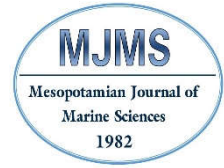**Marine Science Center-University of Basrah**

Mesopotamian Journal of Marine Sciences
Print ISSN: 2073-6428
E- ISSN: 2708-6097
www.mjms.uobasrah.edu.iq/index.php/mms

Oxygen consumption and energy budget of the barnacle *Balanus amphitrite amphitrite* (Darwin, 1854) in an estuarine ecosystem, Basrah-Iraq

iD Ibtsam M. Abdul-Sahib, Salman D. Salman* and iD Malik H. Ali
Marine Science Centre, University of Basrah, Basrah, Iraq
*Corresponding Author: e-mail *alm.sdsalman@gmail.com*

Abstract - The annual O2 consumption, annual energy budget and the ecological efficiencies of a population of the barnacle Balanus amphitrite amphitrite were estimated in Garmat-Ali river, in the period October 1994-September 1995. The annual O2 consumption was 2156 kJ/ m2/yr, the rate of O2 consumption increased with increasing temperature and body weight, the barnacle consumes oxygen at a rate of 0.622 µlO2/mg/h at 15°C, 0.84 µlO2/mg/h at 23°C and 0.954 µlO2/mg/h at 30°C. The Q10 values increased with increasing size of barnacle. The food items provided were the alga, Chlorella sp. with a calorific contents of 3.2 kcal/g DW, and a flesh of the clam C. fluminea with 5.4 kcal/g DW. The barnacle assimilates the flesh of the clam about 7 times more than assimilating the Chlorella. The barnacle allocates 45-55% of the assimilated energy for net growth and 27-37% for metabolic energy expenditure, whereas 18% is channeled for faeces production. The respiratory coefficient (R/P) of this barnacle was 0.6. The assimilation efficiency for the plant and animal food were 88-91%. The annual energy budget equation for a population of barnacle at Garmat-Ali river is: Cp 16271.14 = Pp 11639.55 + Rp 2156 + Fp 2475.60.

<div dir="rtl">

**استهلاك الأوكسجين وميزانية الطاقة في البرنقيل (Darwin, 1854) *Balanus amphitrite amphitrite*
في النظام البيئي المصبي، البصرة- العراق**

أبتسام مهدي عبد الصاحب، سلمان داود سلمان و مالك حسن علي

مركز علوم البحار، جامعة البصرة، البصرة، العراق

المستخلص - تم تقدير الاستهلاك السنوي للاوكسجين، وميزانية الطاقة السنوية، والكفاءة البيئية للجماعة السكانية للبرنقيل *Balanus amphitrite amphitrite* في نهر كرمة - علي، للفترة من تشرين الأول 1994 ولغاية أيلول 1995. بلغ الاستهلاك السنوي للاوكسجين 2156 كيلوجول/م2/سنة، واتضح ان معدل استهلاك الاوكسجين يزداد مع ارتفاع درجة الحرارة وزيادة وزن الجسم، يستهلك البرنقيل الأوكسجين بمعدل 0.622 ميكروليتر أوكسجين/ملغم/ساعة عند 15°م و 0.84 ميكروليتر أوكسجين/ملغم/ساعة عند 23°م و 0.954 ميكروليتر أوكسجين/ملغم/ساعة عند 30°م. هذا وقد ارتفعت قيم المعامل الحراري (Q10) مع زيادة حجم البرنقيل. وكانت المواد الغذائية المقدمة هي *طحالب* .Chlorella sp (كغذاء نباتي) وكان محتوى السعرات الحرارية فيها 3.2 كيلو سعرة حرارية/غم وزن جاف، واللحم الطري للمحار الاسيوي *C. fluminea* (كغذاء حيواني) والذي كان محتوى السعرات الحرارية فيه 5.4 كيلو سعرة حرارية/غم وزن جاف. وتبين ان لحم المحار الاسيوي *C. fluminea* يتم تمثيله في جسم البرنقيل أكثر بحوالي 7 مرات من تمثيل الطحالب .Chlorella sp. يخصص البرنقيل 45- 55% من طاقة التمثيل الغذائي للنمو الصافي و 27- 37 % لإنجاز الفعاليات الأيضية، في حين أن 18 % يتم توجيهها للفضلات. ومعامل التنفس (R / P) عند هذا البرنقيل كان 0.6. وكانت كفاءة التمثيل للغذاء النباتي والغذاء الحيواني 88- 91 %على التوالي. ومعادلة ميزانية الطاقة السنوية للجماعة السكانية عند نهر كرمة علي هي: Cp 16271.14 = Pp 11639.55 + Rp 2156 + Fp 2475.60.

الكلمات المفتاحية: البرنقيل *Balanus amphitrite amphitrite*، الايض، ميزانية الطاقة، منطقة المد والجزر، البصرة، العراق

</div>

Introduction

Balanus amphitrite amphitrite (Darwin, 1854) is a euryhaline and eurythermal species in nature. Stubbing (1961) recorded four species of barnacles to occur in the Arabian Gulf, of which *B. amphitrite* Darwin is represented by two varieties *B.a. communis* Darwin and *B.a. hawaiiensis* Broch. Mohammed (1976) made some observations on the occurrence of *B.a. communis* in the Shatt Al-Arab estuary at Al-Kasabah, Al-Maa'mer, near Al-Fao town, Basrah, Iraq. However, the species was totally absent from the upper reaches of Shatt Al-Arab in the 1970's. Lately two of Mohammed's students (Arif, 1977 ; Rasheed, 1977) designated the species as *B.a. amphitrite* and made some ecological and biological observations on the larvae and adults of the species at Khor Al-Umayah (Arabian Gulf), Al-Fao and Al-Maa'mer. The present species spread throughout the Shatt Al-Arab River in the late 1980s/early 1990s, and was observed in a few number at Soog Al-Sheyookh, Nassiriyah on the Euphrates River, about 200 km north of Basrah in 1994 (Salman, personal observations). In Basrah, *B.a. amphitrite* has become a serious problem to various marine constructions for instance the intake pipes of the power stations and the like. The species is now spreading northward mainly through Euphrates River. It was found in the Third River "Main Outer full Drain" which is extending from Al-Mahmudiyah, south of Baghdad, to the Shatt Al-Basrah canal and empties into Khor Al-Zubair and the Arabian Gulf.

B.a. amphitrite was sampled for 18 months from October 1994-March 1996, from the intertidal zone of Garmat-Ali River. The population density was ranging from 9250 (October 1994)-18333 ind./m^2 (May 1995).The barnacle was breeding all the year round, with larval release throughout the year, the population was polymodal (3-4 cohorts at each sampling occasion). Fecundity was averaged at 2767 egg/ind., the growth rate was changing from 0.84-1.23 mm/mo., with the life span of cohorts fluctuating between 5-9 months (Abdul-Sahib *et al*., 2003a).

In order to construct an energy budget of the population at this site, Abdul-Sahib *et al*. (2007) carried out feeding experiments at 4 test temperatures with 2 kinds of food, the algae *Chlorella* sp. and the flesh of the freshwater clam *Corbicula fluminea*, were given to the barnacle. The results indicated that food consumption was fluctuated between 0.0414 and 0.3209 mg DW/ind./d.(in case of the alga) and 0.1331 and 1.5553 mg DW/ind./d.(in case of the animal food), the average assimilation efficiency of the alga was 77.6% and of the clam was 85.9%, faeces production was ranging from 0.0145-0.0443 mg/ind./d (in case of the alga) and from 0.0289-0.1180 mg/ind./d (in case of the clam).

The present article is aimed at estimating the rate of respiration and metabolism at different temperatures experienced by the adult in the field, and then constructing an energy flow model for a population of *B.a. amphitrite* in order to understand the role of this species of barnacle in the Shatt Al-Arab River System in the hope that it makes the basis for understanding the predator-prey relationship. Such a study has not been done before on this species of barnacle in this region.

Materials and Methods

Oxygen consumption by the barnacle:

Specimens were collected from the supratidal zone of Garmat-Ali river bank for the period October 1994-September 1995. The specimens were brought to the laboratory in plastic bags with some habitat water and branches of the plant *Ceratophyllum demersum*. Experiments were carried out in a few days after collection.

A Gilson differential respirometer was used to measure the oxygen consumption of the barnacle. The experiments were done once each month for the period of sampling stated above. One individual was placed at each 7.6 ml vessel with filtered, boiled then cooled water from the field. Two of the 12 vessels were left without animals as control. The water was aerated for at least 5 minutes before used. The animals were equilibrated for one hour before the septum was closed to

the atmosphere and measurements of oxygen consumption commenced. Temperature of the respirometer was fixed at the mean water temperature of that month at which the experiment was done (the range of field water temperature was 13-32°C). Readings of the respirometer was taken every half an hour for 4 hours. Weak and newly moulted animals were discarded. The animals were killed after each run and their sizes were measured. After calibrating the readings with those of the controls, the mean rate of oxygen consumption per individual per hour (μlO_2/ind./h.) was obtained. Then the animals were dried for 24 hrs at 60°C and the dry weight was measured from the following expression:

$$\log R = \log a + b \log W \text{ , where}$$

R = Mean oxygen consumption (μlO_2/ind./h).
W = Dry weight (mg) of the animal.
a, b = Constants.

The metabolic rate was calculated as weight-specific respiration (R/W) (Crisp, 1984).

$$\log (R/W) = \log a + (b-1) \log W, \text{ where;}$$

$R = \mu lO_2 \text{ mg}^{-1} \text{ DW.h}^{-1}$.

Temperature coefficients (Q_{10}) were calculated as $Q_{10} = (V_2/V_1)^{10/(t_2 - t_1)}$, where; V_1 and V_2 representing mean oxygen consumption at temperatures t_1 and t_2 (Grodzinski *et al.*, 1975).

Energy contents of the *Chlorella* sp. and *C. fluminea*:

Chlorella sp. were dried up in an oven at 60°C for 24h , and a certain weight was taken and the energy contents of which was determined by C400 adiabatic microbomb calorimeter, 5 replicates of each trial were taken. The same procedure was applied to the animal food. The faeces in each case were collected, washed with distilled water, dried out, and because they were very small in quantity, a gelatinous capsule was used and cut into as small pieces as possible, and the specimens were placed in these pieces. A wire, as short as possible was used for combustion. These modification were made to reduce, as much as possible the energy loss during combustion in the calorimeter. A medium-sized barnacle of 6.25 mm (diameter of the shell aperture) with a dry weight of 2.655 mg was chosen to calculate the individual energy budget of the barnacle. Average food consumption and average faecal production at 12 h were obtained from the relation of dry weight of the barnacle with each of the average food consumption ($\overline{C}$) and the average fecal production ($\overline{F}$) of the barnacle for the two kinds of food and the food assimilation was then calculated (Abdul-Sahib *et al.*, 2007).

In calculating the energy budget of the population of *B.a. amphitrite*, the results of the population dynamics were used to obtain the average size (mm) of individual per month and the monthly average density of the population /m^2 for the period October 1994-September 1995 (Abdul-Sahib *et al.*, 2003a). Average dry weight for the mean individual size for each month was obtained from the expression of dry weight and size of the animal (Abdul-Sahib, 1997). Rate of food consumption and rate of faeces production for monthly average weight of the barnacle were obtained from the expressions of dry weight and average food consumption ($\overline{C}$) and average faeces production ($\overline{F}$) (Abdul-Sahib *et al.*, 2007), and the average assimilation rate was then estimated. Oxygen consumption rates were calculated from the relations of the mean oxygen consumption and dry weight, with the addition of aerial respiration at a ratio of 1: 0.23 (Grainger and Newell, 1965). The units of oxygen consumption (μlO_2/h.) were then converted to Joul (J) energy units by using the equivalent 20.197 (Brody, 1945) and the values were multiplied by 24 hour to estimate the O$_2$ consumption per day (J/day). Moreover, the temperature coefficient (Q_{10}) was used to calculate the rates of oxygen consumption at the monthly mean water temperatures. The method

of Phillipson (1970) was used to obtain the annual energy of food consumption, faeces production and oxygen consumption.

Results

Monthly Rates of Oxygen Consumption:

The rates of oxygen consumption (μlO_2/ind./h. ± SD) for monthly mean size of the population of the barnacle *B.a. amphitrite* at Garmat-Ali river and the average dry weight and mean monthly water temperature for the period October 1994-Septemper 1995 are found in Table (1).

Table 1. Rate of oxygen consumption (μlO_2/ind./h.) of *B. amphitrite amphitrite* from Garmat-Ali river for the period Oct. 1994 to Sept. 1995.

Months	Mean Temp. °C	Average Length (mm)	Average Dry Wt. (mg)	Rate of Oxygen Consumption ± SD
Nov. 1994	21	4.25	0.899	0.628 ± 0.272
Dec.	13	5.25	1.880	0.237 ± 0.132
Jan. 1995	15	4.75	1.519	0.542 ± 0.279
Feb.	17	5.25	1.880	0.562 ± 0.287
March	21	5.25	1.015	0.657 ± 0.140
April	24.5	5.25	1.015	0.709 ± 0.359
May	29	5.25	1.220	0.716 ± 0.429
June	30.5	5.25	0.939	0.739 ± 0.309
July	32	4.75	1.551	0.658 ± 0.391
August	31	5.75	2.567	0.713 ± 0.329
Sept.	29	5.75	1.323	0.743 ± 0.384
Oct.	25	4.75	3.213	0.639 ± 0.296

The effects of temperature on the rates of oxygen consumption is quite apparent, as the minimum value (0.237 ±0.132 μlO_2/ind./h) was recorded during December 1994, when the lowest water temperature (13°C) was reported, there was then a gradual increase in O_2 consumption with the rise in temperature until a peak (0.743 ±0.384 μlO_2/ind./h) in September 1995 (water temperature 29°C) was reached.

Monthly changes in O_2 consumption at the density of mean-sized individual of *B.a. amphitrite* with the changes of mean water temperature (Fig. 1), indicate that a peak was attained in November 1994 (1631.5 μlO_2/ind./h/m^2), due to the high density (2600 ind./m^2) of this group at this month at a temperature of 21°C. This is followed by a sharp decline in December, when a minimum O_2 consumption was recorded (287.25 μlO_2/ind./h/m^2), in spite of the relatively high density of the mean-sized group (1210 ind./m^2), which is corresponding very well with the minimum water temperature (13°C). It is apparent that O_2 consumption of the various size-groups at different densities fluctuate according to the mean water temperature of the habitat, indicating a major influence of temperature on O_2 consumption of the barnacle.

Effect of Body Size on the Rates of O_2 Consumptions:

Laboratory experiment of the O_2 consumption of various sizes of the barnacle at 3 different temperatures (15, 23 and 30°C), showed that there was an increase in the O_2 consumption with increasing size and temperature (Fig. 2). At 15°C, the rate of O_2 consumption of the small-sized barnacle (3.75 mm) was 0.377 μlO_2/ind./h, and there was an increase of the O_2 consumption with increasing size when it approximately doubled (0.714 μlO_2/ind./h) at a size of 7.75 mm, but there

was only a slight increase in the O_2 consumed by increasing size to 8.75 mm (0.769 µlO$_2$/ind./h). Whereas at temperatures 23 and 30°C, the rates of O_2 consumption of a size 3.75 mm were very close to each other (0.435 and 0.450 µlO$_2$/ind./h, respectively). But, it was more than double (0.88 and 1.00 µlO$_2$/ind./h, respectively), at larger sizes (7.75 mm) and there was a three folds increase or more (1.21 and 1.40 µlO$_2$/ind./h, respectively) at the next size-group (8.75 mm).
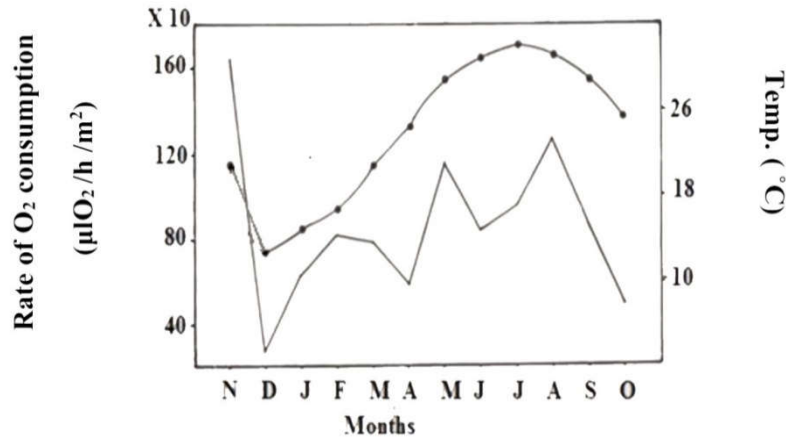

Figure 1. Monthly rate of oxygen consumption (µlO$_2$/h/m^2) of medium-sized group (6.75 mm) of the barnacle *B.a. amphitrite*, with the average monthly temperature for the period from November 1994 through October 1995.
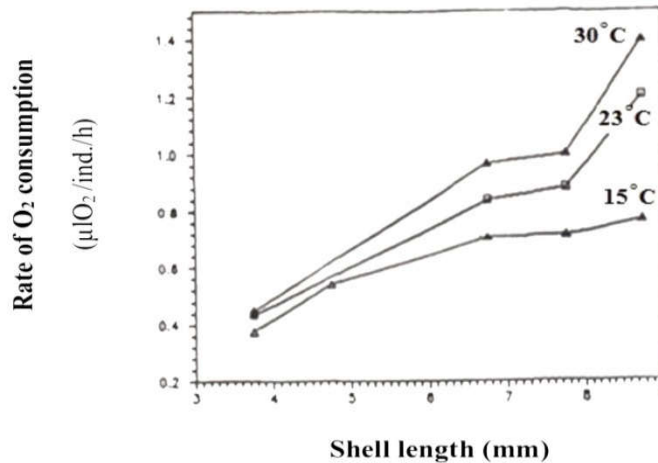

Figure 2. Relations of the mean oxygen consumption (µlO$_2$/ind./h) and shell length of the barnacle *B.a. amphitrite* at different temperatures.

Effect of Temperature on the Rates of O_2 Consumptions:

Six size-groups of the barnacle *B.a. amphitrite* were selected (3.75, 4.75, 5.25, 6.75, 7.75 and 8.75 mm) to demonstrate the effect of laboratory temperatures on the rate of O_2 consumption (Fig. 3). It is apparent that the rate of O_2 consumption is slightly increased with temperature at the smallest sizes (3.75 and 4.75 mm) for instance at a size of 4.75 mm and a temperature of 15°C, the O_2 consumption was 0.542 µlO$_2$/ind./h, and reached 0.658 µlO$_2$/ind./h at 30°C, at the medium-sized group (5.25 mm), and at 23°C, the O_2 consumption was 0.237 µlO$_2$/ind./h and attain 0.739

μlO_2/ind./h at 30°C, whereas at the larger sizes (8.75 mm), the rate of O_2 consumption varied between 0.769 and 1.40 μlO_2/ind./h at 15 and 30°C, respectively.

This indicates that O_2 consumption is low at lower temperatures, and the small-sized individuals are the least affected by temperature than the larger sizes, in which the rate of O_2 consumption had obviously increased with rise in temperature.
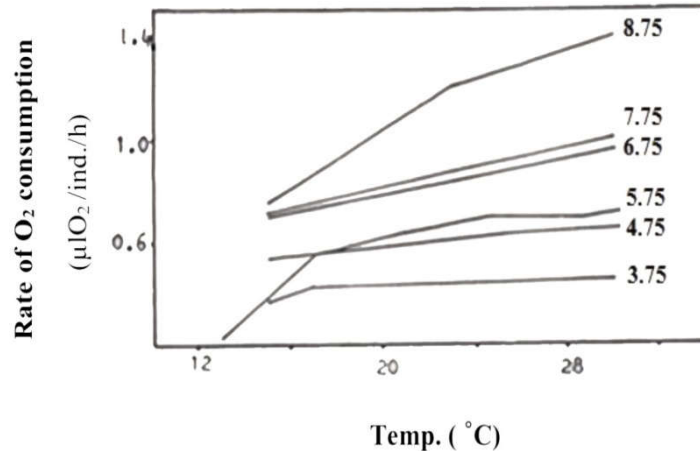

Figure 3. Relations of the mean oxygen consumption (μlO_2/ind./h) and temperature of different size groups of the barnacle *B.a. amphitrite*.

Relation of Respiration with Temperature:

The relationships of the rate of O_2 consumption with the mean dry weight at three temperatures (15, 23 and 30°C), are expressed by the linear equations (Fig. 4):

at 15 °C, Log R = - 0.3757 + 0.3769 Log W;
r = 0.97, (P <0.01)

at 23°C, Log R = - 0.2902 + 0.3237 Log W;
r = 0.98, (P <0.01)

at 30 °C, Log R = - 0.2071 + 0.4799 Log W;
r = 0.99, (P <0.01)
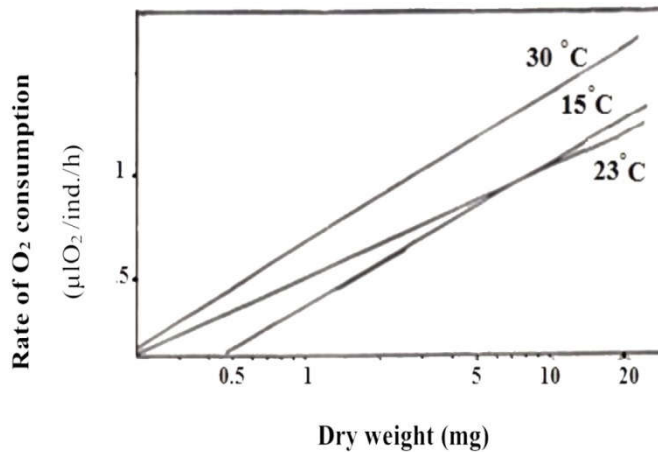

Figure 4. Relations of the mean oxygen consumption (μlO_2/ind./h) and dry weight (mg) of the barnacle *B.a. amphitrite* at 3 test temperatures.

The ANOVA test indicates the heterogeneity of the three relationships and they were significantly different ($p<0.05$, Fcal.=13.132). However, student Newman-Keul's multiple range test (Zar, 1974) showed that there were significant differences in the rates of O_2 consumption at each two temperatures ($\overline{X}$, in Table 2).

Table 2. Student's test for the rate of oxygen consumption of *B. amphitrite amphitrite* at 3 temperatures.

Temp. °C	$\overline{X}$	S^2	N	D
15	0.6224	0.0209	68	0.0874
23	0.8407	0.0749	53	0.1255
30	0.9542	0.1134	30	0.1090
$\overline{X}_{15}$-$\overline{X}_{23}$	0.2183			
$\overline{X}_{15}$-$\overline{X}_{30}$	0.3318	(P<0.05, F cal. 13.132)		
$\overline{X}_{23}$-$\overline{X}_{30}$	0.1135			

Weight Specific Metabolic Rate:

The relationships of the rate of metabolism (rate of O_2 consumption per unit weight, R/W) and dry weight for the individuals at three temperatures, 15, 23 and 30°C are given in Fig. (5). It is obvious that these are inversed relationships, i.e. the metabolic rate is decreasing with increasing weight:

at 15 °C,   Log R/W = - 0.3757 - 0.6231 Log W;
n = 68 , r = - 0.97
at 23 °C,   Log R/W = - 0.2902 - 0.6763 Log W;
n =53, r = - 0.98
at 30 °C,   Log R/W = - 0.2071 - 0.5201 Log W;
n =30, r = - 0.99

Apparently these relations (Fig. 5) are close to each other at the smaller weights and this is an indication that the smaller sizes are having higher metabolic rates than larger sizes.
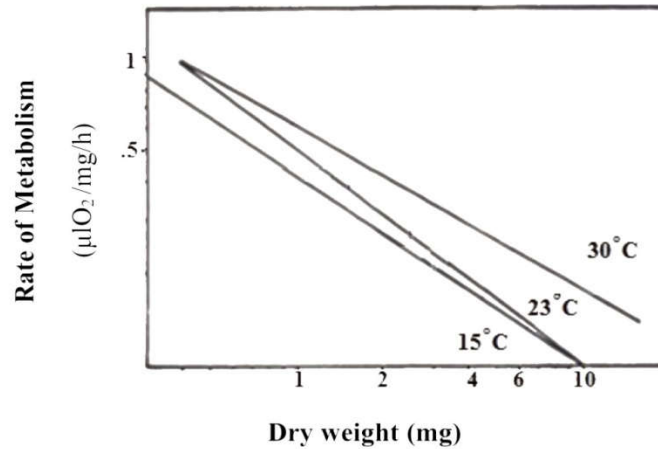
Figure 5. Relations of the rate of metabolism ($\mu l O_2$/mg/h) and dry weight (mg) of the barnacle *B.a. amphitrite* at 3 test temperatures.

Temperature Coefficient (Q_{10}):

The Q_{10} values of the barnacle at two temperature limits, 15-23 and 23-30°C were calculated and for 4 size-groups (Table 3). The values fluctuated between 1.21 and 1.76 at the 15-23°C temperature limit, whereas at 23-30°C, the values were changing from 1.05 to 1.24.

Therefore, the Q_{10} values increase with size, emphasizing that larger barnacles had higher rates of O_2 consumption than smaller sizes and at both temperature limits. But, the rates of O_2 consumption at 15-23°C, were obviously higher than those at 23-30°C. Moreover, the Q_{10} values decreased with increasing temperature and increased with increasing size.

Table 3. Temperature coefficient (Q_{10}) values of *B. amphitrite amphitrite* at two temperature ranges and at four size groups.

Group	Length (mm)	Q_{10}	
		15-23°C	23-30°C
1	3.75	1.21	1.05
2	6.75	1.24	1.22
3	7.75	1.30	1.20
4	8.75	1.76	1.24
Average		1.38	1.18

Annual Population Energy of the Barnacle:

The general individual energy budget of the barnacle was:

$$C_{6.5523} = P_{5.4849} + R_{0.4707} + F_{0.5967} \text{ expressed as:}$$

The results of the population dynamics and the monthly changes in water temperatures from October 1994-September 1995 (Abdul-Sahib *et al.*, 2003a), together with the results of the O_2 consumption were incorporated to estimate the annual energy expenditure of respiration of the population of *B.a. amphitrite* at Garmat-Ali river. Table (4) shows the monthly changes in the rate

of O_2 consumption of an individual barnacle. The highest rate (25.5 μlO_2/ind./d.) was recorded in September 1995, whereas the lowest rate was 16.42 μlO_2/ind./d. and reported in November 1994.

Table 4. Annual energy of the rate of O_2 consumption for the population of *B. amphitrite amphitrite* at Garmat-Ali river. W= ind. mean weight (mg Dw), O_2= daily ind.O_2 consumption (μlO_2/ind./d.), N= mean density (m^2) and ΣO_2= monthly total O_2 consumption (ml O_2/ m^2/mo).

Months	Mean Temp. °C	$\overline{N}$	$\overline{W}$	O_2	ΣO_2
Oct. 1994	27	9250	1.3527	20.7144	5748
Nov.	21	18300	0.9219	16.4208	9015
Dec.	13	15617	2.1419	18.6792	8751
Jan. 1995	15	15217	1.6449	17.7096	8085
Feb.	17	14950	1.9115	19.3464	8677
March	21	13467	0.9699	16.9644	6745
April	24.5	13900	1.031	18.1368	7563
May	29	18333	0.9799	19.3464	10640
June	30.5	16000	1.2899	21.7272	10429
July	32	15833	1.0577	20.9328	9943
August	31	15483	1.1749	21.2688	9879
Sept.	29	14750	2.2997	25.500	11284

Total annual O_2 consumption = 106759 ml O_2/m^2/yr

= 2156 kJ/ m^2/yr

However, the average seasonal respiration emphasize that the highest rate was in summer (21.0894 μlO_2/ind/d.), followed by winter and spring (18.1944 and 18.1554 μlO_2/ind/d., respectively), and the least was in autumn (16.4208 μlO_2/ind/d.). This difference is partially attributed, to changes in water temperature and to differences in the weight of barnacles at various seasons.

Population Energy Budget of the Barnacle:

Annual production of the population of *B.a. amphitrite* at Garmat-Ali river, for the period October 1994-September 1995 was 2583.96 kJ/m^2/yr (Abdul-Sahib *et al*., 2003b), and the annual metabolic energy expenditure was 2156 kJ/m^2/yr. The assimilation of the population was obtained from:

$$A_p = P_p + R_p$$

$$= 2583.96 + 2156 = 4739.96 \text{ kJ/}m^2/\text{yr}$$

The rate of field annual production, food consumption (for both kinds of food) were calculated using the assimilation efficiency of the plant (77.6%) and animal food (86%) (Abdul-Sahib *et al*., 2007), as:

$$C_p = A_p / (A/C)$$

1. In case of the plant food:

$$C_p = 4739.96/0.776 = 6108.2 \text{ kJ/m}^2/\text{yr}$$

2. In case of the animal food:

$$C_p = 4739.96/0.86 = 5511.58 \text{ kJ/m}^2/\text{yr}$$

The annual population energy budget was computed from:

$$C_p = P_p + R_p + F_p$$

1. In case of the plant food:

$$6108.2 = 2583.96 + 2156 + 1368.24$$

2. In case of the animal food:

$$5511.58 = 2583.96 + 2156 + 771.62$$

This emphasize that 22.4% out of the population energy consumption (in case of the plant food) is ejected as faeces, 35.3% is directed for metabolic energy expenditure and 42.3% of the energy is channeled for production. Whereas, when the barnacle fed on animal food: 14% of the population energy consumed is ejected as faeces, 39.1% is directed to metabolism and 46.9% for production, including growth, moulting and reproduction.

Meanwhile, the average field population energy budget of the barnacle at Garmat-Ali river is:

$$5809.89 = 2583.96 + 2156 + 1069.93$$

Annual Rate of Food Consumption:

Food consumption of a population of the barnacle *B. amphitrite amphitrite* was computed from the monthly average size of individual (from October 1994-September 1995), sizes then converted into dry weight according to the regression expressing (Abdul-Sahib *et al*., 2003a), the rates of monthly population food consumption was enumerated according to Phillipson (1970). The monthly average temperature was calculated using the temperature coefficient (Q_{10}) (Grodzinski *et al*., 1975), for both kinds of food (Table 5).

The mean annual food consumption of barnacle fed *Chlorella* was 4705.81 kJ/m^2/yr, and this is about 6 times lower than that of barnacles fed *C. fluminea* flesh (27836.51 kJ/m^2/yr).

Table 5. Annual food consumption of a population of *B. amphitrite amphitrite* fed plant and animal food, for the period Oct.1994-Sept.1995 from Garmat-Ali river. W= Monthly mean individual dry weight (g DW), T= Monthly mean Temp. °C, C= Mean monthly food consumption (mg/mo), N= Mean monthly density (m²/mo).

Months	$\overline{W}$	$\overline{T}$	$\overline{N}$	The Plant Food		The Animal Food	
				$\overline{C}$	$\overline{N} \times \overline{C}$	$\overline{C}$	$\overline{N} \times \overline{C}$
Oct. 1994	1.3527	27	9250	2.1559	19.942	7.5043	69.415
Nov.	0.9219	21	18300	0.682	12.481	1.8796	34.397
Dec.	2.1419	13	15167	0.416	6.497	1.2075	18.858
Jan. 1995	1.6446	15	15217	0.4569	6.953	1.2907	19.641
Feb.	1.9115	17	14950	0.6088	9.102	1.8697	27.952
March	0.9699	21	13467	0.7306	9.839	2.0413	27.490
April	1.031	24.5	13900	1.2092	16.808	3.706	51.513
May	0.9799	29	18333	2.2717	41.647	7.5753	138.878
June	1.2899	30.5	16000	3.3025	52.84	12.2486	195.978
July	1.0577	32	15833	3.6604	57.955	12.9299	204.719
August	1.1749	31	15483	3.4381	53.232	12.5289	193.985
Sept.	2.2997	29	14750	4.1074	60.584	16.9109	249.437
Total Annual				347.88 (gDw/m²/yr)		1232.263 (gDw/m²/yr)	
Total Annual				4705.805 (kJ/m²/yr)		27836.514 (kJ/m²/yr)	

The energy of food assimilation and the laboratory annual population production were obtained:
- For the plant food:

$$A_p = C_p \times (A/C) = 4705.81 \times 0.776 = 3651.71 \text{ kJ/m}^2/\text{yr}$$
$$P_p = A_p - R_p = 3651.71 - 2156 = 1495.71 \text{ kJ/m}^2/\text{yr}$$

- For the animal food:

$$A_p = 27836.51 \times 0.86 = 23939.4 \text{ kJ/m}^2/\text{yr}$$
$$P_p = 23939.4 - 2156 = 21783.4 \text{ kJ/m}^2/\text{yr}$$

Consequently, the annual population energy budget was computed as:

$$C_p = P_p + R_p + F_p$$

- In case of the plant food:

$$4705.81 = 1495.71 + 2156 + 1054.1$$

- In case of the animal food:

$$27836.5 = 21783.4 + 2156 + 3897.1$$

Then the general annual laboratory population energy budget for the barnacle is:

$$16271.14 = 11639.55 + 2156 + 2475.60$$

It is apparent therefore, that the energy for food assimilation and annual production of the population fed on *C. fluminea* are higher than those fed on *Chlorella*, for 14% of the energy entering the population fed on animals are ejected as faeces, 7.7% channeled for metabolic activities and

the remaining 78.3% are directed for production. Whereas, when barnacle fed plants, 22.4% of the energy ejected as faeces, 45.8% goes for metabolic energy expenditure and the 31.8% of the energy remaining is directed for production.

Obviously, the laboratory annual population production is higher than that calculated from the field:

Laboratory energy flow of the barnacle *B.a. amphitrite* from Garmat-Ali river:
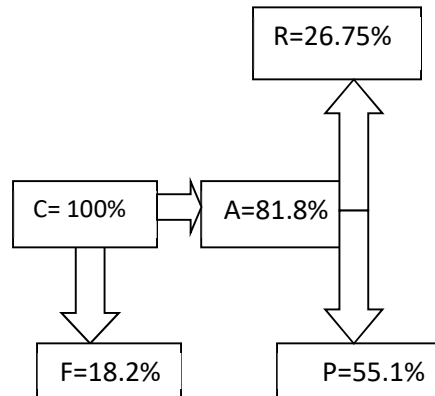
Field energy flow of the barnacle *B.a. amphitrite* at Garmat-Ali river:
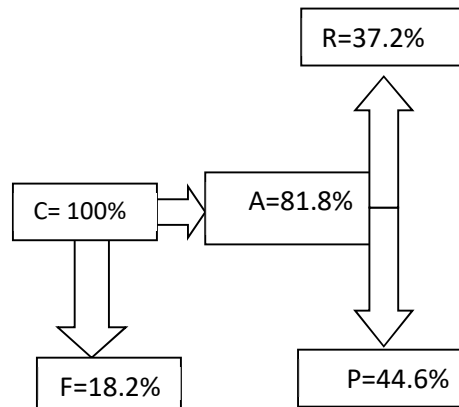
Discussion

In most animals, the energy expenditure to withstand environmental changes occurred in the intertidal zone, can be measured by estimating the oxygen uptake, as it reflexes the metabolic activities of the tissues. Most aquatic invertebrates are poikilotherms, and the lower rates of O_2 uptake at lower temperatures or during colder months indicate the drastic conditions the animals are exposed to when the body temperatures changes, together with the scarcity of food availability and the low level of food reserves (Barnes *et al*., 1963a). The present results emphasize this, as O_2

uptake of *B.a. amphitrite* increases or decreases with increasing or decreasing environmental temperature.

The relation of the rate of O_2 consumption of the barnacle *B.a.amphitrite* follow the normal pattern of increase with increasing temperature and body weight, and this concur with the results of Dame (1976); Al-Dabbagh and Marina (1986); Idrisi and Salman (2005); Abdullah (1996).

The present results showed that the b values of the relationships of metabolism at 15, 23 and $30°C$ were -0.623,-0.676 and -0.520, respectively which are lower than the b value of *B. balanoides* (-0.77) at 15 °C (Newell and Northeroft ,1967), and more than those of *B. balanoides* and *B. balanus* reported by Barnes and Barnes (1969) (-0.388 at $15°C$ and -0.327 at $20°C$ for the former and -0.4204 at $15°C$ and -0.2145 at $20°C$, for the latter). Moreover, the present results indicate that *B.a. amphitrite* consume oxygen at a rate of 0.622 $\mu lO_2/mg/h$ at $15°C$, 0.84 $\mu lO_2/mg/h$ at $23°C$ and 0.954 $\mu lO_2/mg/h$ at $30°C$, and these are more than the values recorded for *B. balanoides* and *B. balanus viz* 0.49 & 0.43 $\mu lO_2/mg/h$ at $15°C$ for the 0.212 mg and 0.530 mg, respectively and 0.505 and 0.447 $\mu lO_2/mg/h$ for the same weights at $20°C$, respectively (Barnes and Barnes, 1969) This is apparently due to the fact that *B.a. amphitrite* of the Shatt Al-Arab region is living in a subtropical region and is certainly acclimated to high temperatures, whereas *B. balanoides* and *B. balanus* are from boreal region (Scotland) in which temperature does not exceed $20°C$, therefore, they are acclimated to cold weather. Moreover, *B. balanoides* was collected from a subtidal region which is more stable than the intertidal region from which *B.a. amphitrite* was obtained. Furthermore, Lucas *et al*. (1979) recorded rates of oxygen uptake of newly settled *B. balanoides* of 0.7-1 $\mu lO_2/mg/h$, and for a cyprid at the swimming period 0.37 $\mu lO_2/mg/h$ and for a cyprid at the searching stage 0.2 $\mu lO_2/mg/h$.

The Q_{10} values of *B.a. amphitrite* obtained here at the two temperature limits of 15-23 and 23-$30°C$ emphasize that they increase with the increase of size of the barnacle and this is in accordance with the conclusion of Rao and Bullock (1954), and are lower at the higher temperature limit and higher at the lower temperature limit. This is coincides with the behavior of the snail *Littorina littorea* when the Q_{10} values was lower during summer than during winter (Newell and Roy, 1973). This is probably due to the thermal stress the animal subjected to in the intertidal zone. Moreover, the Q_{10} values of *B.a. amphitrite* obtained here are lower than 2.

However, Venables (1981) showed that the absolute values of the Q_{10} of the amphipod *Talorchestia margaritae* are low indicating good regulatory capability. Rao and Bullock (1954) suggested that there were geographic trends in Q_{10} distribution, with high values for animals from the tropics, although terrestrial organisms often do not conform to this trend. Newell (1969) provides much evidence in support of low Q_{10} values for intertidal organisms which experience wide daily fluctuations in temperature. A number of authors have reported elevations in metabolic rate associated with decreased habitat temperatures in populations or species widely separated geographically (see Vanables, 1981 for Ref.). Moreover, different compounds used in metabolism in barnacles may give different Q_{10} values, for instance when proteins and fats are used, Q_{10} values resulted would be approaching 1, whereas when carbohydrates were used the value would be 2 (Barnes *et al*., 1963).

Gernerally, changes in the respiration of barnacles would be controlled by the levels of carbonic acid in the tissues and body cavity as in the case of many other animals (Southward and Crisp, 1965). It is then possible to predict the relative success of species settlement in their natural habitat by measuring the rate of their respiration, as higher rates indicate higher metabolic activity and this is an indication of higher ecological efficiency. Thus, the present results suggest that the barnacle *B.a. amphitrite* is having higher ecological efficiency, furthermore, it's ability for aerial respiration

at low tide by closing and opening the valves of the shell in addition to the aquatic respiration by pumping and cirral activities at high tide qualified it to colonize the intertidal as well as the subtidal zone.

Energy is produced from the food the animal is feeding upon. Feeding is not an automatic process, but is a process controlled by the need to the food or appetite (Ritz and Crisp, 1970). The present results emphasize that the average energy contents of *Chlorella* sp. was 3.2 kcal/g and this is almost similar to the energy contents of *Cladophora* sp. (3.1 kcal/g; Abdullah, 1996) and less than that of *Microcystis* sp.(4.8 kcal/g) and *Pandorina* sp. (4.9 kcal/g) (Comita and Schindler, 1963). Whereas, the flesh of the clam *Corbicula fluminea* contained 5.4 kcal/g DW and is slightly higher than that of *Modiolus demissus* (4.5 kcal/g), and than the average energy contents of bivalves (4.2 kcal/g) (Wacasey and Atkinson, 1987).

Moreover, the barnacle *B.a. amphitrite* assimilates the flesh of the clam about 7 times more than assimilating the *Chlorella*, this difference is probably due to the kind of food, it's chemistry, nature of the alimentary canal, and type and quantity of enzymes available. In this respect, it resembles, the barnacle *B. improvisus* which consumes 3-5 times, the diatome *A. japonica*, 2-3 times the barnacle nauplii more than the alga *Cladophora*, and assimilates 7.3 cal/day, 3.6 cal/day and 15.4 cal/day of these foods, respectively (Kuznetsova, 1973).

Whereas the calorific values of the assimilated and non assimilated food of the barnacle *B.a. amphitrite,* was 14% for the *Chlorella* sp. and 9.6% for the flesh of the clam. However, in *B. improvisus,* the assimilated and the non assimilated animal food (larvae of barnacles) and the alga *Cladophora* varies by more than 10% as an average (Kuznetsova, 1973).

The present results indicate that the barnacle allocates 45-55% of the assimilated energy for net growth and the metabolic energy expenditure was low (27-37%), this is because the barnacle is a poikelotherm and does not use energy to regulate it's body temperature and the high net growth efficiency reflects the species strategy to efficiently use the consumed energy. This is expected for a sessile organism as a relatively small amount of energy would be required to maintain their normal activities. This is opposed to the results of Wu and Levings (1978) that in *B. glandula* a large portion of energy (67.4%) was lost in respiration, therefore, the animal is of no benefit to the next trophic level. The annual field energy budget of the population of *B.a. amphitrite*, indicates that it's consumption is 5511.58 kJ/m^2/yr (37.2%), it's production is 2583.96 kJ/m^2/yr (44.6%) and it's assimilation is 4739.96 kJ/m^2/yr (81.8%) which are less than those of *B. glandula* (Wu and Levings, 1978), which consumes 35991kJ/m^2/yr and it's production is 8212 kJ/m^2/yr and it's assimilation is 33307 kJ/m^2/yr. Also the consumption of *B.a. amphitrite*, is less than that of the oyster *Crassostrea gigas* (6466 kJ/m^2/yr; Bernard, 1973). The respiratory coefficient R/P of the barnacle was 0.6 which is very less than that of the crab *E. kempi*, (2.129; Ali *et al.*, 2013) and less than the freshwater snails of the Shatt Al-Arab region *Melanopsis nodosa* and *Melanoides tuberculata* (1.9 and 0.7, respectively; Abdullah, 1996).

Generally, the value of this coefficient for the invertebrates is less than 5 (Grodzinski *et al.*, 1975). This emphasize that the barnacle is having a short life span and with very low respiratory energy due to it's limited activities, for the animal is sessile and it's energy expenditure mostly channeled for reproduction and building up the shell. It can be concluded, therefore, that the barnacle *B.a. amphitrite* is an important consumer in the intertidal zone, moreover, it is opportunistic and contribute very well to the production of the ecosystem of the Shatt Al-Arab region.

References

Abdullah, S.B. 1996. Ecological study and population dynamic of two gastropods in the intertidal zone *Melanopsis nodosa* Ferussac and *Melanoides tuberculata* (Müller), at Southern Iraq. Ph.D. Thesis, College of Science, University of Basrah, 122p. URL

Abdul-Sahib, I.M. 1997. Energy flow in the barnacle *Balanus amphitrite amphitrite* Darwin (Crustacea: Cirripedia) in the intertidal zone of Garmat-Ali River, Ph.D. Thesis, College of Science, University of Basrah, 102p. URL

Abdul-Sahib, I.M., Salman, S.D. and Ali, M.H. 2003a. The biology of the barnacle *Balanus amphitrite amphitrite* Darwin (Crustacea: Cirripedia) at Garmat Ali River, Basrah, Iraq. Marina Mesopotamica,18(1): 55-76. URL

Abdul-Sahib, I.M., Salman, S.D. and Ali, M.H. 2003b.Secondary production of the barnacle *Balanus amphitrite amphitrite* Darwin (Crustacea: Cirripedia) Garmat-Ali River, Basrah, Iraq. Marina Mesopotamica, 18(2):151-163. https://scholar.google.com/scholar?cluster=10887772359512125511&hl=ar&as_sdt=2005&sciodt=0,5

Abdul-Sahib, I.M., Salman, S.D. and Ali, M.H. 2007. The effect of temperatures on the feeding of the barnacle *Balanus amphitrite amphitrite* Darwin in the Garmat-Ali River, Basrah, Iraq. Marina Mesopotamica, 22(1): 135-146.URL

Al-Dabbagh, K.Y. and Marina, B.A.1986. Relationship between oxygen uptake and temperature in the terrestrial isopod *Porcellionides pruinosus*. J. Arid Envir., 11: 227-233.https://doi.org/10.1016/S0140-1963(18)31208-4

Ali, M.H., Salman, S.D. and Al-Adhub, A.H.Y. 2013. Energy budget of a population of the Hymenosomatid crab, *Elamenopsis kempi* from Garmat-Ali River, Basrah, Iraq. Animal Diversity, Natural History and Conservation, 2: 151-163. Ed

Arif, A.M. 1977. Ecological studies on *Balanus amphitrite amphitrite* (Crustacea: Cirripedia) in Shatt Al-Arab. M.Sc. Thesis, College of Science, University of Baghdad, 73p (In Arabic). URL

Barnes, H. and Barnes, M. 1969. Seasonal changes in the acutely determined oxygen consumption and effect of temperature for three common cirripedes, *Balanus balanoides* (L.) *B. balanus* (L.) *Chthamalus stellatus* (Poli.). J. Exp. Mar. Biol. Ecol., 4: 36-50.https://doi.org/10.1016/0022-0981(69)90022-7

Barnes, H., Barnes, M. and Finlayson, D.M. 1963. The seasonal changes in body weight, biochemical composition, and oxygen uptake of two common boreoarctic cirripedes, *Balanus balanoides* and *B. balanus*. J. Mar. Biol. Ass. U.K., 43: 185-211.URL

Bernard, F.R. 1973. Annual bio depositions and gross energy budget of mature Pacific Oysters, *Crassostrea gigas*. J. fish. Res. Bd. Can., 31: 185-190.https://doi.org/10.1139/f74-030

Brody, S. 1945. Bioenergetics and growth. Reinhold, New York, 1023p.https://doi.org/10.1002/ajpa.1330040117

Comita, W.G. and Schindler, D.W. 1963. Calorific values of Microcrustacea. Science, N.Y., 140: 1394-1395.https://doi.org/10.1126/science.140.3574.1394

Crisp, D.J. 1984. Energy flow measurements. In, "Methods for the study of marine Benthos", IBP Handbook, No.16. (N.A. Holme and A.D. McIntyre, eds.). Black- Well, Oxford, UK, pp: 284-372.URL

Dame, R.F. 1976. Energy flow in an intertidal oyster population. Estuar. Coast. Mar. Sci., 4(3): 243-253.https://doi.org/10.1016/0302-3524(76)90058-X

Darwin, C.R. 1854. A monograph on the sub-class Cirripedia, with figures of all the species. The Balanidæ, (or sessile cirripedes); the Verucidae, etc., Vol. 2., London, UK: The Ray Society.URL

Grainger, F. and Newell, G.E. 1965. Aerial respiration in *Balanus balanoides*. J. Mar. biol. Ass. U.K., 45: 469-479.URL

Grodzinski, W., Klekowski, R.Z. and Duncan, A. 1975. Methods for ecological bioenergetics. IBP. Handbook No. 24, Blackwell, Oxford, 367p.URL

Idrisi, N.A. and Salman, S.D. 2005. Distribution, development and metabolism of larval stages of the warm water shrimp *Caridina babaulti basrensis*, (Decapoda, Atyidae). Marine and Freshwater Behavior and Physiology, 38(1): 31-42.https://doi.org/10.1080/10236240400029366

Kuznetsova, I.A. 1973. Utilization of several kinds of feed by cirripede crustaceans. Hydrobiol. J., 9: 33-40. URL

Lucas, M.I., Walker, G., Holland, D.L. and Crisp, D.J. 1979. An energy budget for the free-swimming and metamorphosing larvae of *Balanus balanoides* (Crustacea: Cirripedia). Mar. Biol., 55: 221-229.https://doi.org/10.1007/BF00396822

Mohammed, M.B.M. 1975. Competitive relationship between *Balanus amphitrite amphitrite* and *Pomatoleios kraussii* with special reference to their larval settlement. Hydrobiologia, 46 (1): 1-15.https://doi.org/10.1007/BF00038722

Newell, R.C. 1969. Effect of fluctuations in temperature on the metabolism of intertidal invertebrates. American Zoologist, 9: 293-307.https://doi.org/10.1093/icb/9.2.293

Newell, R.C. and Northeroft, H.R. 1967. A re-interpretation of the effect of temperature on the metabolism of certain marine invertebrates. J. Zool. Lond., 151: 229-262.https://doi.org/10.1111/j.1469-7998.1967.tb02878.x

Newell, R.C. and Roy, A. 1973. A statistical model relating the oxygen consumption of a mollusk (*Littorina littorea*) to activity, body size and environmental conditions. Physiol. Zool., 46: 253-275.URL

Phillipson, J. 1970. The best estimate of respiratory metabolism: its applicability to field situations. Pol. Arch. Hydrobiol., 17: 31-41. URL

Rasheed, A.A. 1977. Reproduction of *Balanus amphitrite amphitrite* (Crustacea: Cirripedia) in Shatt Al-Arab. M.Sc. Thesis. College of Science, Univ. of Baghdad, 63 p. (In Arabic).

Ritz, D.A. and Crisp, D.J. 1970. Seasonal changes in feeding rate in *Balanus balanoides*. J. Mar. Biol. Ass. U.K., 50: 223-240.URL

Rao, K. and Bullock, T.H. 1954. Q_{10} as a function of size and habitat temperature in poikelotherms. Amer. Natur., 838: 33-44.URL

Southward, A.J. and Crisp, D.J. 1965. Activity rhythms of barnacles in relation of respiration and feeding. J. Mar. Biol. Ass. U.K., 45: 161-185.URL

Stubbings, H.G. 1961. Some Cirripedia from the Persian Gulf. Ann. Mag. Nat. Hist. Ser., 13, 4(34): 171-176.https://doi.org/10.1080/00222936108655798

Venables, B.J. 1981. Oxygen consumption in a tropical beach amphipod, *Talorchestia margaritae* Stephenson: effect of size and temperature. Crustaceana, 41(2): 89-94.URL

Wacasey, J.W. and Atkinson, E.G. 1987. Energy values of marine benthic invertebrates from the Canadian Arctic. Mar. Ecol. Prog. Ser., 39: 243-250.URL

Wu, R.S.S. and Levings, C.D. 1978. An energy budget for individual barnacle (*Balanus glandula*). J. Mar. biol. Ass. UK, 45: 225-235.https://doi.org/10.1007/BF00390605

Zar, J.H. 1974. Biostatistical Analysis. Englewood Cliffs, N.J.: Prentice-Hall, 620p.URL