INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 11, No. 6, p. 219-231, 2017

RESEARCH PAPER OPEN ACCESS

Study of weight gain and reproduction in the *Perna perna* mussel using a standard animal

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Key words: *Perna perna*, Weight gain, Standard animal, Reproduction, Gulf of Annaba

http://dx.doi.org/10.12692/ijb/11.6.219-231 Article published on December 30, 2017

Abstract

This study aims to establish a link between weight variation of the brown mussel *Perna perna*, condition index and the environmental parameters. In order to eliminate the effect of growth on the weight variation, a standard sized animal of about 60 mm, was used. Random sampling of mussels and seawater was conducted once a month, from two sites in the Gulf of Annaba (Algeria), over an annual cycle. Growth parameters were determined by reference to shell length, fresh and dry mass tissue weight, as well as shell and total weight. Temperature, dissolved oxygen, salinity, chlorophyll *a* and suspended matter were recorded at each site. The results show that, the CI variation in the SI is a function of weight, which is itself a function of the sexual stage as well as the availability of food (especially chlorophyll-a and suspended matter). The period of the maximum of gain weight corresponds with the increases in the condition index and was associated with high concentrations of chlorophyll-a and suspended matter, recorded during the spring period. This is supported by statistical analysis showing a significant correlation. *Perna perna* has two spawning periods, one in the autumn and one in winter. The knowledge of the reproductive cycle and environmental parameters that could influence them may constitute a basic data, necessary not only for any commercial exploitation of this mussel species, but for its use as bio-monitoring as well. Such monitoring assures a qualitative analysis of shellfish aquaculture products and helps to choose mussel cultivation sites.

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Introduction

The rapid population growth in coastal communities has all the more exerted increasing pressure on the productivity of these resources as fishing effort from the artisanal fishing sector has been increasing. A strategy which Algeria could undertake to find alternative economic activities for small-scale, fisher-men would be in bivalve farming such as oysters and mussels. These mollusks are easy to farm; they are nutritious food items and with proper management and direction of bivalve farming development programmes, the product could be a source of protein and essential nutrient. Among the species of bivalves harvested from the wild in the North East of Algerian Coastline include the mussel *Perna perna*.

Bivalve growth depends on the environmental quality; due to the rapid growth rates of mussels, these organisms are well suited for culture on a commercial scale in subtidal biotopes (Rivonker *et al*., 1993; Rajagopal *et al*., 2006). By definition, growth comes to be known as the measure of the increase in size and weight of individual according to time and environmental variables. Bautista (1989) has indicated that mussel growth is a function of a number of environmental parameters, mainly food and temperature. The environment influences the somatic and reproductive tissue growth of marine bivalves both directly and indirectly (Griffiths and Griffiths, 1987; Lodeiros and Himmelmam, 2000). In given mussels population, the weight dynamics is closely linked to the reproductive activity of individuals (Seed, 1973). Bouhaimi *et al*., (2000) reported that different parameters of growth show variations being closely related with different phases of the reproductive cycle, either for *M. galloprovincialis* or *Perna perna*. According to Barillé (1996), temporary accumulation of reserves are converted into gametes, and then expelled in the environment in order to ensure fertilization, induce a sudden loss and slowing down of weight, or even the halt of growth. This author suggests separating these two processes, in order to determine precisely the influence of the environmental constraints' either on growth or reproduction. In this sense, Baird (1958) stressed that in order to compare the condition of samples of mussels "the mussels should be of approximately the same size". From individual condition index measurements, Baird showed a curvilinear relationship between length and condition in *Mytilus edulis*, with optimum condition at between 50 and 60 mm length. According to Hilbish (1986), temporal variations of standard animal weight reflect changes in productivity and fertility of individuals.

Biology and dynamic population study of bivalves species presents undeniable scientific interest; the knowledge of their reproductive cycle and environmental parameters that could influence them, may constitute a basic data necessary not only for any commercial exploitation of this given mollusk, but for its use as bio-monitoring as well. In Algeria, the reproduction as well population structure has been carried out by Abada-Boudjema (1981) and Boukroufa (1987) at Bordj El Kiffan, also by Chaoui (1993) in Annaba Gulf. At present, this species is used as indicator in the coastal water quality monitoring (Belabed *et al*., 2007; Belabed *et al*., 2013; Khati *et al*., 2007; Khati *et al*., 2012 ; Kadri *et al*, 2015).

The aim of this study is to firstly follow the weight growth (total weight, weight of fresh flesh, dry flesh and shell weight) and condition index of standard size animal (60mm) and secondly, to identify the effect of some environmental factors on the parameters mentioned above. Such monitoring assures a qualitative analysis of shellfish aquaculture products during the biological cycle and helps to choose mussel cultivation sites.

Material and methods

Study Area

Random sampling was conducted in brown mussel from natural beds at the Gulf of Annaba, Algéria. The two sampling sites are the Cap de Garde (36°58'50.335' N and 7°47'8.056' E) and Lahnaya (36°53'6.59"N and 8°4'8.70' E). The currents over Annaba Gulf present circulation oriented from west to the east with fluctuating speeds according to the seasons and reaching around 0.5 to 1m/s. This current starts from South East side of Cap de Garde to the Mafragh River (Fig. 1).

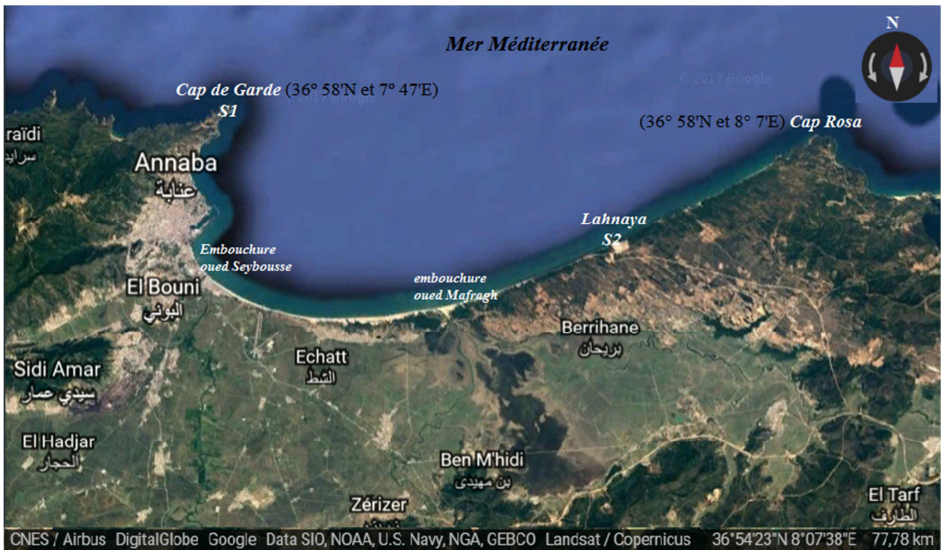


Fig. 1. Study area; sampling sites (S1: Cape of Guard and S2: Lahnaya (Google earth, 2017 modified).

The study was carried out for twelve months from January 2010 to December 2010, and samplings of mussels and seawater were conducted once a month.

Environmental variables

Multi-parameters environmental sensor (Consort 535) was used to measure the in situ environmental parameters which included temperature (Temp; °C), salinity (SS; $g.L^{-1}$) and dissolved oxygen (DO; $mg.L^{-1}$) at 0.5m below the water surface.

The chlorophyll-a (Chll-a; $\mu g.L^{-1}$) was extracted in 90% acetone, after pre-filtration of seawater samples through 200 to 250µm pore size membrane filters to remove large particulate matter and zooplankton. A second filtration was carried out on GF/C 0.45 µm filters (WHATMAN) then followed by absorbance determination at two wavelengths (665 and 750µm) before and after acidification. Thereafter, the chlorophyll-a concentration was calculated according to monochromatic method of Lorenzen (1967).

To determine the content of the suspended matter (SM; $mg.L^{-1}$), the seawater samples were filtered on pre-weighed GF/C 0.45 µm filters (WHATMAN). Subsequently, the GF/C 0.45 µm filters (WHATMAN) were dried in an oven (100°C for 24h) before final weighing to estimate the total suspended matter according to differential weighing method of Aminot and Chaussepied (1983).

Mussel's treatment

Fifty mussels of different size were collected monthly from two sites, and then transported in isothermal containers to laboratory, where they were sorted and cleaned of encrusting organism. For each harvested mussel, the morphometric and weight measurements including shell length (SL; mm; anterior-posterior axis), total weight (Wt; g; whole body weight) and a weight of the different components (shell weight (SW; g), wet flesh weight (Wf; g) and the dry flesh weight (DWf; g)) were carried out to the nearest 1/20mm and 0.01g, using a vernier caliper and an analytical balance (Kern 440-33) respectively.

Each weight per mussel in each monthly sample at each site was related and plotted against shell length.

The relationship of $W=aL^b$ (W= weight (g); L= length (mm); a= condition factor; b= growth coefficient) was used to establish the length-weight relationship (Quinn and Deriso, 1999) and then to calculate monthly weight changes in different component for standard-sized individuals (60mm). At this size (60mm), individual intend the most of products that it synthesize for reproduction. Indeed, for young individual, the greatest part of energy is intended for their somatic growth (Parache, 1983).

Dry weight variation of a standard individual check out the principle according to which, the dry flesh weight fluctuations essentially depends on the maturity degree of genital organs.

The regression coefficients and b have been estimated by the method of least squares after linearization (logarithmic transformation). The linear function is then:

$\log Y = \log a + b \log X$

The report of the parameters and b is determined by the linear regression, while the correlation rank inter-variables have been established by calculating of determination coefficient R^2.

The purpose of the biological cycle study of the given species is to determine the outstanding phenomena that occur during this cycle, such as the growth or reproduction.

The condition index gives us a clear idea about physiological condition of the individuals in a given population (Bodoy and Massé, 1979; Bodoy, 1980; Lucas and Beninger, 1985). And permit estimation of the organic matter part emanated during the reproduction (Bodoy and Massé, 1979). According to Pellerin-Massicotte (1994), it is also an indicator of general stress and physical condition of organisms.

The index chosen within the framework of this study is that proposed by Phernambucq and Vroonland (1983) and demonstrated by Bodgy *et al.*, (1986); it will allow us to follow the steps of the gametogenesis and gametes emission periods; Condition index (CI) of brown mussel was calculated from the ratio of dry flesh weight (DWf)/ total weight (Wt):

$CI = (DWf/ Wt) \times 100$

The improvements in accuracy and speed of measurements which are possible with the Cl method permit quite large samples of mussels to be evaluated individually, with a high degree of precision.

Statistical analysis

The statistical analysis of data was performed using the software R (for Windows, Version 3.3.2); prior to analyses, all variables were tested for normality and homogeneity of variances (Test of Shapiro-Wilk).

Relationship between growth parameters and five hydrographic parameters was investigated by using performing a Spearman rank correlation procedure.

Regarding the inter-station comparisons, the non-parametric test of Wilcoxon-Mann-Whitney was applied on all measured parameters.

Results

The total weight of the standard individual (SI) fluctuates between 13 and 18g at the Cap de Garde mussels (an average of about 15.50g) and between 12 and 15g at those of Lahnaya (either on average 13.67g). At the Cap de Garde, the total weight of the SI shows peaks in January (17g), May (16g) and August (18g). At Lahnaya, the Wt of the SI shows two peaks in February (16g) and in June (14.5g) (Fig. 2a).

The evolution of the Wt shows a very significant difference between Cap de Garde individuals and those of Lahnaya ($p = 0.003$).

Regarding shell weight, Values oscillate between 9.6 and 11.6g (average weight = 10.31g) with a peak in October for mussels collected in Cap de Garde and from 7.5 to 10.5g (average weight =8.95g) with three peaks close to 10 in February, June and August for the mussels of Lahnaya (Fig. 2b).

A very highly significant difference ($p < 0.001$) was recorded in the evolution of mussels shell weight collected from the both sites.

The fresh flesh weight of SI shows variation from 3 to 5.5g in the Cap de Garde (for an average weight of 4.23g); the values fluctuate between 3.5 and 4.5g except for the rise of December and January (5.45g) and the decrease in March (2.91g). At Lahnaya, this weight fluctuates between 3 and 4.5g (with 3.67g as average weight); it lies between 3.5 and 4.5g from February to October and falls to 3g between November and January (Fig. 2c).

The SI fresh flesh weight of the Cap de Garde and Lahnaya mussels showed a significant difference ($p= 0.04$) in values evolution between both sites.

Significant positive correlation ($r \geq 0.59$; $p = 0.041$) at Lahnaya and very significant ($r \geq 0.80$; $p = 0.0014$) at the Cap de Garde was recorded between total weight and fresh flesh weight of SI.

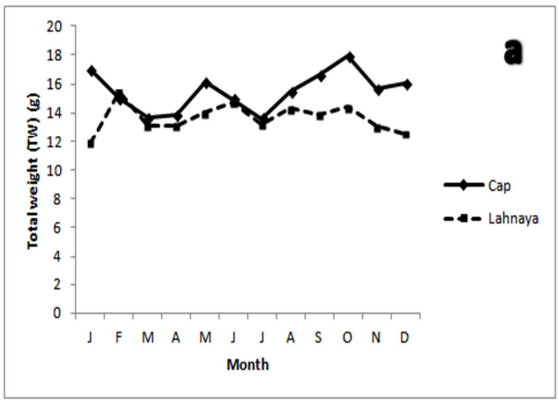
In both sites, the dry flesh weight of the SI shows important fluctuations which varies from 0.3 to 0.8g (for an average weight of 0.54g) for mussels of Cap de Garde and from 0.3 to 0.7g (either an average weight of 0.51g) for those of Lahnaya.

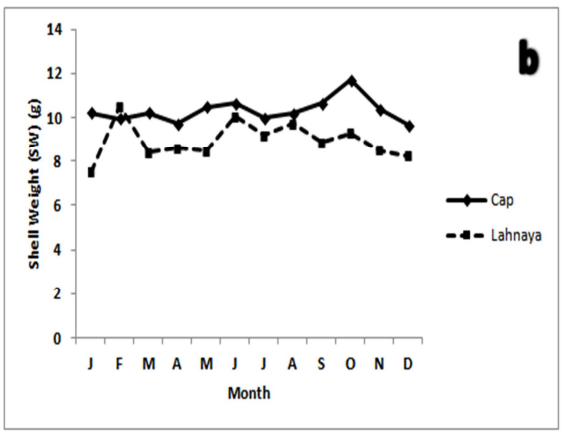
The values recorded to the mussels collected from the Cap de Garde are more often between 0.5 and 0.7g except for the peak of May and the heavy decrease of February, March and September.

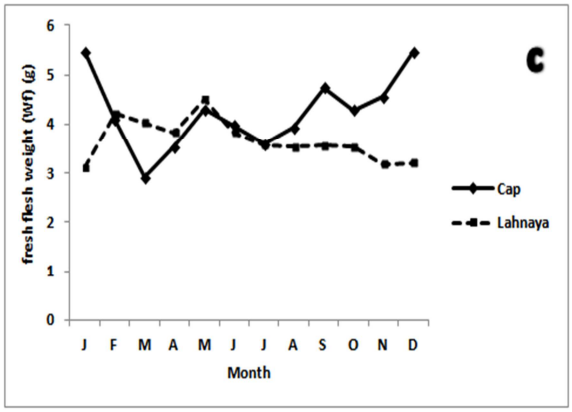
As regards with the dry flesh weight of Lahnaya mussels, it oscillates between 0.6 and 0.75g from February to may, decreases and remains close to 0.55g from June to August. Subsequently, it shows a second fall up to 0.4g from September to November, to finally reaching its minimal value (0.3g) in December and January (Fig. 2d).

No difference was found between the both sites, regarding the evolution of the weight of SI dry flesh weight.

The SI condition index (CI) of *Perna perna* mussel ranged from 2 to 4.9 with a mean (± SD) of 3.49 ± 0.81 at the Cap de Garde and from 2,5 to 5,2 (a mean (± SD) of 3.75 ± 0.93) at Lahnaya.







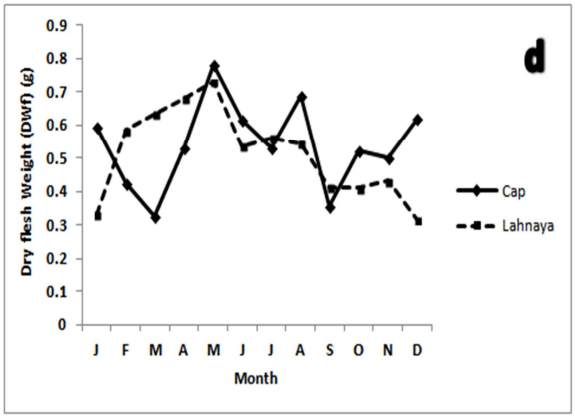


Fig. 2. Monthly evolution of different weights of the Standard Individual (a: total weight (Wt); b: shell weight (SW); c: fresh flesh weight (Wf); d: Dry flesh weight (DWf)).

Mussels of Cap de Garde show that their CI fluctuates between 4 and 5 from April to August and between 3 and 4 from October to December, except for low values recorded in March (2.39) and in September (2.14). For mussels belonging Lahnaya, the values of CI are close to 5 from March to May, then decrease to 4 from June to August and 3 from September to November. Subsequently, it records values lower than 3 in December-January (Fig. 3).

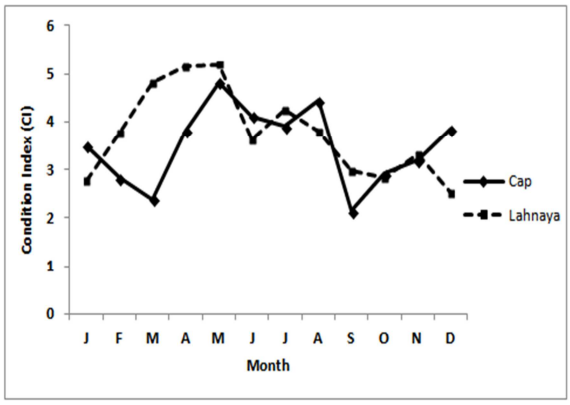


Fig. 3. Monthly evolution of the standard individual condition index (CI).

The Wilcoxon-Mann-Whitney test applied for comparison of CI raised in both sites does not show a significant difference. However, a very highly significant positive correlation (<0.001) was noted between the condition index and the dry flesh weight of SI collected in both sites of study.

Environmental factors

The spatio-temporal variations of the seawater parameters recorded throughout the sampling period are summarized in table 1.

Table 1. Monthly values of the environment parameters of seawater recorded in the site 1 (Cap de Garde) and the site 2 (Lahnaya).

	Chll-*a*		SM		DO		SS		Temp	
Month	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
January	74.76	0	0.217	0.024	7.4	5.05	37.2	36.5	15	13
February	0	0	0.238	0.218	10.09	11.7	40.3	39.7	18	7
March	0	0	0.203	0.22	10.2	11.1	39.8	39.8	13	7
April	192.24	10.68	0.237	0.275	5.4	0.6	37.4	36.5	13	17
May	104.13	26.7	0.024	0.109	5.21	6.2	38.01	37.8	26	18
June	24.03	0	0.024	0.23	5.2	7	39.2	37.6	26	26
July	202.92	72.09	0.244	0.254	5.04	5.9	40.4	39.8	26	26
August	165.54	42.72	0.225	0.035	5.56	5.7	35.6	36	28	26
September	10.68	8.01	0.02	0.197	5.72	8.67	39.6	36.5	26	18
October	16.02	50.73	0.04	0.122	6.3	8.6	35.9	36.5	12	17
November	4	13.35	0.033	0.045	7.75	5.02	36.5	36.4	12	13
December	0	0	0.226	0.028	7.46	4.96	37.3	36.4	15	13

Temperature ranged between 12 and 28°C (average temperature = 19.16°C) in the Cap de Garde and from 7 to 26°C (average temperature = 16.75°C) at Lahnaya. Salinity values varied between 35.6 and 40.4 g/l (average salinity = 38.10 g/l) in the Cap de Garde and between 36.4 and 39.8 g/l (average salinity= 37.45) at Lahnaya. Dissolved oxygen levels fluctuate between 5.04 and 10.2 mg/l (with an average of 6.77 mg/l) in the Cap de Garde and between 4.96 and 11.7 mg/l (average content = 6.7 mg/l) at Lahnaya. In the Cap de Garde, the content of suspended matter range from 0.02 to 0.24 mg/l (an average of 0.144 mg/l) and in Lahnaya, they vary from 0.02 to 0, 27 mg/l (average of 0.146 mg/l). Recorded chlorophyll-a content shows fluctuations between 0 and 202.9 µg/l (average of 66.19 µg/l) in the Cap de Garde and between 0 and 72 µg/l (average of 18.69 µg/l) at Lahnaya.

The environmental parameters measured in this study do not show any significant difference between the both sites. However, the matrix of Spearman correlation established between environment settings and those of the growth in each study site, allows us to include the maximum of data and set at best, the type and amplitude of correlations.

At the Cap de Garde, the SI condition index (CI) correlates positively with chlorophyll-a ($r = 0.62$; $p < 0.05$) and negatively with dissolved oxygen ($r = 0.68$; $p < 0.05$).

Suspended matter and the weight of shell, show a negative correlation very highly significant ($r = 0.85$; $p < 0.001$). Regarding salinity and temperature, no significant correlation was recorded with none of weight parameters.

However, these are the suspended matter at Lahnaya, which seems to be the most associated with the weight variables; a significant correlation is recorded between suspended matter and dry flesh weight ($r = 0.60$; $p < 0.05$), the weight of fresh flesh ($r = 0.65$; $p < 0.05$) and condition index ($r = 0.58$; $p < 0.05$).

Positively correlated with suspended matter ($r = 0.61$; $p < 0.05$), the salinity seems to have effect on the evolution of the fresh flesh weight; we note, in fact, a highly significant positive correlation between these two parameters ($r = 0.75$; $p < 0.01$).

We note a positive correlation ($r = 0.68$; $p < 0.05$) between the level of dissolved oxygen and the evolution of the SI total weight.

Discussion

Reproduction and growth performance of the brown mussel (*Perna perna*) in a coastal marine environment can be affected by many factors, including environmental change, pollution, disease outbreaks, physiochemical, hydrodynamic, food, predation, and competition for space.

Askew (1972) and Utting (1986), showed that several factors influence the rate of weight gain and linear growth in bivalves, such as the physical and nutritional status of the environment, besides the physiological (Bayne *et al.,* 1999) and genetic parameters of bivalves (Newkirk, 1980; Gaffney, 1988; Hedgecock *et al*., 1996).

Changes in total weight (Wt) and fresh flesh weight (Wf) of the SI differ very significantly between the two study sites, whereas changes within each site show a positive correlation ranging from significant ($p = 0.04$) to very significant ($p = 0.001$) respectively at Lahnaya and the Cap de Garde sites. This can be explained by the fact that a loss of weight suffered during the biological cycle of the animal is compensated for by intravalvular water (for Wt) and by the occupation of tissues by sexual cells or reserves and water (for Wf).

Therefore, neither of these weight parameters really reflects the state of growth of the tissues, which leads us to conclude that these weights are not reliable predictors of weight variations related to reproduction, as demonstrated by Aloui-Bejaoui *et al.*, (2002).

Nor is total weight a reliable predictor of commercial quality. If we consider the entirety of the biomass produced, it does provide a good indication of productivity for shellfish farming, but it does not provide an indication of the exact proportion of tissue mass compared to the rest of the animal. The same results have been reported for the Mediterranean mussel *Mytilus galloprovincialis* in the Bizerte lagoon in Tunisia (Aloui-Bejaoui *et al.*, 2002).

Several authors have highlighted the value of studying dry flesh weight (DWf) when estimating the weight changes of *Mytilus edulis* (Brown *et al*., 1976; Rodhouse *et al*., 1984; Hilbish, 1986; Barillé, 1996), of *M. galloprovincialis* (Ceccherelli and Rossi, 1984; Naciri, 1998; Aloui-Bejaoui *et al*., 2002) and of *Perna perna* and *Perna viridis* (Garcia *et al*., 2016), as well as when monitoring the reproductive cycle represented by the condition index of *Perna picta* (Shafee, 1989) and *Perna canaliculus* (Hickman and Illingworth, 1980). The variations of dry flesh weight for a standard individual accord with the principle that weight fluctuations depend mainly on the degree of maturity of the gonads, and thus have the advantage of explaining a gain or loss of weight in organic terms, without taking into account either variations of weight relating to linear growth, or the volume of water retained by the animal during its biological cycle.

In the present study, changes in DWf show no significant difference between the two sites under consideration. However, this weight does vary considerably according to the phase of the sexual cycle, itself depending on local environmental conditions, which would explain the very highly significant positive correlation noted between DWf and CI at both study sites. A similar finding was also reported by Hickman and Illingworth (1980), who showed that the CI reduction results from an increase in the contents component combined with a decrease in the dry flesh component.

The period of maximum fattening extends from May until August for the mussels at the Cap de Garde, and from March to May for the mussels at Lahnaya. Contrary to what has been found in the present study, Braid (1966), found that highest levels of condition in *Mytilus edulis* in Europe occurred in autumn and winter, prior to the spring spawning season

This fattening period includes both the resumption phase of sexual activity (gametogenesis and gonadal maturity) and the part of the year when high levels of chlorophyll-a and suspended matter (SM) are recorded.

This correlation between the physiological condition of the individuals and the availability of food has already been highlighted by Naciri (1998), who explains that the fluctuations in DWf of the *M. galloprovincialis* mussel (standard animal of 40 mm) may be due to several factors such as the growth of the tissue mass and the shell, the formation and emission of gametes, the use of reserves during certain periods of the biological cycle and the availability of food in the environment. Aloui-Bejaoui *et al.*, (2002) report that temperature, and phytoplankton biomass represented by the levels of chlorophyll-a, play an important part in explaining the increase in weight of the standard animal of the *Mytilus galloprovincialis* mussel in the Bizerte lagoon in Tunisia. According to these authors, temperature and chlorophyll-a content explain both the variation in fresh flesh weights and in dry flesh weights only. These two parameters have an impact on tissue growth, itself largely influenced by the reproductive cycle, which interferes markedly with somatic weight increase (Parache and Massé, 1987).

Lubet (1973) notes, that the very substantial *M. galloprovincialis* biomass in the Adriatic and the Atlantic Ocean is due to the abundance of phytoplankton in these environments. The study results of Garcia *et al.*, (2016) showed that the growth rate of *Perna perna* and *Perna viridis* grown on ropes in the gulf of Cariaco in Venezuela was related to environmental factors, in particular the influence of food and temperature. These two parameters also appear among the main environmental parameters cited by Héral *et al.*, (1987) and Seed and Suchanek (1992) including temperature, seston biomass, particulate organic matter and phytoplankton biomass.

Rajagopal *et al.*, (1998) and Alfaro (2006) demonstrated that there is a strong correlation between the availability of food and the density of green mussels; but the chlorophyll-a measurement is not enough on its own to show the exact significance of food availability as a factor in the growth of bivalves, given their selective feeding behavior (Ren *et al.*, 2000; Rouillon and Navarro, 2003). This was demonstrated and confirmed by Mohd-Taib *et al.*, (2016), Garcia *et al.*, (2016) and Soon *et al.*, (2016).

In mussels deprived of a supply of food, Cherifi *et al.*, (2015) noted a significant decrease in the condition index after 10 days. However, in specimens fed with powdered *Ulva intestinalis* seaweed, mass was observed to be maintained. In the present study, contrary to what was found by Aloui-Bejaoui *et al.*, (2002), the influence of the chlorophyll-a content on the weight of dry flesh (DWf) was greater than that of the temperature. This accords with the results of Kautsky (1982) on *Mytilus edulis* in the Baltic. He indicated that the abundance of food was the primary factor controlling gonad growth, and that this was linked to a probable adaptation of mussels to the low temperatures of the Baltic. In the present study, the influence of temperature is indirect; this parameter acts in combination with other environmental factors such as dissolved oxygen and salinity. Hickman and Illingworth (1980), show a correlation between the mean level of condition in mussel populations and the latitude (and water temperature) at which they occur. Data from a variety of species indicates a direct relationship between latitude and condition, and a corresponding inverse temperature/condition relationship. The temperature tolerances of the various species must limit these relationships, but they appear to exist over a wide range of latitudes for several mussel species. In this sense, Lubet (1981) specified that weight gain is influenced by, amongst other factors, the temperature, which has a direct action on the kinetics of gametogenesis, resulting in competition between the somatic and germinal compartments, inducing a significant weight gain. This author also showed that the temperature acts indirectly on the primary productivity of the environment and the availability of the food and consequently, on the nutrition of the bivalve.

Salinity cannot have a direct effect on growth, according to Seed and Suchanek (1992), unless low salinities create a nutrient-poor environment. On this subject, Arnaud (1966) noted that only a salinity lower than 15 g/L has an effect on the growth of mussels, linear growth in particular. Soon *et al.*, (2016) reported for the *Perna viridis* mussel that a low condition index corresponded to relatively lower salinity. Salinity has been positively associated with the filtration rate (Rajesh *et al.*, 2001) and condition index (Navarro, 1988) of marine bivalves.

Consistent with this result, salinity was positively correlated with the fresh flesh weight (Wf), itself positively correlated with the CI of the standard individual.

Regarding the change in shell weight (SW), very highly significant differences (p=0.000) were recorded between the two study sites; the SW of the Cap de Garde mussels shows a very highly significant negative correlation with suspended matter.

The standard individual being of fixed size, the increase observed in October in the Cap de Garde mussels and in February at Lahnaya can only reflect a thickening shell following peak levels of suspended matter and chlorophyll-a that had been noted during the previous months.

According to Sato (1994), the nutrient wealth of the environment promotes, in the tissues of the oyster, the accumulation of energy reserves necessary for somatic tissue growth and for the synthesis of $CaCO_3$ for shell growth. Kim *et al.*, (2016) showed that the rise of CO_2 concentrations in seawater influences the process of calcification responsible for formation of the larval shell of the clam *Mactra veneriformis*. Thus, organisms which use $CaCO_3$ to form their shells are sensitive to CO_2 concentrations in the water.

In oysters, as in other species of bivalves, the storage of metabolites is closely related to the stages of the sexual cycle. Storage tissue (vesicular cells) represents an important energy reservoir, which is exhausted during the sexual activity period of the animal (Berthelin *et al.*, 2000).

The CI reflects the physiological condition of the living organism. The annual variation of this index provides us with an idea of the gonad state and the progress of the reproductive cycle of *Perna perna* and may determine the period of emission of gametes (spawning).

An evaluation of the condition index of *P. perna* mussels in the Gulf of Annaba shows that this index is much better in the spring. These values are explained not only by the probable occurrence of phytoplankton blooms, and thus food availability, but also the attainment of optimal physiological temperatures, enabling greater metabolisation of products of digestion. This increase in the condition index coincides with high levels of chlorophyll-a and suspended matter. This finding is supported by the statistical analysis results, which show a significant correlation between these parameters in both study sites.

Urrutia *et al.*, (1999), showed that in a nutrient-rich environment, the surplus of energy may be shared between the somatic growth of tissues and gonad development of the bivalve. According to Hickman and Illingworth (1980), seasonal changes in the condition of *Perna canaliculus* result from complex interactions between a variety of factors, including nutrition, temperature and salinity, on the metabolic activities of the mussel, and particularly on the growth and reproductive processes.

In the present study, reduction of CI in autumn and winter corresponds with partial spawning phases. According to many authors, lower Fig. s for this index occur either following food supply depletion or following spawning which leads to a significant loss of weight (Dorange *et al.*, 1989; Paulet *et al.*, 1992; Barillé, 1996). Similar results, noting the existence of two spawning periods of which one is in the winter, were recorded by Shafee (1989) for *Perna picta* (Morocco) and Mohd-Taib *et al.*, (2016) for *Pernaviridis* (Malaysia). Autumn spawning was reported by Zaouali (1973) in Tunisia, by Zardi *et al.*, (2007) on the south coast of South Africa for *P. perna* and by Soon *et al.*, (2016) for *P. viridis* in Malaysia.

In contrast, only a single spring spawning has been reported for *P. perna* in Algeria (Abada-Boudjema and Moueza, 1981) and for *Mytilus galloprovincialis* in Tunisia (Aloui-Bejaoui, 2002). A summer spawning was reported by Hickman and Illingworth (1980) for *P. canaliculus* in New Zealand and also by Zardi (2007) for *P. perna,* apart from the autumn spawning.

Gosling (1992) reports, after monitoring the sexual cycle of *Mytilus edulis* for several years that gametogenesis and sperm production are highly variable in terms of both time and space.

Conclusion

The mussel *Perna perna* has a sexual cycle that extends throughout the year, with two spawning periods, one in winter and the other in autumn. The period of maximum weight gain for individuals extends from May to August for the mussels at the Cap de Garde, and from March to May for the mussels of Lahnaya. Levels of chlorophyll-a and suspended matter are the environmental factors which have the greatest impact on weight parameters for the standard animal, whilst other factors, such as temperature, dissolved oxygen and salinity, operate in an indirect and combined manner on variations to the tissue mass of the standard animal.

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