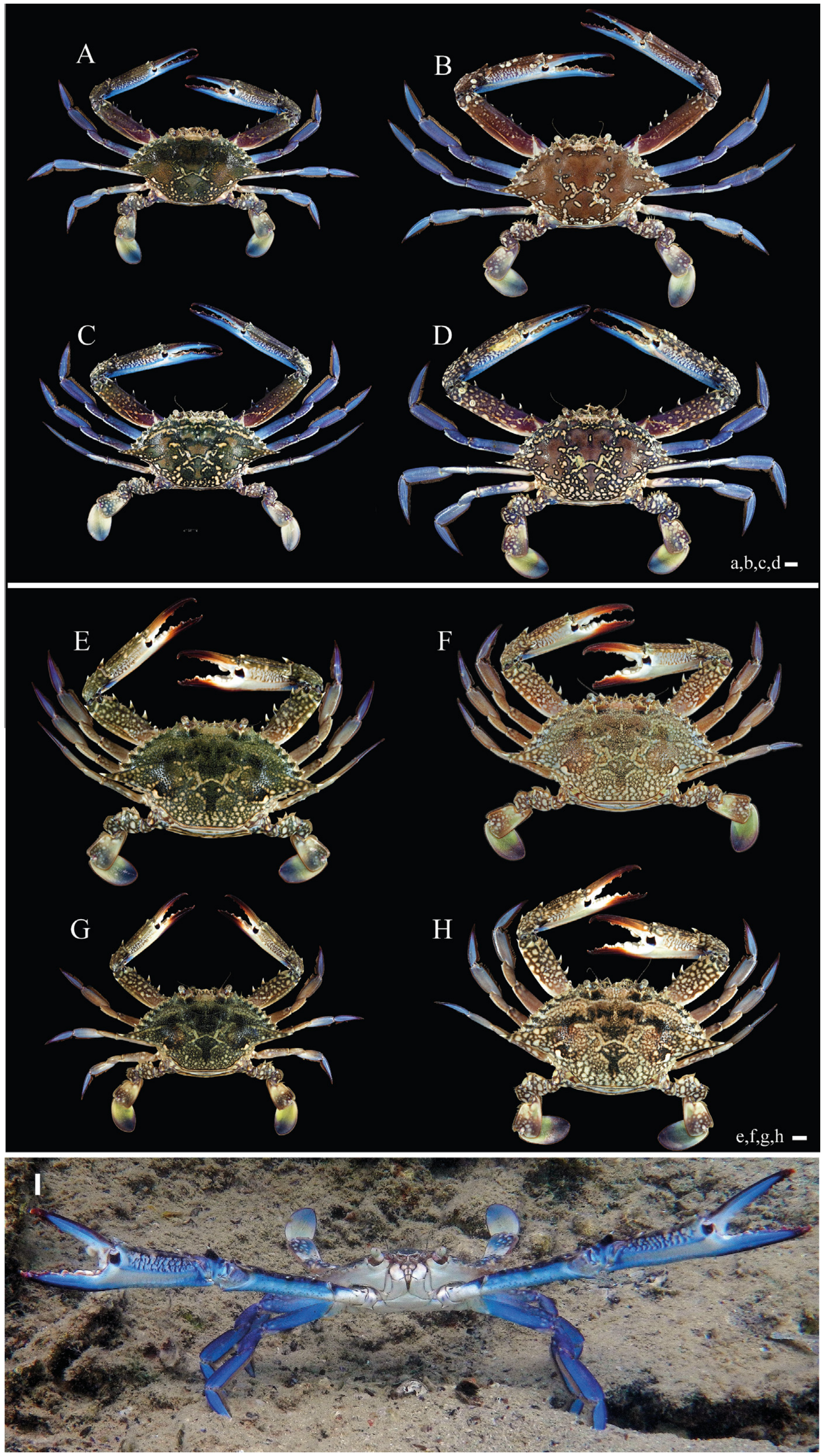

Figure 3 *Portunus segnis* of western Arabian Gulf. (A–D) males, (E–H) females. Scale 1 cm (a–h). (I) *Portunus segins in situ* with aposematic position and colour, highlighting the eyespot (ocelli) in the palm of the chelas.

described in references; however the population adaptation required for the extreme environmental conditions may be driving a speciation or a differing meta-population adapted to survive in hyper-thermic and hyper-saline conditions, presenting only subtle morphological differences. The morphometric results presented in this study have not been previously undertaken, in particular the differences between males and females, with females presenting significant larger carapace and abdomen rates and males larger chelipeds and pereiopods (Table 1) (Fig. 2G–J). The ratios presented here (Table 1) will be of use in future studies when comparing the sizes and ratios of other species in the complex acting as reference to differences in relation to body size within the species; as well as comparisons for the same species in different regions and life stages.

Life colour patterns

The colour patterns of specimens in Western Arabian Gulf agree in parts with the descriptions for *P. segnis* (Lai et al., 2010). However we are describing here different colour patterns for males and females and those differences can be addressed to different habitat with different environmental conditions and different diet, a defence behaviour using mimetic strategies. The colour patterns described here have already been well discussed within the insect evolution of colouration in arthropods (Vasconcellos-Neto and Gonzaga, 2010). This mimicry with different colour morphotypes as a predatory avoidance strategy has also been recorded for decapod species which inhabit heterogeneous substrates as a means of protection against visual predators such as: *Cancer productus* J.W. Randall, 1840 in Krause-Nehring et al. (2010), *Lepidopa benedicti* Schmitt, 1935 in Nasir and Faulkes (2011), *Paraxanthus barbiger* (Poeppig, 1836) in Manríquez et al. (2008) amongst others.

Regarding young mature males with female colour details and patterns, this can be a result of ecological adaptation to avoid competition between males for a mate or niche. The species within the *P. pelagicus* complex are known to be extremely competitive and this is commonly expressed in cannibalistic behaviour (Marshall et al., 2005), which in turn leads to habitat segregation (Tanner, 2007). This constant competition can go some way to explaining the aggressive behaviour of males, the constant aposematic position and colour displays. The aggressive competition between sexually mature males may be the reason why young adult males hide their identity by presenting feminised characteristics. On the other hand, females present more cryptic behaviour with a greater plasticity in colours which allows a more accurate camouflage amongst its habitual substrate type; but also presents an aposematic position and colour when threatened.

Adaptation for extreme salinity and temperature

The most influential abiotic pressure suffered by marine species in the western Arabian Gulf is the extreme hyperthermic and hyper-saline conditions. The effects of shallow water and high evaporation rates during the summer months can result in water temperatures of 40 °C and salinities reaching 70 (Kämpf and Sadrinasab, 2006; Le Vay and Falamarzi, 2009; Riegl and Purkis, 2012). These localised harsh conditions can influence the life cycle of *P. segnis* in several ways: size maturity, growth, fecundity, spawning, recruitment and mortality. When compared with other species in the *P. pelagicus* complex, *P. segnis* from the Arabian gulf is smaller than Australian specimens, with maturity attained at a smaller size (Abdel Razek, 1988; Reeby et al., 1990; Le Vay and Falamarzi, 2009; Sumpton et al., 2003). One of the main characteristics which are affected by extreme conditions in "R strategist" such as marine invertebrates is mortality, particularly during the first life stages (larvae and juveniles) (Clarke, 1979; McConaugha, 1992). This is due to the fact that salinity and temperature represent the most important synergistic ecological parameters in relation to larvae mortality (Rumrill, 1990). Abiotic contributing factors such as temperature and salinity will undoubtedly influence an animals biology and this was observed when comparing this studies results to those for *P. segnis* in Iranian waters on the east cost of the Arabian Gulf (Kamrani et al., 2010). The referred authors showed that *P. pelagicus* presents a larger maximum size, larger average size of fecundity and higher fecundity. Highlighting that the east coast of the Gulf is exposed to a different range of abiotic conditions such as a lower salinity and temperature (Riegl and Purkis, 2012). Therefore, these reproductive differences and reductions in size displayed by *P. segnis* on the West coast of Arabian Gulf may be a result of reproductive and physiological adaptations to avoid the extreme summer conditions.

One important strategic adaptation is the reproductive migration to deeper waters performed by females of *P. segnis* in the western Arabian Gulf (Al-Rumaidh, 2002; Le Vay and Falamarzi, 2009). This behaviour ensures a higher rate of successful spawning as more favourable temperatures for the spawn are achieved in deeper waters between 15 and 40 m; at these deeper depths water temperature remains at an almost constant (22–28 °C) while in shallow coastal areas temperatures regularly fluctuate and can reach > 35 °C (de Lestang et al., 2003; Le Vay and Falamarzi, 2009; Riegl and Purkis, 2012). This migratory behaviour is seen in other swimming crab species such as *Callinectes ornatus*, *Scylla serrata*, *Callinectes sapidus* and species within the *P. pelagicus* complex but it performed as a strategy to ensure safe spawning without competition from aggressive males (Shields and Wood, 1993; Hill, 1994; Carr et al., 2004; de Andrade et al., 2014). However the migratory episodes displayed by *P. segnis* in the Arabian Gulf are more than a strategic avoidance behaviuor to minimize competition from aggressive males. They ensure a higher rate of spawning success in biologically favourable temperatures. A similar scenario has been documented in relation to the larvae of *P. pelagicus* in Australia where the highest survival rate of larvae was recorded in temperatures of between 22.5 and 25 °C, with a rapid increase in mortality as temperatures deviated from this optimal range (Bryars and Havenhand, 2006). Comparable responses to temperature variations have been recorded in tropical decapod species under laboratory conditions, with constant reproduction and high viability documented at an ideal tropical temperature of approx. 28 °C (Dawirs et al., 1986; Goy, 1981; Johns, 1981; Thessalou-Legaki, 1990; Rhyne et al., 2005).

The present study also revealed other reproductive adaptations to avoid extreme summer conditions during spawning as two specific spawning periods were identified for *P. segnis* females. The most prolific periods being in spring (March-April), and the second in autumn (October–November) (Al-Rumaidh, 2002; Le Vay and Falamarzi, 2009). These spawning periods fit with the seasonal temperature changes which can range from 40 °C in June and July dropping to less than 15 °C in January and February (Le Vay and Falamarzi, 2009; Sheppard et al., 2010; Riegl and Purkis, 2012). The recruitment of juveniles is synchronised with the spawning period peaks during August, exactly two months after the height of the spawning period (Le Vay and Falamarzi, 2009). The same authors report a small but constant recruitment of juveniles demonstrating that some females present a constant spawning period with a low survival rate of smaller larvae. This suggests a constant reproduction of *P. segnis* in the Gulf with spawning and recruitment peaks limited by seasonal temperatures.

Baseline for fishing management of P. segnis

The Arabian Gulf has been recognised as a sea in ecological decline with several contributing factors such as; anthropogenic impacts, harsh environmental conditions, (Sheppard et al., 2010) and overfishing, this is in combination with a fishery resource in a compromised state since the late 1970s (Valinassab et al., 2006). References (Al-Abdulrazzak and Pauly, 2013) and personal communication with local fishermen has revealed that a considerable number of fish species are disappearing from the shorelines of Qatar. The largest fishery biomass removal has been through the implementation of a combination of fishing activities, these include gillnets placed along inshore subtidal zones near mangroves or in sea grass beds. This form of fishing practice is particularly non-selective and is contributing to an already high fishing impact on *P. segnis* (Al-Abdulrazzak and Pauly, 2013), and personal observation] with this sort of activity leading to several tons of landings that recently intensely increase (Carpenter et al., 1997; Al-Abdulrazzak and Pauly, 2013). Unchecked fishing practices such as these may be skewing official figures for the fishery. The actual scenario may be a regional fishery already overfished for some considerable time (Al-Abdulrazzak and Pauly, 2013), and the true state of the stock is now only being reflected by the low trophic level species which are now becoming more abundant. Now that *P. segnis* is recognised as a new species to the western Arabian Gulf, the baseline information presented here may go some way in assisting the implementation of management strategies and monitoring programmes. These could be used as tools for the better understanding of the current standing stock of this species and its ecological relation with other species.

Conclusion

A considerable proportion of data presented here in this study represents new information for this species with particular reference to taxonomic features, morphometric, colour patterns and reproductive biology and behaviour. The documented biological information will help in further comparative studies for other swimming crab species. The findings about biological adaptations to survive in this harsh environment reported in this study may also help in the understanding of some ecological patterns for marine species in the Arabian Gulf. The target species in this study has different population and biological patterns and therefore it is very important to describe and differentiate it from other species in the *P. pelagicus* complex. This research actively questions the status of the species in the Western Arabian Gulf with particular emphasis on its morphological similarities to other species in the complex. The findings suggest a hybridisation has occurred. The most significant outcome of this study is in the provision of ecological and biological baseline information. This will be invaluable to the successful implementation of future species monitoring programmes and management strategies. Which will be needed in the near future to address the dramatic decline in this important marine resource if a fishery stock collapse scenario is to be avoided.

Conflict of interest

The authors declare that there are no conflicts of interest.

Acknowledgements

The authors would like to thank the staff from the Environmental Scientific Centre for logistical support during the study with particular thanks to Mr. Ahamed Abdel Aziz for illustrations and Ms. Amanda Engmann for the deposit of species in the Marine collection.

References

Abdel Razek, F.A., 1988. Some biological studies on the Egyptian crab *Portunus pelagicus* (Linnaeus 1766). Acta Adriat. 29, 133–143.

Al-Abdulrazzak, D., Pauly, D., 2013. From dhows to trawlers: a recent history of fisheries in the Gulf countries, 1950 to 2010. Fish. Center Res. Rep. 21, 59.

Al-Rumaidh, M.J., 2002. The Biology Population Dynamics and Fishery Management of the Blue Swimming Crab *Portunus pelagicus* (Linaeus, 1758) in Bahareini Waters. University of Wales, Bangor.

Bryars, S., Havenhand, J., 2006. Effects of constant and varying temperatures on the development of blue swimmer crab (*Portunus pelagicus*) larvae: Laboratory observations and field predictions for temperate coastal waters. J. Exp. Mar. Biol. Ecol. 329, 218–229.

Carpenter, K.E., Krupp, F., Jones, D.A., Zajonz, U., 1997. Living Marine Resources of Kuwait, Eastern Saudi Arabia, Bahrain, Qatar, and the United Arab Emirates: FAO Species Identification Field Guide for Fishery Purposes. FAO, Rome.

Carr, S.D., Tankersley, R.A., Hench, J.L., Forward, R.B., Luettich, R. A., 2004. Movement patterns and trajectories of ovigerous blue crabs *Callinectes sapidus* during the spawning migration. Estuar. Coast. Shelf Sci. 60, 567–579. http://dx.doi.org/10.1016/j.ecss.2004.02.012.

Clarke, A., 1979. On living in cold water: K-strategies in antarctic benthos. Mar. Biol. 55, 111–119.

Dawirs, R., Püschel, C., Schorn, F., 1986. Temperature and growth in *Carcinus maenas* L. (Decapoda: Portunidae) larvae reared in the laboratory from hatching through metamorphosis. J. Exp. Mar. Biol. Ecol. 100, 47–74. http://dx.doi.org/10.1016/0022-0981(86)90155-3.

de Andrade, L., Bertini, G., Fransozo, V., 2014. Differential occupation of habitat as a reproductive strategy of the blue crab *Callinectes ornatus* Ordway, 1968 (Crustacea: Decapoda). Mar. Biodivers. 44, 27–36.

de Lestang, S., Norman, G.H., Potter, I.C., 2003. Reproductive biology of the blue swimmer crab (*Portunus pelagicus*, Decapoda: Portunidae) in five bodies of water on the west coast of Australia. Fish. Bull. 101, 745–757.

Goy, J., 1981. Larval development of the spider crab *Mithrax pleuracanthus* Stimpson reared in the laboratory (Decapoda: Brachyura: Majidae). J. Crustac. Biol. 1, 51–62.

Hill, B.J., 1994. Offshore spawning by the portunid crab *Scylla serrata* (Crustace : Decapoda). Mar. Biol. 120, 379–384. http://dx.doi.org/10.1007/BF00680211.

Johns, D., 1981. Physiological studies on *Cancer irroratus* larvae. I. Effects of temperature and salinity on survival, development rate and size. Mar. Ecol. Prog. Ser. 5, 75–83.

Kämpf, J., Sadrinasab, M., 2006. The circulation of the Persian Gulf: a numerical study. Ocean Sci. 2, 27–41. http://dx.doi.org/10.5194/os-2-27-2006.

Kamrani, E., Sabili, A.N., Maziar, Y., 2010. Stock assessment and reproductive biology of the blue swimming crab, *Portunus pelagicus* in Bandar abbas coastal waters, Northern Persian Gulf. J. Persian Gulf 1, 11–22.

Krause-Nehring, J., Starck, J.M., Palmer, A.R., 2010. Juvenile colour polymorphism in the red rock crab, *Cancer productus*: patterns, causes, and possible adaptive significance. Zoology 113, 131–139. http://dx.doi.org/10.1016/j.zool.2009.09.002.

Kumar, M., Xiao, Y., Venema, S., Hooper, G., 2003. Reproductive cycle of the blue swimmer crab, *Portunus pelagicus*, off southern Australia. J. Mar. Biol. Assoc. UK 83, 983–994.

Lai, J.C.Y., Ng, P.K.L., Davie, P.J.F., 2010. A revision of the *Portunus pelagicus* (Linnaeus, 1758) species complex (Crustacea: Brachyura: Portunidae), with the recognition of four species. Raffles Bull. Zool. 58, 199–237.

Le Vay, L., Falamarzi, M., 2009. Population Biology and Inshore Fishery assessment for the blue swimming crag, *Portunus pelagicus*. Doha, Qatar.

Lee, S.Y., 1996. Distribution pattern and interaction of two infaunal bivalves, *Tapes philippinarum* (Adams and Reeve) and *Anomalocardia squamosa* (Linnaeus) (Bivalvia: Veneridae). J. Exp. Mar. Biol. Ecol. 201, 253–273. http://dx.doi.org/10.1016/0022-0981(96)00015-9.

Manríquez, K.C., Pardo, L.M., Wells, R.J.D., Palma, A.T., 2008. Crypsis in *Paraxanthus barbiger* (Decapod:Brachyura): mechanisms against visual predators. J. Crustacean Biol. 28, 473–479.

Marshall, S., Warburton, K., Paterson, B., Mann, D., 2005. Cannibalism in juvenile blue-swimmer crabs *Portunus pelagicus* (Linnaeus, 1766): effects of body size, moult stage and refuge availability. Appl. Anim. Behav. 90, 65–82.

McConaugha, J., 1992. Decapod larvae: dispersal, mortality, and ecology.A working hypothesis. Am. Zool. 32, 512–523. http://dx.doi.org/10.1093/icb/32.3.512.

Nasir, U., Faulkes, Z., 2011. Color Polymorphism of Sand Crabs, *Lepidopa benedicti* (Decapoda: Anomura: Albuneidae). J. Crustacean Biol. 31, 240–245. http://dx.doi.org/10.1651/10-3356.1.

Potter, I.C., de Lestang, S., 2000. Biology of the blue swimmer crab *Portunus pelagicus* in Leschenault Estuary and Koombana Bay, south-western Australia. J. R. Soc. West. Aust. 83, 443–458.

Reeby, J., Prasad, P.N., Kusuma, V., 1990. Size at sexual maturity in the male crabs of *Portunus sanguinolentus* and *P. pelagicus*. Fish. Technol. 27, 115–119.

Rhyne, A.L., Penha-Lopes, G., Lin, J., 2005. Growth, development, and survival of larval *Mithraculus sculptus* (Lamark) and *Mithraculus forceps* (A. Milne Edwards) (Decapoda: Brachyura: Majidae): economically important marine ornamental crabs. Aquaculture 245, 183–191. http://dx.doi.org/10.1016/j.aquaculture.2004.11.016.

Riegl, B., Purkis, S., 2012. Coral Reefs of the Gulf: Adaptation to Climatic Extremes in the World's Hottest Sea, vol. 3. Springer, Netherlands. http://dx.doi.org/10.1007/978-94-007-3008-3_1.

Rumrill, S., 1990. Natural mortality of marine invertebrate larvae. Ophelia.

Sheppard, C., Al-Husiani, M., Al-Jamali, F., Al-Yamani, F., Baldwin, R., Bishop, J., Benzoni, F., Dutrieux, E., Dulvy, N.K., Durvasula, S.R.V., Jones, D.A., Loughland, R., Medio, D., Nithyanandan, M., Pilling, G.M., Polikarpov, I., Price, A.R.G., Purkis, S., Riegl, B., Saburova, M., Namin, K.S., Taylor, O., Wilson, S., Zainal, K., 2010. The Gulf: a young sea in decline. Mar. Pollut. Bull. 60, 13–38. http://dx.doi.org/10.1016/j.marpolbul.2009.10.017.

Shields, J., Wood, R.-E., 1993. Impact of parasites on the reproduction and fecundity of the blue sand crab *Portunus pelagicus* from Moreton Bay, Australia. Mar. Ecol. Prog. Ser. 92, 159–170. http://dx.doi.org/10.3354/meps092159.

Sumpton, W., Gaddes, S., McLennan, M., Campbell, M., Tonks, M., Good, N., Hagedoorn, W., Skilleter, G., 2003. Fisheries Biology and Assessment of the Blue Swimmer Crab (*Portunus pelagicus*) in Queensland. Canberra, Australia.

Tanner, J.E., 2007. The influence of introduced European green crabs (*Carcinus maenas*) on habitat selection by juvenile native blue crabs (*Portunus pelagicus*). Estuaries Coasts 30, 601–606. http://dx.doi.org/10.1007/BF02841957.

Thessalou-Legaki, M., 1990. Advanced larval development of *Callianassa tyrrhena* (Decapoda: Thalassinidea) and the effect of environmental factors. J. Crustacean Biol. 10, 659–666.

Valinassab, T., Daryanabard, R., Dehghani, R., Pierce, G.J., 2006. Abundance of demersal fish resources in the Persian Gulf and Oman Sea. J. Mar. Biol. Assoc. UK 86, 1455. http://dx.doi.org/10.1017/S0025315406014512.

Vasconcellos-Neto, J., Gonzaga, M., 2010. Evolução de padrões de coloração em artrópodes. Oecol. Aust. 8, 337–370.

Wassenberg, T., Hill, B., 1987. Feeding by the sand crab *Portunus pelagicus* on material discarded from prawn trawlers in Moreton Bay, Australia. Mar. Biol. 95, 387–393.

Zainal, K.A.Y., 2013. Natural food and feeding of the commercial blue swimmer crab, *Portunus pelagicus* (Linnaeus, 1758) along the coastal waters of the Kingdom of Bahrain. J. Assoc. Arab Univ. Basic Appl. Sci. 13, 1–7. http://dx.doi.org/10.1016/j.jaubas.2012.09.002.