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Allometry, condition index and secondary production in bivalve *Barbatia decussata on* rocky intertidal shores in the Northern Persian Gulf, Iran

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Abstract

Biological parameters including allometry, condition index and secondary production were estimated for *Barbatia decussata* on rocky intertidal shores in the northern Persian Gulf (Iran) between August 2011 to September 2012. Relationship between shell dimensions (length, height, width, hinge) as well as relationship between shell length and weight (total wet weight, tissue wet weight, tissue dry weight, tissue ash free dry weight, shell dry weight, shell ash free dry weight) were estimated with *b* (equilibrium constant) values ranging from 3.023 to 3.347 (3.180±0.120). The *b* value between shell length and total wet weight was 3.181, indicating positive allometric growth pattern. Relationships between shell length-total wet weight (TLW), shell length-tissue wet weight (WW), shell length-tissue dry weight (DW), shell length-tissue ash free dry weight (AFDW), shell length-shell dry weight (sDW) and shell length-shell ash free dry weight (sAFDW) were $0.0001\times SL^{3.181}$, $0.000015SL^{3.347}$, $0.000006SL^{3.169}$, $0.000004SL^{3.234}$, $0.000074SL^{3.150}$ and $0.000004SL^{3.023}$, respectively. The condition index varied from 13.80 to 20.26 increasing from January 2012 to August 2012. Annual production, mean biomass and production to biomass ratio ($P/\bar{B}$) were 6.31 (g AFDWm^{-2} year^{-1}), 5.52 (g AFDWm^{-2}) and 1.14year^{-1} respectively.

Key words

Barbatia decussata, Environmental variables, Lengeh Harbour, Morphometry

Introduction

Globally distributed bivalves are excellent candidates for studying the effect of global climate change on marine organisms (Ambrose *et al.,* 2006; Beukema *et al.,* 2009). Arcide bivalves are found in Indo-West Pacific from East and South Africa including Madagascar, Red Sea and Persian Gulf to eastern Polynesia north to Japan and Hawaii and south to Queensland and are also marketed fresh or salted as food in the Philippines (Carpenter and Niem, 1998). Arcidae family, with over 200 species, is an important source of protein for human consumption (Zupan *et al.,* 2012). *Barbatia decussata* (Sowerby, 1833) (Bivalvia: Arcidae) is a member of rocky shore invertebrate communities in the northern Persian Gulf that have been able to survive severe environmental conditions in this region with wide fluctuation in water temperature and salinity (Bosch *et al.,* 1995). *Barbatia* is currently represented by at least eight nominal species including *B. obliquata, B. foliata*, *B. decussata*, *B. setigera*, *B. parva, B. perinesa, B. cibotina* and *B. avellanaria* that occur on rocky shores and coralline biotopes in the Persian Gulf (Bosch *et al.,* 1995). *Barbatia decussata* inhabits intertidal zones occurs under rocks, boulders, cobbles, corals and at the edge of cervices (Bosch *et al.,* 1995; Oliver and Holmes, 2006; Zeinalipour *et al*., 2014). Although several studies (e.g., reproduction, population dynamic, sex determination, systematic) on Arcidae have been conducted earlier (Silva and Bonilla, 2001; Oliver and Holmes, 2006; Peharda *et al.,* 2006; Garcia and Oliver, 2008; Sahin *et al.,* 2006; Zeinalipour *et al.,* 2014), the morphometric and allometric relationship as well as condition index and secondary production of these bivalves have remained unknown in the Persian Gulf.

Variations in allometry of bivalves have been linked to species, physiological characteristics and habitat conditions (Gosling, 2003; Ramesha and Thippeswamy, 2009; Caill-Milly *et* *al.,* 2012). The allometry of bivalves in the Persian Gulf experiencing extreme environmental conditions (e.g., wide fluctuation in air and water temperatures, high salinities) (Bosch *et al.,* 1995) are expected to differ from those individuals living in more optimum environmental conditions elsewhere. Living under extreme environmental conditions close to the physiological limits of marine organisms in the Persian Gulf (Sheppard, 1993) has made its organisms to allocate adaptations. Such adaptations are likely to be reflected in the allometry of marine organisms in this region. The link between environmental variables and allometric characteristics of marine organisms has been identified in many studies. In this context, these studies have recognized a subset of environmental variables as the major influential factors in allometric variations (Costa *et al.,* 2008; Ramesha and Thippeswamy, 2009; Caill-Milly *et al.,* 2012; Sujitha, 2013).

In the Persian Gulf, no such studies have been carried out on the biological aspects (allometric relationships, condition index, secondary production) of *B. decussata*. To fill this gap, the present study was conducted to report the morphometric relationships, shell length- weight relationships, condition index and secondary production of *B. decussata* collected from a rocky shore in the northern Persian Gulf. Further, the effects of environmental variables on temporal changes in shell dimensions, shell length and weight were explored.

Materials and Methods

Study area and sampling : The present study was conducted from August 2011 to September 2012 at 4 rocky shores at Bandar Lengeh (Iran: Hormozgan Province) in the northern Persian Gulf (Fig. 1). Specimens of *B. decussata* were collected on monthly basis from the intertidal zone at Bostaneh, Lengeh Port,

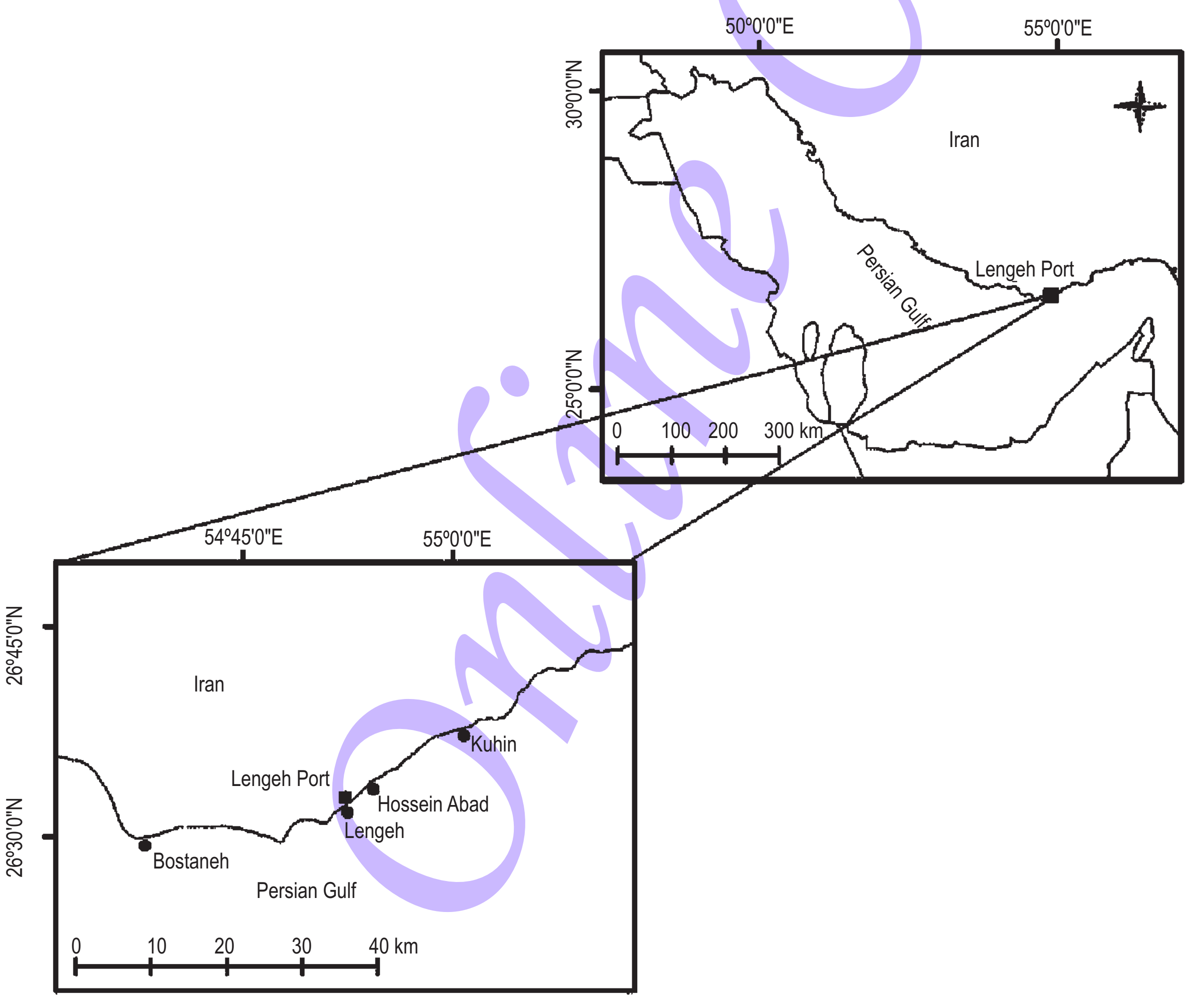

Fig. 1 : Sampling stations (circles) in Bandar Lengeh, at the northern Persian Gulf

Hosseinabbad and Kuhin during the period of maximum low tide (Fig. 1). Monthly specimens were collected at two replicate sites (approximately 100 m apart) at each sampling station by haphazardly placing four quadrats (0.25m^2) in each zone(high, mid and low inertidal) (2 replicate sites × 3 zone × 4 quadrates = 24).

Laboratory procedures : Bivalves were allowed to depurate their gut content in ambient seawater for 24 hr. The exteriors of the shells were brushed to remove fouling organisms (e.g., sponges, building polychaetes, gasteropods and hydroids) on them. The byssal threads were removed and the individuals cleaned in sea water. *Barbatia decussata* was identified using keys (Oliver, 1992; Bosch *et al.,* 1995; Garcia and Oliver, 2008). Shell length (maximum anterior-posterior distance), shell height [maximum dorso (at the umbo)-ventral distance], shell width (maximum distance between the outer edges of two valves of the closed shell) and shell hinge (maximum distance parallel to the hinge line) were measured to nearest 0.01mm using digital vernier calipers.

Total wet weight, wet body weight, dry body weight, body ash weight, dry shell weight and shell ash weight were measured using an electronic balance with 0.001g accuracy. Total wet weight was determined after drying the shell with paper towels. For tissue dry weight (tDW), internal tissues of each specimen were removed and dried at 65°C for 48 hr in an oven. Tissue ash free dry weight (t AFDW) was obtained by ignition of dried tissues at 550°C for 5 hr (Herrmann *et al.,* 2009) in a muffle furnace. Tissue ash-free dry weight (tAFDW) was calculated by subtracting dry weight from ash weight. The shells were dried at 60°C for 12 hr in an oven. After recording dry weight, the shells were burned at 750°C for 8 hr in an electric furnace. Their shell ash was then weighed. Shell ash-free dry weight (s AFDW) was calculated by subtracting shell dry weight from shell ash weight. Prior to ash weighing, all the samples were cooled in a desiccator. Physico-chemical parameters including water temperature (°C), salinity (PSU) and pH were measured using portable analyzer model HQ40D (Hach Lange, Germany) on monthly basis. Air temperature was measured using a thermometer.

Data analyses : The allometric equation W =aLb was used to describe the relationship between shell length with weight and to estimate morphometric relationship between shell dimensions, a linear regression was calculated (King, 2007). Coefficient of determination (R^2) was used as an indicator of quality of the power regression. Difference between estimated *b* in this study from 3 (repressing the isometric growth) for total wet weight was tested using Student t-test (Pauly, 1983).

The following equation was employed to estimate the condition index (Sahin *et al.,* 2006; Mladineo *et al.,* 2007)

$$CI = \frac{\text{Dry soft tissue weight (g)}}{\text{Dry shell weight (g)}} \times 100$$

Asymptotic length (L_∞) and growth coefficient (K)were estimated by annual size frequency distribution using ELEFAN-1 routine in FAO-ICLAM stock assessment tool (FISAT2) (Gayanilo, 2005). Von Bertalanffy growth function was defined by the following formula (King, 2007) :

$$Lt = L_\infty \; [1 - e{-}K^{(t\text{-}t0)}]$$

Total annual production was calculated using the equation (Herrmann *et al.,* 2009):

$$P = \Sigma\, M_i N_i G_i \; (\text{gAFDWm}^{-2}\ \text{yr}^{-1})$$

Gi is mass –specific growth rate that estimated as:

$$G_i = bk\,((L_\infty/L_i)\text{-}1)$$

Mean annual biomass was estimated by the formula : $\bar{B} = \Sigma M_i N_i$ (gAFDW m^{-2}) (Herrmann *et al.,* 2009):

Also annual turnover ratio ($P/\bar{B}$) of *B. decussata* populations was calculated from annual total production (P) and mean annual biomass ($\bar{B}$). Association between biological parameters and environmental variables was investigated by Canonical Correspondence Analysis (CCA) using CANOCO 4.5 software (ter Braak and Smilauer, 2002).

Results and Discussion

The results of the present study showed strong pairwise significant correlation between shell dimensions (length/height, length/width, length/hinge, height/width, height/hinge, width/hinge) of *B. decussata* (Table1, Table2). Monthly b values ranged from 0.67 (Oct. 2011) to 0.60 (Apr. 2012) for relationship between shell length and shell height from 0.67 (Nov. 2011) to 0.50 (Aug. 2012) for relationship between shell length and shell width and from 0.73 (Sep. 2011) to 0.62 (Nov. 2011) for relationship between shell length and shell hinge, respectively (Fig. 2). Asymptotic length (L_∞) of von Bertalanffy growth function and the growth coefficient (K) was 57.75 mm and 0.47 per year, respectively.

Biometric data obtained for *B. decussata* from 7230 measurements of shell length and 2605 measurements of total wet weight showed that the former ranged from 2.21 to 53.93 mm and latter from 0.055 to 38.360 g. Relationship between shell length and total wet weight was defined as $TLW = 0.0001 \times SL^{3.181}$ (R^2=0.97; N=2605; $P \leq 0.001$) (Fig.3; Table 3). The condition factor (*a*) was 0.0001 and the computed equilibrium constant (*b*) was 3.181 that was significantly different from 3 (t= 16.56, df=2604, $P \leq 0.05$). Correlation coefficient of 0.97 indicated a strong significant relationship between shell length and total wet weight.

Growth curve and associated equations using relationship between shell length–total weight, shell length–tissue wet weight, shell length–tissue dry weight, shell length–tissue ash free dry weight, shell length–shell dry weight and shell length- shell ash free dry weight are presented in Table 2 and Fig. 3.

Table 1 : Comparison of shell length statistics for sampling stations

Station	Number	Minimum shell length (mm)	Maximum shell length (mm)	Mean (±SD)
Hosseinabbad	1798	5.17	53.93	22.34±0.23
Kuhin	2229	3.91	51.27	31.35±0.13
Lengeh port	529	2.21	47.06	22.91±0.38
Bostaneh	2508	4.48	53.73	25.40±0.18

Table 2 : Regression statistics for relationships between morphometric parameters of *B. decussata*(**P*<0.001) (N= number, R^2=correlation coefficient, a= intercept, b= slope)

Y(mm)	X(mm)	Regression equations	a	b	R^2	N
Shell width	Shell length	W=0.56SL-2.60	-2.59	0.56	0.94*	1000
Shell hinge	Shell length	SHi=0.67SL+1.21	1.21	0.66	0.95*	1000
Shell height	Shell length	SH=0.64SL-1.17	-1.17	0.64	0.95*	1000
Shell width	Shell height	SW=0.86SH-1.45	-1.45	0.86	0.96*	1000
Shell hinge	Shell height	SHi=1.01SH+2.88	2.88	1.01	0.91*	1000
Shell hinge	Shell width	SW=1.13SHi+4.93	4.93	1.13	0.90*	1000

Table 3: Regression statistics for shell dimensions and weights for *B. decussata* (**P*<0.001)

Y(g)	X (mm)	Regression equation	a	b	R^2	N
TLW (total wet weight)	Shell length	$TLW = 0.0001 \times SL^{3.181}$	0.000100	3.181	0.97*	2605
tWW (tissue wet weight)	Shell length	$tWW = 0.000015 \times SL^{3.347}$	0.000015	3.347	0.93*	2448
tDW (tissue dry weight)	Shell length	$tDW = 0.000006 \times SL^{3.169}$	0.000006	3.169	0.91*	2448
tAFDW (tissue ash free dry)	Shell length	$tAFDW = 0.000004 \times SL^{3.234}$	0.000004	3.234	0.89*	2198
sDW (shell dry weight)	Shell length	$sDW = 0.000074 \times SL^{3.150}$	0.000074	3.150	0.97*	2353
sAFDW (shell ash free dry)	Shell length	$sAFDW = 0.000004 \times SL^{3.023}$	0.000004	3.023	0.89*	2170

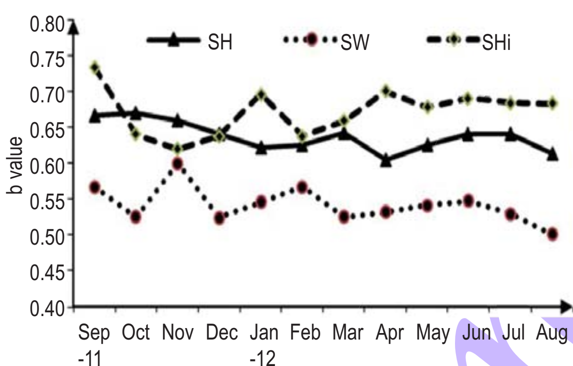

Fig. 2 : Monthly variability in *b* values of shell dimensions (Length/ height, length/width, length/hinge) relationship in *B. decussata*

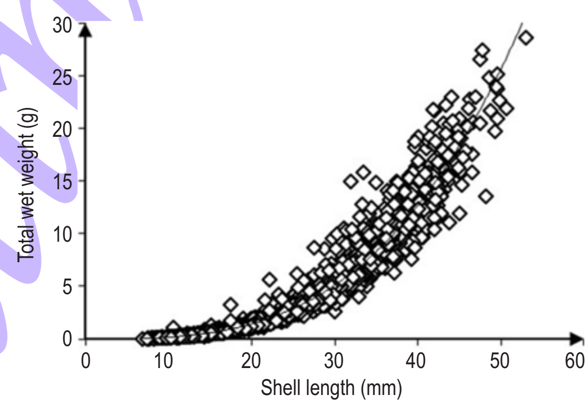

Fig. 3 : Shell length–total wet weight relationship of *B. decussatea.*

The monthly *b* values ranged from 3.29 (Oct. 2011) to 2.94 (Aug. 2012) for shell length-total wet weight relationship, from 3.89 (Sep. 2011) to 3.20 (Mar. 2012) for shell length-tissue wet weight relationship, from 3.59 (Sep. 2011) to 2.90 (Aug. 2011) for shell length-tissue dry weight relationship and from 3.07 (April 2012) to 3.70 (May 2012) for shell length-tissue ash free dry weight relationship (Fig. 4). The *b* values for relationship between shell length-shell dry weight and shell length-shell ash free dry weight fluctuated uniformly with mean of 3.12 and 3.11 respectively (Fig. 5).

Monthly mean values of condition index varied from 13.80 (Sep. 2011) to 20.26 (Aug. 2012) (Fig. 6). Temporal changes in condition index showed an increasing trend from February to a peak (20.26) in August 2012. Subsequently, condition index declined during September. Mean annual intertidal biomass ($\bar{B}$)

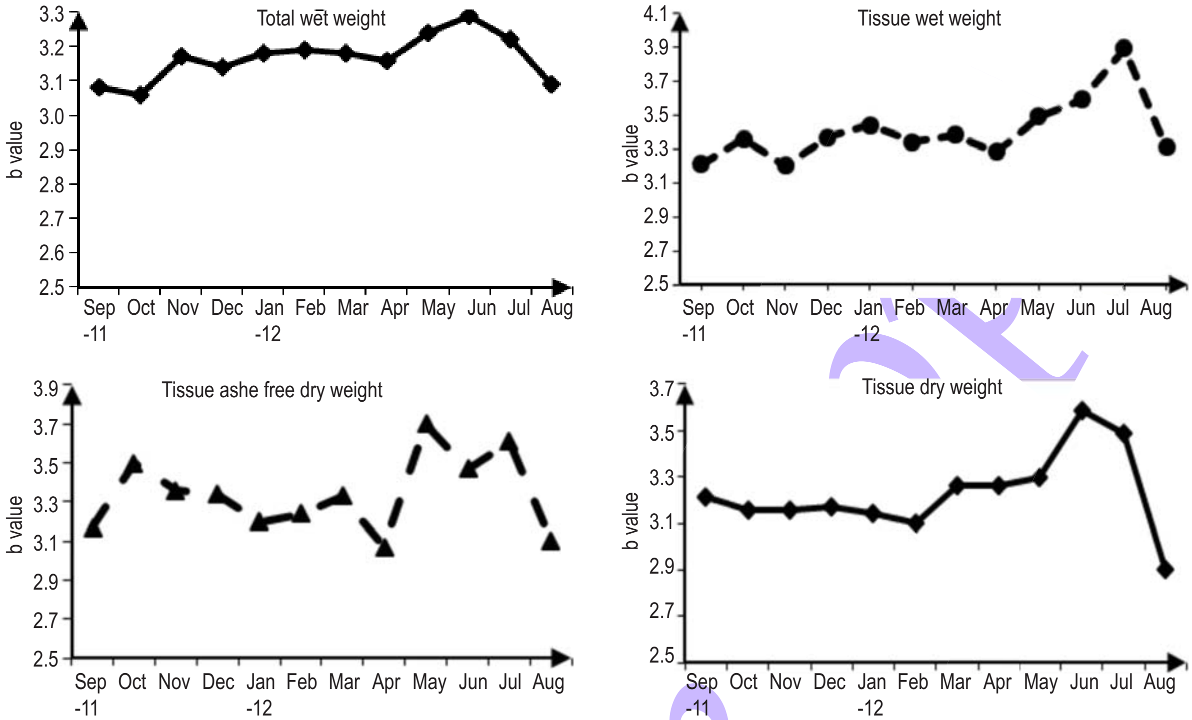

Fig. 4 : Temporal changes in the b values of shell length-weight relationships of *B. decussata*

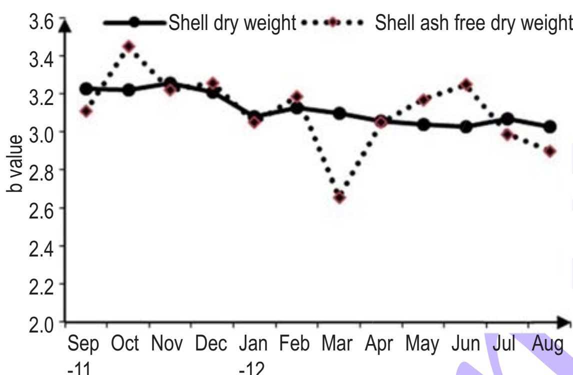

Fig. 5 : Monthly variability in b values of shell length and shell weight in *B. decussata*

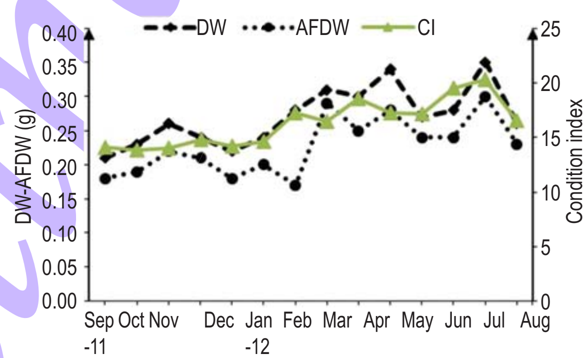

Fig. 6 : Monthly changes in mean of dry weight (DW), ash free dry weight (AFDW) and condition index (CI) of *B. decussata*

was 5.52±0.20 gAFDWm^{-2} for *B. decussata* at all the studied shores. Secondary production was estimated by means of population parameters (K= 0.47, L_∞= 57/75) and relationship between shell length and tissue ash free dry weight (tAFDW= $0.000004SL^{3.234}$ (R^2=0.89, N= 2.198, $P\leq0.001$). Individual production increased to 0.36g AFDW m^{-2}yr^{-1}at 32mm shell length and thereafter declined (Fig. 7). Annual production and turnover ratio (P/$\bar{B}$) was 6.31(gAFDWm^{-2} year^{-1}) and 1.14 (year^{-1}) at all the studied shores respectively.

Relationship between biological parameters and environmental variables were investigated by CCA analysis. In CCA diagram (Fig. 8) arrows represent maximum variation in environmental variables from biological parameters. Significance of each of these variables is shown by the proportional lengths of the arrows. The results showed that no environmental variables were responsible for variations in biological parameters for *B. decussata* in the study area during the sampling period. Based on the proximity to one another, all the biological parameters except for shell ash free dry weight (sAFDW) seemed to have a similar non-significant relationship with environmental variables. While shell ash free dry weight (sAFDW) was mildly associated with these variables, this relationship was also non-significant ($P > 0.05$) (Fig.8).

Members of epibyssate Arcoidea have elongate shell with height to length ratio of< 1:1.35. In the present study, ratio for *B. decussata* was 0.59, which is in accordance with the previous report of Oliver and Holmes (2006). A strong significant relationship between different shell dimensions and shell length indicated that small individuals were narrow and short, while large individuals were wide and long. These significant relationship further indicated that length, height, width and hinge are influenced by size. Yet, some individuals of same length possessed different heights, widths or hinges indicating the role of these parameters in shape variation. Inconsistency in relationship between length, height, width and hinge in some individuals is likely due to difference in shell shape (Ramesha and Thippeswamy, 2009). The results of the previous studies have shown that shell dimensions are affected by variations in environmental factors, in addition to shell shape (Ramesha and Thippeswamy, 2009; Caill-Milly *et al.,* 2012). Linear relationship between various morphological characteristics of *B. decussata* is in accordance with that identified for other bivalves such as *Marcia optima* (Suja and Muthiah, 2008), *Parreysia corrugata* (Ramesha and Thippeswamy, 2009), *Mytilaster lineatus* (Zeinalipour, 2011) and *Paphia malabarica* (Sujitha, 2013).

Although homogeneous growth in all dimensions is linked to genetic factors in bivalves (Ejlali Khankghah *et al.,* 2007), space limitations and a lack of freedom in rocky crevices and cracks cause them to undergo uneven growth (Ejlali Khankghah, 2007; Gaspar *et al.,* 2001). A probable strategy to compensate this limitation is to seek crevices and cracks with larger spaces as in the species of *Mytilus* (Castro and Huber, 2003; Nybakken and Bertness, 2005) and *Pinctada radiata* (Ejlali Khankghah *et al.,* 2007). Byssal threads that anchor *Barbatia decussata* can be broken securely and remade to allow limited and slow movement.

Few studies have focused on the relationship between dimensions and weight of bivalves in the Persian Gulf (Zeinalipour *et al.,* 2014). The results of the present study displayed a strong relationship between shell length and weight (total wet weight, tissue wet weight, tissue dry weight and tissue ash free dry weight) of *B. decussata.* A strong correlation between shell length and weight for *B. decussata* was similar to that reported in other bivalves such as *Chamelea gallina* (Deval, 2001), *Pinctada margaritifera* and *P. maxima* (Yukihira *et al.,*1998). The estimated *b* (3.18) value obtained for *B. decussata* was significantly higher than the isometric value (3), indicating a positive allometric growth. Positive allometric growth for 11 species and negative allometric growth for 3 species of bivalves have been reported from the southern coast of Portugal (Gaspar *et al.,* 2001). In the Persian Gulf, allometric growth has been reported for other bivalves such as *Solen brevis* (Niamaimandi, 2012) and *Pinctada radiata* (Ejlali Khankghah *et al.,* 2007). A wide range of coefficient *b* between 2.28 to 3.29 has been reported for 6 species of *Anadara* (Arcidae) from different parts of the world (Sahin *et al.,* 1999). The *b* value for *B. decussata* in the present study was within this range suggesting that *B. decussata* has a similar growth pattern as other arcoids bivalves. The condition factor in the equation $W=aL^b$ can be used as an index of "well-being" condition of a given fish. The calculated value of *a* from monthly samplings might be used to detect variations in fish conditions, such as food availability and reproductive state (King, 2007). In this study, a value from shell length and total wet weight was 0.0003 for *B. decussata*. In the previous studies in the Persian Gulf, a values were reported upon for *Amiantis umbunella*, *Solen dactylus* and *Pinctada radiata* as 0.0009, 0.0001 and 0.00004 respectively. Shell length, wet weight, dry weight and ash free dry weight are generally used to measure growth, biomass and secondary production in bivalves (Gimin *et al.,* 2004). Results of the present study showed that *Barbatia decussata* shell length might be a good estimator for its weight in estimation of biomass and production.

Growth, reproduction and hence condition index in *B. decussata* can be effected by biotic (food, competition, predation) and abiotic (salinity, temperature, substratum, dissolved oxygen) parameters (Gosling,2003). Although changes in condition index are sensitive to reproductive state and increasing gonadal growth, it is also affected by food availability and increasing temperature (Gosling, 2003; Peharda *et al.,* 2006; Sahin *et al.,* 2006; Mladineo, 2007; Ramesha and Thippeswamy, 2009; Mohite *et al.,* 2009). Gonadal growth might also influence bivalve condition index (Ramesha and Thippeswamy, 2009; Mohite *et al.,* 2009). According to the previous studies conducted on pearl oyster *Pinctada fucata*, increasing temperature is an important factor in gonadal growth from mid-winter to mid-summer (Behzadi et al., 1997). Spawning during mid summer leads to reduction in ovarian volume and thus decreases the condition index. In the present study, condition index ranged from 13.80 (October 2011) to 20.26 (August 2012), with an average of 17.03. Condition index for two species *Anadara tuberculosa* and *A. similis*, (Arcidae) were 17.20 and 21.20 with maximum shell length in the range of 31 mm to 35 mm in the Pacific Ocean (Silva and Bonilla, 2001). Condition index for *Anadara inequivalis,* with a minimum value of 5 in mid-summer and a maximum of 12 in early spring, was reported to be affected by food availability and water temperature in Black Sea (Sahin *et al*., 2006). In most bivalves, gonadal growth, tissue size and weight rise and condition index grows and vice versa. Gamete accumulation in ovarian follicles and subsequent gonad largeness causes condition index to rise (Behzadi *et al.,* 1997).

Production to biomass ratio (P/B) has been compared among bivalve species in different regions (Cardoso and Veloso, 2003; Herrmann *et al*., 2009; Zabbey *et al*., 2010). Unfortunately, data on biomass and production of Persian Gulf bivalves for

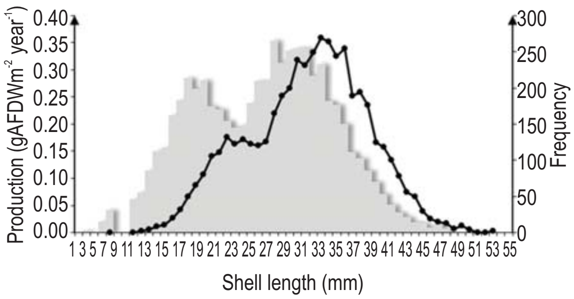

Fig. 7 : Shell length frequency distribution and relationship between shell length and secondary production in *B. decussata*

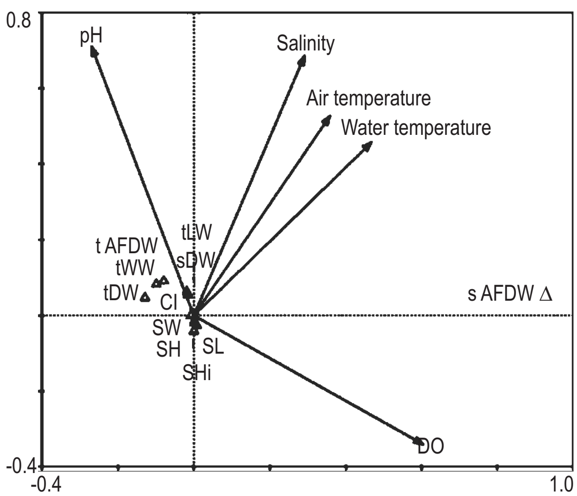

Fig. 8 : Canonical correspondence analysis on biological parameters with environmental variables. Biological parameters are listed by the first letter (shell length, shell height, shell width, shell hinge, total wet weight, tissue wet weight, tissue dry weight, tissue ashe free dry weight, shell dry weight, shell ash free dry weight and condition index)

comparison with the result of the present study are negligible. Production to biomass ratio for *B. decussata* in the present study was relatively high in relation to other species in other parts of the world. For bivalves, (P/B) ratio usually increases from temperate to tropical regions although it may not be a general rule for all species and ecosystems (Abrahao *et al.,* 2010). Other possible factors influencing (P/B) ratio includes latitude, food availability (Cardoso and Veleso, 2003), increasing organic matter from urban waste water (Abrahao *et al.,* 2010), population structure, density, longevity, growth rate and mortality (Cardoso and Veleso, 2003; Herrmann *et al.,* 2009; Abrahao *et al.,* 2010). The results on population dynamic showed that *B. decussata* is a short-lived species (approximately 6 years), with relatively fast growth rate (k= 0.47) and high natural mortality (M=0.92) (Zeinalipour *et al.,* 2014). Relatively high (P/B) ratio in *B. decussata*, in the present study, might be justified by short longevity, high growth rate and high mortality in the study area.

The present research found no significant association between environmental variables and biological parameters in *B. decussata*. Further studies are needed to confirm the result of *Barbatia decussata* in the Persian Gulf.

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