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الغذاء الطبيعي و طرق تغذية السرطان السابح الأزرق التجاري *Portunus Pelagicus* (لينوس 1758) في المنطقة الساحلية في مملكة البحرين

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الملخص:

ينتشر السرطان السابح الأزرق *Portunus pelagicus* في نطاق جغرافي واسع حول العالم وهو من الأنواع التجارية المهمة على إمتداد مياه الدول الواقعة في المنطقة شبه الإستوائية، ولهذا فهو يشكل جزء رئيسي من الثروة السمكية. وبالرغم من أن إستهلاك هذا النوع من القشريات محدود محليا إلا أنه يدعم صناعة متنامية في هذا المجال. يتواجد السرطان السابح في الموائل الرملية والطينية وبين الحشائش البحرية. أن المعلومات عن المكون الغذائي الطبيعي لأنواع القشريات التي تتبع العائلة (Portunidae) على سواحل البحرين والخليج العربي تكاد تكون نادرة. تبحث هذه الدراسة عن المكون الغذائي للسرطان السابح الذي تم الحصول عليه بإستخدام عدد محلية للصيد وذلك خلال الأعوام 2004 و2005 و2007. لقد تم إجراء قياسات مورفولوجية على 371 فرد بحيث تم إستخدام 271 معدة لتحليلات مدى الإمتلاء و196 معدة لتحليل المكون الغذائي. الاختلاف في النتائج تبعا للجنس أو الموسم تم فحصه بتطبيق إختبارات احصاء ANOVA وANCOVA بإستخدام برنامج SPSS-v18. لقد وجد بأن المحتوى الغذائي لهذا النوع من السرطان البحري متنوع بشكل كبير جداً مما يعكس قدرته على اللجوء إلى وسائل متعددة للحصول على الغذاء. ويمكن وصف هذا السرطان بأنه Omnivorous (أي يتناول مكونات غذائية من مصادر حيوانية و نباتية على حد سواء)، ولكن هناك أدلة على تفضيل المصادر الحيوانية عند التغذية. لقد وجد بأن هناك جزء كبير من محتويات المعدة شملت على القشريات والرخويات والأسماك مقارنة بالمواد النباتية. أيضا تبين وجود ترسبات في أكثر من 50 % من معد الأفراد مما يدل على اعتماد هذا النوع من السرطان على التغذية الترسيبية (Deposit Feeding). كما وجدت الدراسة بأن هناك العديد من معد السرطانات احتوت على ألياف صناعية وبلاستيكية مما يدل على وجود تلك الملوثات في البيئة المحيطة. بالنسبة لاثر الجنس، فإن النتائج الإحصائية لم تبين وجود فروق ذات دلالة إحصائية بين الذكور والإناث من حيث المكون الغذائي بالرغم من أن المعد الأكثر إمتلاء كانت في الغالب تعود للذكور. كما بينت النتائج بأن الذكور من الناحية المرفولوجية أكبر جسماً من الإناث ومحتوى معدها من الأسماك والديدان البحرية كان أكثر تكرارا منه للإناث. بالرغم من هذه الاختلافات فأنها ليس لها أثر على النتائج عندما يتم أخذ أثر حجم الجسم بعين الإعتبار عند التحليل الإحصائي بإستخدام ANCOVA. كما وجدت الدراسة بأن الإختلافات في إمتلاء المعدة مع الموسم وخصوصا خلال شهري أغسطس ويونيو كان معتبراً حسب الدلالة الإحصائية.

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ORIGINAL ARTICLE

Natural food and feeding of the commercial blue swimmer crab, *Portunus Pelagicus* (Linnaeus, 1758) along the coastal waters of the Kingdom of Bahrain

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KEYWORDS

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Stomach content;
Stomach fullness;
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Diet analysis

Abstract The blue swimmer crab *Portunus pelagicus* has a wide geographical distribution and is an important commercial species throughout the subtropical waters and as such constitutes part of the fisheries resources. Although, local consumption of this species is low, the species support a fast growing industry. They are found inshore on sandy and muddy habitats and among sea grass beds. Data are lacking on the natural diet of Portunids along the coastal waters of Bahrain and the Arabian Gulf. This study investigates the natural diet and feeding of *P. pelagicus*. The crabs were obtained from local fish-trap catches during 2004, 2005 and 2007. Morphometrics were carried out on 371 individuals but 271 stomachs were used for the stomach fullness analysis and 196 were used in the diet analysis. The difference between sexes and seasonality was assessed using ANOVA and ANCOVA through SPSS v.18. The diet of this species is highly variable reflecting the ability of adopting different modes of feeding. *P. pelagicus* can be described as omnivorous although, the preference for animal matter was evident. Higher proportion of stomachs had tissues of crustaceans, molluscs and fish compared to plant matter. The occurrence of sediment in over 50% of the stomachs indicates adopting periods of deposit feeding. Many individuals had synthetic fibres and plastics confirming the presence of these pollutants in the surrounding. No significant dietary difference was obtained between the sexes although the trend for greater stomach fullness was apparent in the males. Morphometrically, males were significantly ($p \leqslant 0.05$) larger than females. Fish and polychaetes were found more frequently in the males than females but these differences disappeared when adjusted for body size (ANCOVA). The difference in stomach fullness over time was significant ($p \leqslant 0.05$) in particular, between the months of August and June.

1. Introduction

Blue swimmer crab, *Portunus pelagicus* has a wide geographical distribution worldwide and is an important commercial species throughout the subtropical waters and as such, constitutes part of the fisheries in Bahrain. Portunidae is widely distributed in the Gulf and growing fisheries exist in Bahrain and Saudi Arabia landing respectively 3248 and 4472 tonnes in

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2007 (FAO, 2010). These animals are generally found inshore in sandy and muddy habitats as well as among sea grass beds.

The best method of diet analysis and the relative importance of food items in Portunid crabs have been recognised by Williams (1981), who compared a sample size of around 30 gastric mills (50% full) and concluded that this sample size is adequate in order to determine the description of a natural diet of these crabs. Information on diet analysis helps formulating a nutritional requirement of the animal, its interaction with other organisms and its potential for aquaculture (Williams, 1981). *P. pelagicus* has been described to be a bottom feeding carnivore eating a wide variety of sessile and slow moving invertebrates (Williams, 1982). Furthermore, juvenile *P. pelagicus* in intertidal areas have a more stable diet compared to the adult and little changes are detected with body size (Williams, 1982). It is known that these crabs stop feeding prior to and during the moulting stage. Also, the diets of smaller crabs and larger crabs were different in the Leschenault Estuary, Australia (De Lestang et al., 2000). This was related to the greater ability of larger crabs to consume larger preys. These authors have also found that crabs will stop feeding and fill their stomach with calcareous pieces prior to moulting. Cannicci et al. (1996) have reported no significant difference in the diet composition between juveniles and adults of some other portunidae of the mangroves but their diet varied with the time of the day and with the tidal rhythm.

On the other hand, the morphology of the stomach of decapod crustaceans has been related to the type of food taken though phylogenetic constraints cannot be overlooked (Patwardhan, 1935a–e; Schaefer, 1970; Caine, 1975). Data are lacking on the natural diet of Portunid crabs along most of the coastal areas of Bahrain and the Arabian Gulf. The study objectives can be summarised into three main areas: (i) the stomach content and fullness to determine the natural diet (ii) the effect of gender, size and temporal variation on the diet/food preferences and stomach fullness and (iii) general investigation of the stomach internal morphology of *P. pelagicus*.

2. Materials and methods

P. pelagicus were collected monthly for 6 months during 2004–2005 from early morning catches using traps locally known as Haddrah. Further data were obtained during 2007 using trap baskets known as Gargoor off the coastal areas of Bahrain. On arrival, 50 individuals of both males and females were randomly selected from each monthly batch. In total, 371 individuals were kept frozen, measured to the nearest mm for their carapace width, carapace length, chelae and abdominal width. They were weighed to the nearest gramme, their gastric mills carefully dissected out and preserved in 5% formalin prior to the examination using both dissecting and compound microscopes. Out of 371, a total of 271 were used in the stomach fullness analysis and out of 271, 196 were used for diet/stomach content analysis for both male and female individuals.

Data were analysed using SPSS version-18 package to compare between different sizes, sexes and seasonality. Carapace length, width and a range of other morphometric analyses were carried out as part of allometric growth studies for this species (Zainal, unpublished data). The body size was used as a covariate in the ANCOVA analysis.

Each individual stomach was placed on its ventral side in a Petri dish and its general appearance was noted. The stomachs of *P. pelagicus* were examined by cutting along a longitudinal axis either through the cardio–pyloric valve or through the dorsal tooth so that in this latter case the intact cardio–pyloric valve could be seen. A longitudinal cut was made carefully using fine scissors and the stomach was assessed for its fullness. The following categorisation of fullness was followed; (100%), (50%), (25%) and ($<25\%$).

Stomach contents were removed by overturning the stomach and flushing it with water to ensure that all the fine particles were separated from the tissues and that the stomach structures (ossicles/gastric mill) were clean. The stomach contents were examined at magnifications ranging from 50 to 250×. Identifications of the content were restricted to the general taxonomic grouping level. Occasionally, much of the gut material was highly digested and such contents were included under the term 'unidentified'.

One-way analysis of variance (ANOVA) was used to test whether the stomach fullness of crabs varied significantly between months (temporal variation) or between sexes. Tuckey's post hoc test was carried out to determine which means were significantly different at $p \leqslant 0.05$. A comparison was made using ANOVA to test between sex differences in terms of food preferences.

The mean percentage occurrence of each dietary category to the diets of different size of classes over time was root-transformed and a similarity matrix constructed using the Bray–Curtis similarity coefficient. Bray–Curtis similarity coefficient was constructed for a combination analysis of dietary category and sex.

To investigate the feeding behaviour of this species, individuals of crabs were held in the laboratory aquarium at room temperature and salinity of normal sea water (45 ppt) and fed on a daily basis either on processed feed or freshly frozen shrimps.

3. Results

The diet of *P. pelagicus* appears to be very variable (Table 1) and indicates an ability to adopt different modes of feeding. The content of 196 stomachs was divided between 15 categories ingested as food items, regardless of the quality of that item. For example, plastic, glass or sand. The diet appears to be mainly of the animal origin with fish and crustaceans appearing to dominate. The percentage of food item out of all stomachs examined included fish (50.5%), crustacean (44.4%), molluscs (20.4%), polychaetes (15.6%) and highly digested animal matter (39.6%). The crabs also consume a considerable amount of algae both brown and green (30.6%). Sand or mud was present in over 50% of the stomachs. Variation in polychaete setae and jaws indicates that several species of these worms were taken. The crustacean component of the diet included smaller crustaceans such as the mysids, crabs and others. Fish component was highly digested and although fish spines, scales and bones can be easily recognised, no taxonomic identification can be made. Molluscs included both gastropods and bivalves. On rare occasions, echinoderms such as the spines of sea urchins were identified. The algal material and sea weeds contributed considerably to the diet. In laboratory observations, the crabs were readily fed on processed animal

Table 1 Stomach content items of 196 both male and female *P. pelagicus* from coastal waters of Bahrain. Frequency of occurrence and rankings are indicated. Rank 1 indicates the highest frequency of occurrence.

No.	Category	Frequency of occurrence	Percentage frequency of occurrence (%)	Ranks
1	Animal tissues	109	39.6	4
2	Crustaceans	122	44.4	3
3	Polychaete	43	15.6	9
4	Mollusca	56	20.4	7
5	Oil droplets	19	6.9	13
6	Fish bones and scales	139	50.5	2
7	Chaetae	82	29.8	5
8	Spines	21	7.6	12
9	Brown algae	59	21.5	6
10	Green algae and other seaweeds	25	9.1	10
11	Sand/quartz/mud	141	51.3	1
12	Synthetic fibres	48	17.5	8
13	Glass pieces	9	3.3	14
14	Plastics and nylon	3	1.1	15
15	Unidentified/ highly digested	30	10.9	11
	Total	1213	100.0	

matter such as frozen shrimps. However, starved individuals will accept any food item. The occurrence of sediment (sand and quartz) in the majority of stomachs is an indicative of periods of deposit feeding. In addition, many crabs had synthetic fibres in their stomachs from fishing nets. Pieces of glass, plastic and nylon indicate the presence of these pollutants in the bottom sediment where they can be taken during feeding. The variation in diet with size was not obvious since most individuals belonged to the large sizes category (Fig. 2). Microorganisms, sand particles, setae and a small amount of undigested tissue were found entrapped by the stomach ossicles (Table 1).

The stomach fullness analysis was carried out on 271 individuals. During this investigation, no 100% empty stomachs were obtained although some stomachs could be regarded as virtually empty <25–10% full. Approximately equal number of males and females were examined. Table 2 shows that more males were obtained in the category 1 (100% full stomach) compared to those of females. Out of 271 stomachs, 118 were in the ($<25\%$) category whereas, 101 stomachs were in the

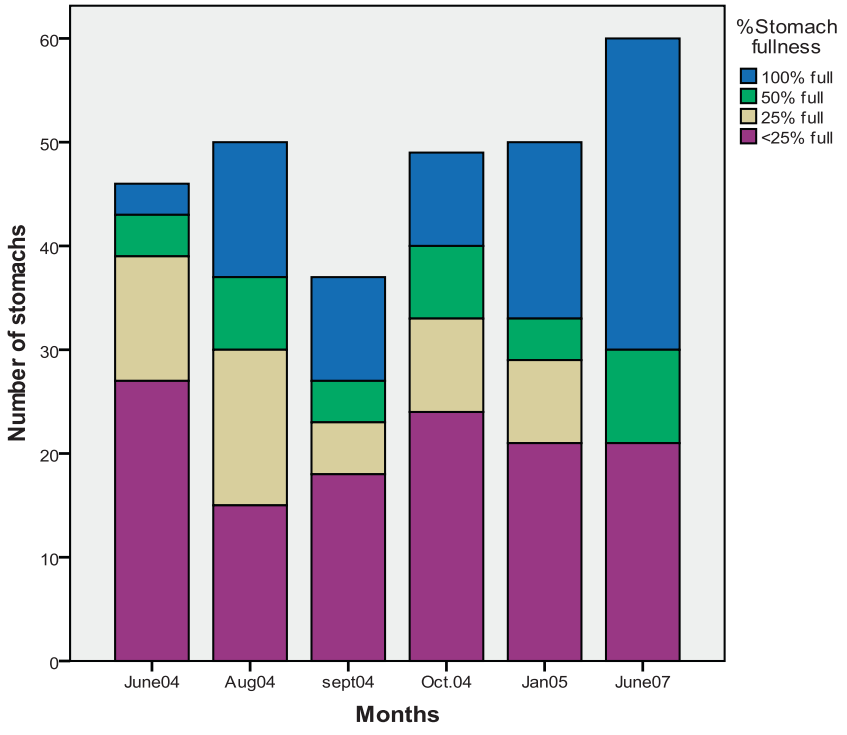

Fig. 1 Temporal variation in the stomach fullness categories for *P. pelagicus* along the coastal waters of Bahrain.

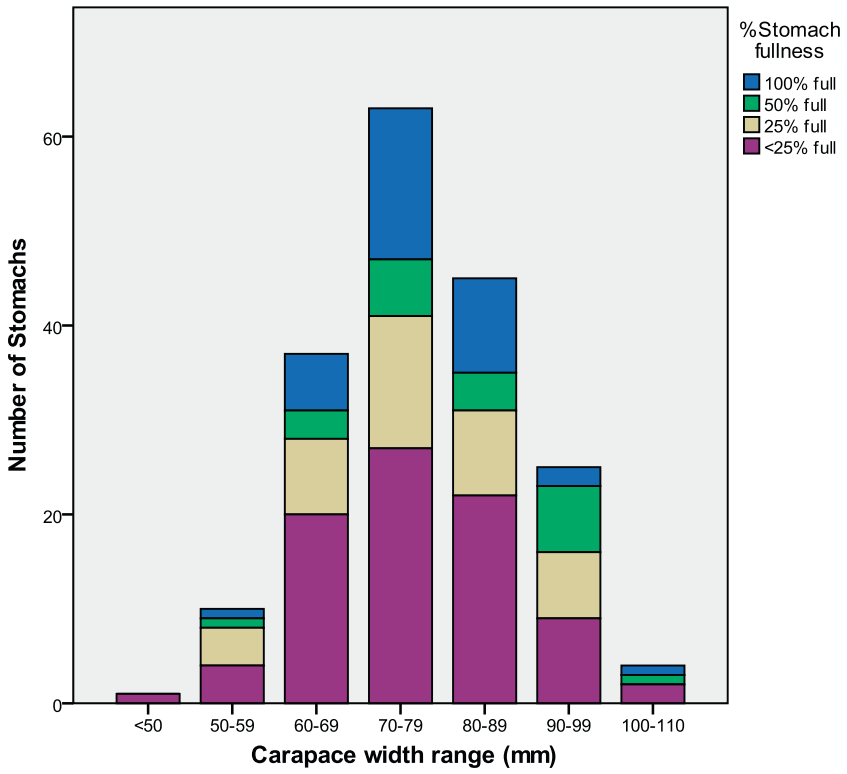

Fig. 2 Variation in the stomach fullness with different size ranges taken as carapace width in mm.

Table 2 Total number and percentage occurrence of stomach fullness of both males and females *P. pelagicus* over the study period.

Stomach fullness categories	No. of females (%)	No. of males (%)	Total
100%	30 (41.1)	43 (58.9)	73
50%	16 (57)	12 (43)	28
25%	26 (50)	26 (50)	52
<25%	61(51.7)	57 (48.3)	118
Grand total	133	138	271

category range (50–100% full). In addition, more full stomachs were obtained during the months of summer.

The trend for greater stomach fullness (100%) in the catches was particularly apparent in males (58.9% of the total) whereas, females had greater fullness within the category (50%) or below (57% and 52% of the total) (Table 2). However, under the stomach fullness category of 25%, equal occurrences of both males and females were observed.

No significant difference ($p \leqslant 0.05$) was observed between sexes in terms of diet preference although, slight temporal variation was clear in particular between the months of August and June within two different years (2004 and 2007) ($p \geqslant 0.05$) (Fig. 1).

To further summarise the obtained data, animals were divided into different size classes based on the carapace width in mm as: 50–59, 60–69, 70–79, 80–89, 90–99, and 100–110 (Table 3) within the stomach fullness of the four categories of 100%, 50%, 25% and <25%.

Over all, more stomachs were grouped in the first and second categories (50–100%) combined. Whilst the total of 101 crabs considered with full stomachs, a considerable proportion of the total were in the <25% fullness category. Nevertheless, when the total number in the first two categories were combined, the sample size for the diet or stomach content assessment was more than adequate. The majority of the assessed stomachs were belonging to crab sizes ranging between 70–79 and 80–89 mm carapace width. It appears that more large crabs >60 mm carapace width were obtained than smaller sized individuals <60 mm.

The results showed no significant differences between sexes in terms of food preference except for the presence of fish tissues ($p < 0.05$) in favour of the males (Table 4).

When food was presented to the crabs, each moved fast towards it but mainly sideways and they seemed to preferentially select larger pieces. Food capture and initial manipulation was achieved using the chelate first appendage and/or other legs and the third maxillipeds. Small pieces of food were often difficult to grasp and were sometimes swept away in the exhalant respiratory currents. After manipulation, the food was rapidly ingested using the inner mouth parts (2nd, 1st maxillipeds and the mandibles). The chelipeds were used to probe the sand and gravel provided at the bottom of the aquarium and to transfer food to the mouth. Pereiopods 2–4 except the 5th which is adapted for swimming are used in the search for buried food items. During feeding the inner mouth parts were observed to move in the horizontal plane and all function in food manipulation and in pressing the food into the mouth opening. *P. pelagicus* is therefore capable of herbivory, carnivory and deposit feeding. It appears to have a preference for animal

Table 3 Total number and percentages (%) of stomach fullness in different size classes of *P. pelagicus* taken as the carapace width in (mm) over the study period. Male and female data were pooled.

Stomach fullness category (%)	Size classes (mm)						Total number of stomachs
	50–59	60–69	70–79	80–89	90–99	100–110	
100	–	10 (23.8%)	21 (26.9%)	15 (24.2%)	13 (24.5%)	14 (45.1%)	73
50	–	4 (09.5%)	5 (6.4%)	6 (9.7%)	10 (19.6%)	3 (9.7%)	28
25	4 (57%)	6 (14.2%)	15 (19.2%)	10 (16.1%)	11 (21.6%)	6 (19.4%)	52
<25	3 (43%)	22 (52.3%)	37 (47.4%)	31 (50%)	17 (33.3%)	8 (25.8%)	118
Total	7	42	78	62	51	31	271

food over plant food. When overcrowded, the individuals were seen to attack each other and the larger ones win.

Morphologically, the stomach consists of two compartments: an anterior cardiac stomach into which the oesophagus opens and where grinding of the food occurs and the posterior pyloric stomach. The cardiac stomach contains teeth carried by ossicles which form the grinding apparatus known as 'gastric mill'. The stomach ossicles articulate with each other and are moved by a complex musculature. There is a median dorsal and on each side, a lateral tooth. There are a series of setae, spines, smaller projections and denticulations. The wall of cardiac stomach is membranous and chitinized. The cardiac and pyloric stomach communicate through the cardio–pyloric valve where filtering of food occurs.

4. Discussion

Ideally, detailed analysis of stomach fullness and diet should be based on periodic sampling over 24 h so that daily variation in the fullness and the type of diet can be established. It is well known that most portunidae feed during the night, this might explain the high proportion of the <25% full stomachs and highly digested contents.

The larger proportion of highly digested material has perhaps resulted in an underestimate of the occurrence of soft-bodied prey in the diet and prevented anything but a general identification of dietary components. The dietary analysis though crude has revealed the feeding habit of the species. *P. pelagicus* is a carnivore with a preference for animal food. It could be considered an omnivore because, it will scavenge, predate and in addition deposit feeding is indicated by the presence of mud or sand in over 50% of all stomachs. Deposit feeding is perhaps only resorted to as a supplementary source of feeding. This was suggested by the laboratory observations that particulate material was ingested along with other food and that deposit feeding usually ceased when discrete food items were presented. Periods of deposit feeding were also reported by Sukumaran and Neelakantan (1997). Stomach content of Portunid crabs was always found to consist of animal food with plants occurring rarely (Wu and Shin, 1998). The food taken by Portunids is therefore, of two sorts: large pieces of animal and vegetable matter or small particles of organic debris and microorganisms such as the Foraminifera (counted with the sand particles) from sea bed deposits. The preference for animal matter was also in agreement with other authors for example, Batoy et al. (1988), De Lestang et al. (2000) and Sukumaran and Neelakantan (1997).

The mouth parts and chelipeds of portunids are adapted for food manipulation. The mandibles work fast in synchrony to cut through the food and mandibular palps help in pushing food into the oesophagus and in the cleaning of the mandible. Large variations in the chelipeds between different groups of decapods reflect differences in diet and mode of feeding (Warner, 1977). In addition to the size of food, the chelae are arched which indicate that chela is capable of generating greater pressures to crush open bivalves or other mollusc shells.

The stomach is similar to other decapods containing very complicated masticatory (gastric mill), sorting and filtering structures whose morphology varies with the type of food eaten (Schaefer, 1970; Powell, 1974). Also, the differences in stomach morphology are of taxonomic significance (Mocquard, 1883 cited in Patwardhan, 1935a). It has been noted that for each natural group, there is a given type of gastric mill and if the gastric mill of crustaceans placed within that natural group does not conform to the type, then that species should be removed from that group (Mocquard, 1883). This was confirmed in the extensive studies of Patwardhan (1934), Patwardhan (1935a–e). Amongst decapods, the most complex gastric mills are found in Brachyura and Anomura (Patwardhan, 1935e). A detailed comparative morphology of the gastric mills in decapods has also been given by Felgenhaur and Abele (1983). The stomach is divided into anterior cardiac and posterior pyloric regions. The ossicles supporting the stomach walls are numerous. They form two arches, an anterior arch formed by the mesocardiac ossicle in the middle and the lateral pterocardiac ossicles and a posterior arch formed by the pyloric ossicles. In Brachyura, the pterocardiac ossicles are large and elongated as compared to the anomuran decapods. The cardiopyloric valve is simple in Brachyura compared to the situation in Anomura (Patwardhan, 1935e). More recent development in the morphology of gastric mills and the occurrence of newly recognised ossicles of portunidae – brachyuran has been reported by Brosing (2010). Overall the ossicles of this species are based on a complex system (Brosing, 2010). Therefore, the stomach morphology is ideally examined by Scanning Electron Microscope using a specialised staining technique. During this study, the electron microscope is needed to obtain good quality pictures of the stomach internal morphology. However, the detailed structures of all decapods including portunidae could be found in Felgenhaur and Abele (1983) and Brosing (2010).

In conclusion, fish and crustaceans are the dominant components of the diet of *P. pelagicus* but these animals would ingest any food item depending on the availability. No significant differences were reported between the sexes in terms of food preference except for the presence of fish tissues as more males than females had this item in their stomachs. Greater stomach fullness was also observed in the males. There was some evidence of temporal variation in the stomach fullness. Diet

Table 4 The results of the ANOVA analysis comparing between male and female crabs in terms of food preferences.

		Sum of squares	df	Mean square	*F*	Sig.
Animal tissues	Between groups	.424	1	.424	1.711	.193
	Within groups	45.338	183	.248		
	Total	45.762	184			
Crustacean body parts	Between groups	.204	1	.204	.849	.358
	Within groups	43.990	183	.240		
	Total	44.195	184			
Polychaetes	Between groups	.445	1	.445	2.542	.113
	Within groups	32.020	183	.175		
	Total	32.465	184			
Gastropod/bivalve shell	Between groups	.026	1	.026	.127	.722
	Within groups	38.211	183	.209		
	Total	38.238	184			
Oil droplets	Between groups	.129	1	.129	1.631	.203
	Within groups	14.487	183	.079		
	Total	14.616	184			
Fish tissues and scales	Between groups	.899	1	.899	4.358	.038
	Within groups	37.750	183	.206		
	Total	38.649	184			
Chaetae	Between groups	.016	1	.016	.067	.796
	Within groups	44.578	183	.244		
	Total	44.595	184			
Spines	Between groups	.166	1	.166	1.644	.201
	Within groups	18.450	183	.101		
	Total	18.616	184			
Brown algae	Between groups	.020	1	.020	.093	.761
	Within groups	39.796	183	.217		
	Total	39.816	184			
Green algae/seaweed	Between groups	.057	1	.057	.485	.487
	Within groups	21.564	183	.118		
	Total	21.622	184			
Sand/quartz/mud	Between groups	.400	1	.400	2.005	.159
	Within groups	36.540	183	.200		
	Total	36.941	184			
Synthetic fibre/threads	Between groups	.216	1	.216	1.133	.288
	Within groups	34.844	183	.190		
	Total	35.059	184			
Glass pieces	Between groups	.014	1	.014	.310	.578
	Within groups	8.548	183	.047		
	Total	8.562	184			
Plastics and nylons	Between groups	.042	1	.042	2.658	.105
	Within groups	2.909	183	.016		
	Total	2.951	184			
Unidentified/highly digested	Between groups	.134	1	.134	1.006	.317
	Within groups	24.320	183	.133		
	Total	24.454	184			

No significant differences were reported except for the presence of fish tissues.

analysis data provide the basis for the species ecological and behavioural aspects and its potential for Mari-culture.

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