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Population dynamics and secondary production of *Donax trunculus* (Mollusca, Bivalvia) in the Gulf of Annaba (Northeast Algeria)

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Abstract

The population dynamics and secondary production of the wedge clam *Donax trunculus* Linnaeus, 1758 were studied in the Gulf of Annaba (Northeast Algeria) monthly for one year at a site close to the Annaba Port and the Seybouse River, which is affected by domestic, agricultural and industrial pollution (Sidi Salem), and at a site farther from major pollution sources, but exploited by fishery (Echatt). The number of individuals (*N*) was lower at Sidi Salem (36–148 ind m^{-2}) than at Echatt (63–272 ind m^{-2}) in most sampling dates, while the biomass was more variable from one date to another, with no consistent pattern of differences between sites. The condition index (*CI*), although slightly higher at Sidi Salem than at Echatt, at both sites showed a major increase in March/April, June/July and October, reflecting two main periods of gonads development and an increase in the level of stored reserves at the end of the reproductive period. Consistently, the recruitment of *D. trunculus* ran from April to October with a major peak of abundance in spring and a minor one in early fall. The maximum age of *D. trunculus* was 3 years and the growth rate was the highest in the first year. Annual somatic production (*P*) was lower at Sidi Salem (0.773 g AFDM m^{-2} yr^{-1}) than at Echatt (1.262 g AFDM m^{-2} yr^{-1}), possibly reflecting a lower mean annual biomass at Sidi Salem (1.642 g AFDM m^{-2}) than at Echatt (3.046 g AFDM m^{-2}), while the annual P/B ratio was similar between the two sites (i.e. 0.471 and 0.414 yr^{-1}, respectively). Lower *N* and *P* at Sidi Salem compared to Echatt are consistent with the proximity of Sidi Salem to pollution source sand lower hydrodynamic conditions which may favor the accumulation of pollutants. On the other hand, moderate secondary production of *D. trunculus* at Echatt compared to other Mediterranean sites may be due to excessive harvesting. We suggest that the low secondary production described in this study should be taken into account for the development of sustainable strategies of clam exploitation in the Gulf of Annaba. In particular, efforts should be made to reduce land-based pollution and to regulate the collection of *D. trunculus* according to the life cycle and production potential of this species.

Keywords: Bivalve, *Donax trunculus*, Dynamics, Abundance, Growth, Secondary Production, Southern Mediterranean, Algeria.

Introduction

Donax trunculus Linnaeus, 1758, commonly named wedge clam, is an Atlantic-Mediterranean bivalve colonizing fine sand beaches in the upper subtidal (Ansell & Lagardère, 1980; Salas, 1987; Mazé & Laborda, 1988). It is a strictly intertidal burrowing species that dominates in the wave breaker zone with strong hydrodynamics where it filters resuspended organic material (Wade, 1964; Degiovanni & Mouëza, 1972), particularly phytoplankton (Mouëza & Chessel, 1976).

Many studies dealing with different aspects of *D. trunculus* have been performed both in the Mediterranean (Mouëza, 1972; Mouëza & Chessel, 1976; Ansell & Bodoy, 1979; Bodoy & Massé, 1979; Ansell *et al*., 1980; Costa *et al*., 1987; Neuberger-Cywiak *et al*., 1990; Ramón *et al*., 1995) and the Atlantic (Ansell & Lagardère, 1980; Guillou & Le Moal, 1980; Bayad & Guillou, 1985; Bayed, 1991, 1998; Guillou & Bayed, 1991). Like the majority of filter feeder bivalves, *D. trunculus* has an important role in the bioaccumulation of pollutants, since it is in direct contact with contaminated water, sediment and food particles (Gunther *et al*., 1999; Miller *et al*., 2000), hence its use as a bioindicator species in assessing the health status of marine waters (Romeo & Gnassia-Barelli, 1988; Tlili *et al*., 2010, 2013; Colakoglu *et al*., 2012; Sifi *et al*., 2013). This species also has an important economic interest. As an example, the production in France was 418 tons in 2012 (Gariglietti-Brachetto, 2014), in Portugal it increased from 347 in 2000 to 540 tons in 2003 (Thébaud *et al*., 2005). Overall, the annual production of this clam in Europe has increased from 535 in 2002 to 970 tons in 2004 (FAO-FIGIS, 2007).

Most studies on the population structure, growth and production of *D. trunculus* have been conducted in the Atlantic region and in Northern Mediterranean countries, while significant data gaps exist in the Southern and Eastern basin of the Mediterranean Sea. Along the Algerian coast (ca. 1,200 km), several studies have used *D. trunculus* as a bioindicator species (Beldi *et al*., 2006; Sifi *et al*., 2007; Drif & Abdennour, 2010; Hamdani & Soltani-Mazouni, 2011; Soltani *et al*., 2012). However, in spite of its socio-economic value also in this region, no published study dealing with the population structure and production of this species has been conducted in Algeria, or in other Southern Mediterranean countries. Thus, in the present study we have sought to assess the population dynamics and secondary production of *D. trunculus* at two sites of the Gulf of Annaba in order to provide basic information for the development of strategies for the sustainable fishery of this bivalve. This study has been conducted in the framework of a long term cooperative regional effort aimed at contributing new knowledge to the biodiversity and ecosystem functioning of Southeastern Mediterranean marine and lagoon systems (Magni, 2003; Draredja *et al*., 2006; Magni *et al.,* 2004, 2015).

Materials and Methods

Study area

The Gulf of Annaba is located at the extreme northeast of Algeria between two capes distant about 40 km from one another, Cape of Garde to the west (7°16'E – 36°68'N) and Cape Rosa to the east (8°15'E – 36°38'N). The Gulf has a maximum depth of 65 m (LCHF, 1976) and receives most fresh water inputs from the Seybouse (southwestern sector) and Mafrag (southeastern sector) Rivers (Fig. 1). For the present study two sites about 8 km apart were selected in the southwestern sector of the Gulf of Annaba (Fig. 1). One site was the beach of Sidi Salem (36°50'N – 7°47'E) characterized by slow vortices and relatively low hydrodynamic conditions (LCHF, 1976). This site is located to the east of the Seybouse River which carries domestic and agricultural pollutants, such as untreated sewage, fertilizers and pesticides (Abdennour *et al*., 2000; Djabri *et al*., 2003; Belabed *et al*., 2013). In addition, the proximity of Sidi Salem to the Port of Annaba (the second largest industrial port in the country) may contribute to the accumulation of other pollutants, such as sewers and hydrocarbons, in the area (Djabri *et al*., 2003). At Sidi Salem, collection of *D. trunculus* is prohibited by law and is very sporadic because of pollution, thus clam exploitation has little relevance here. The second site was the beach of Echatt (36°50'N – 8°50'E) located relatively far from pollution sources and characterized by high hydrodynamics. At this site, *D. trunculus* is collected for marketing by fishermen using rakes towed to shallow waters (<1.5 m). From an interview survey conducted among professional fishermen, collection of *D. trunculus* in 2014 reportedly amounted to 3.6 tons per fisherman for a total annual catch of about 63.9 tons, of which about 20% was marketed locally and 80% was sold to hotels in Algiers (unpublished). At our study sites, water temperature and salinity range at 15-29 °C (February-July) and 28.0-35.7 psu (April-September), respectively (Draredja *et al*., 2014), and the sediment is dominated by medium sand (Beldi, 2007).

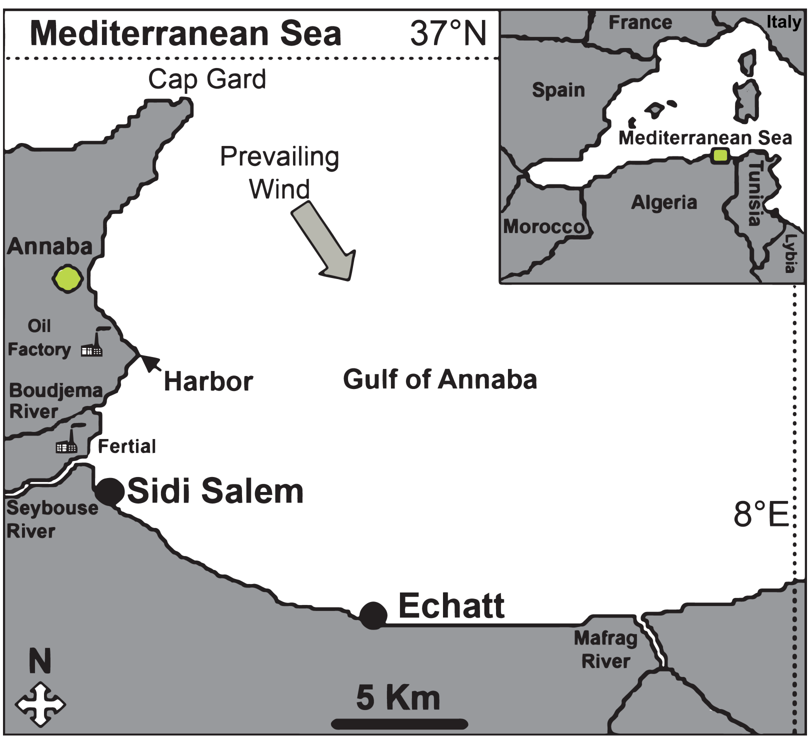

Fig. 1: Study area and location of the sampling sites (Sidi Salem and Echatt) in the Gulf of Annaba.

Sampling procedures

Monthly sampling of *D. trunculus* was conducted during 2012 at Sidi Salem and Echatt sites using a hand rake commonly called "cope" consisting of a metal frame and a mesh net of 5 mm^2. The collection device is hung by a harness at the waist of the fisherman. The sampling gear was dragged over a distance of 5 m by a fisherman who moved backwards to two successive depths of 1 and 1.5 m. This collection method has already been described in works dealing with the dynamics of this bivalve in Italy (southern Adriatic Sea, (Manca-Zeichen *et al*., 2002) and Portugal (Atlantic coast, Gaspar *et al*., 2002).

Population dynamics

Individuals of *D. trunculus* were collected, counted and divided into size classes according to their total length at 2 mm interval (Mouëza, 1971; Guillou & Le Moal, 1980; Bayed & Guillou, 1985; Gaspar *et al.,* 2002) to calculate the size frequency distribution of the clam. Individuals were measured according to their antero-posterior length (Lt) using a caliper with a precision of 0.01 mm. Each frequency mode polygon obtained corresponds to an age group. The interpretation of the curves is not easy when the breeding season is short; therefore, subsequent generations are well isolated (Mouëza, 1971). The biomass was expressed as grams (g) ash free dry masst (AFDM) after decalcification of the individuals. The visceral mass was first dried at 60°C until constant weight and then incinerated at 500°C for 4 hours (ash weight). The difference between the two weights represents the biomass in g AFDM.

The study of the growth of *D. trunculus* was based on three parameters: age, linear absolute growth and relative growth. For the age determination in *D. trunculus,* we adopted the indirect method of Bhattacharya (1967), based on a logarithmic transformation of the number of individuals grouped into classes of equal amplitude of 2 mm sizes. This method has been used by other authors who have studied the family of Donacidae (Bodoy, 1982; Ramón *et al*., 1995; Manca-Zeichen *et al.,* 2002; Marcano *et al*., 2003). For the study of the absolute linear growth, we used the Von Bertalanffy (1938) model. This model is most suited to express the individual growth in length in particular as regards juveniles. Several authors have used this model to study the growth of *D. trunculus* (Ansell & Lagardère, 1980; Bodoy, 1982; Bayed & Guillou, 1985; Mazé & Laborda, 1988; Vakily, 1992; Ramón *et al*., 1995; Bayed, 1998; Manca-Zeichen *et al*., 2002; Çolakoğlu, 2014). The mathematical development of this method leads to an absolute linear growth following the equation:

$$Lt = L_{\infty}\,[1 - e^{-K\,(t-to)}]$$

where Lt: total length at age t (mm); L_{∞}: asymptotic length or maximum theoretical length (mm); K: growth rates or instantaneous growth coefficient (K>0); to: theoretical age (year) that individuals would have had at size zero (Lt = 0). The mathematical expression of Von Bertalanffy (1938) shows three adjustment parameters L_{∞}, *to* and K, determined using the FISAT software, version 1.2.2 (Gayanilo & Pauly, 1997). The size-weight relationship was a power curve type:

$$W = a\,L^b$$

where W: total weight, which is the fresh weight; a: intercept; b: coefficient of allometry. The values of "*a* and *b*" are obtained after logarithmic transformation of the exponential function to a linear function type:

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

The relative growth between biometric variables can be reduced to the simple law of allometry (Huxley & Teissiert, 1936). The regression line is calculated using the method of the reduced major axis or Teissier's line to test the existence of an isometry or allometry between the correlated variables. Comparing the value of the slope of the fitted line with a theoretical value, three cases are possible: b=3 (isometric), b>3 (positive allometry) and b<3 (negative allometry).

In order to compare the overall fitness of animals from the populations studied, the condition index (CI) was calculated as wet weight [mg] per volume (volume calculated from $length^3$ [cm]) (Beukema & de Bruin, 1977).

Secondary production

Annual somatic production (P) was estimated at each site by the mass-specific growth rate method (Crisp, 1984; Brey, 2001), using the spreadsheet provided by Brey (2001), from the length-frequency distribution obtained from all pooled samples, length-mass relationship, and the von Bertalanffy growth parameters:

$$P = \sum N_i \cdot M_i \cdot G_i$$

where N_i is the annual average number of individuals per m^2, M_i is the mean individual AFDM in length class i, and G_i is the mass-specific growth rate, calculated using the equation:

$$G_i = b \cdot K \cdot [(L_{\infty}/L_i) - 1]$$

where b is the exponent of the length-mass relationship, K and L_{∞} are von Bertalanffy growth parameters, and L_i is the mean length in class i. The mean annual biomass was calculated from:

$$B = \sum N_i \cdot M_i$$

The P/B ratio (annual renewal rate) was calculated from the annual total production P and the annual mean biomass B. Production was estimated in g AFDM m^{-2} yr^{-1}, however only tissue wet weight was determined per single specimen. Therefore, prior to production calculation, the wet weight of single animals was transformed to AFDM. Since the relation between wet and dry weight often varies seasonally (due to changes in biochemical composition and gonad development) conversion factors were calculated separately for each month, as the total (pooled) ash-free tissue dry weight divided by the total tissue wet weight of sampled animals. The length-mass relationship was defined as $log(AFDM) = a + b \cdot log(L)$.

Statistical analysis

Differences in abundance and biomass between sites and among dates were analyzed by using a two-way analyses of variance (ANOVA, Underwood, 1997), with Site (S, Echatt and Sidi Salem) and Date (D, 12 levels) as crossed, fixed factors, and two replicates. Homogeneity of variance was checked using Cochran's C-test (Winer *et al.*, 1991). When required, the Student-Newman-Keuls (SNK) tests were used as *a posteriori* comparisons of the mean estimated by analysis of variance (Underwood, 1997). Regression analysis was done to test the relationship between the length, weight and width of *D. trunculus* at each site separately. Differences in the CI between sites and among dates were tested by Kruskal-Wallis non-parametric ANOVA. All analyses were done using Statistica (version 12, Statsoft Inc., Tulsa, OK, USA).

Results

Population dynamics

The number of individuals (*N*) of *D. trunculus* varied between 36-148 ind m^{-2} (March-July, respectively) at Sidi Salem and 63-272 ind m^{-2} (April-July) at Echatt (Fig. 2a); the biomass varied between 0.42-2.75 g m^{-2} (July-February) at Sidi Salem and 1.19-3.32 g m^{-2} (July-January) at Echatt (Fig. 2b). Differences in the Site × Date interaction term were found for both abundance and biomass (Table 1). *D. trunculus* was less abundant at Sidi Salem than at Echatt at all dates (SNK test; Fig. 2), except February, April and December, when no differences between sites were found (SNK test at $P > 0.05$; Fig. 2). Although the abundance was low from January to June and tended to increase in July at both sites, the numerical increment was highest at Echatt (Fig. 2). More variable results were found for the biomass which was lower at Sidi Salem than at Echatt in January, April, June and August, whereas it showed an opposite pattern in February (Sidi Salem>Echatt) and no differences in March, May, July, and from September to December (SNK test; Fig. 2).

The monthly size frequency's distribution of *D. trunculus* at Sidi Salem and Echatt was rather similar (Fig. 3). Overall, the recruitment period ran from April to October with a major peak of abundance in May and a minor one in September. However, the appearance of young recruits (4-6 mm) was first observed in May at Sidi Salem and in April at Echatt. From June to December, we detected a shift of polygons to the right, reflecting a relatively rapid growth for young stages of development. The smaller size of *D. trunculus* collected was 4.88 mm (Echatt in May), while the largest one was 39.67 mm (Echatt in April).

We identified three cohorts from three age groups

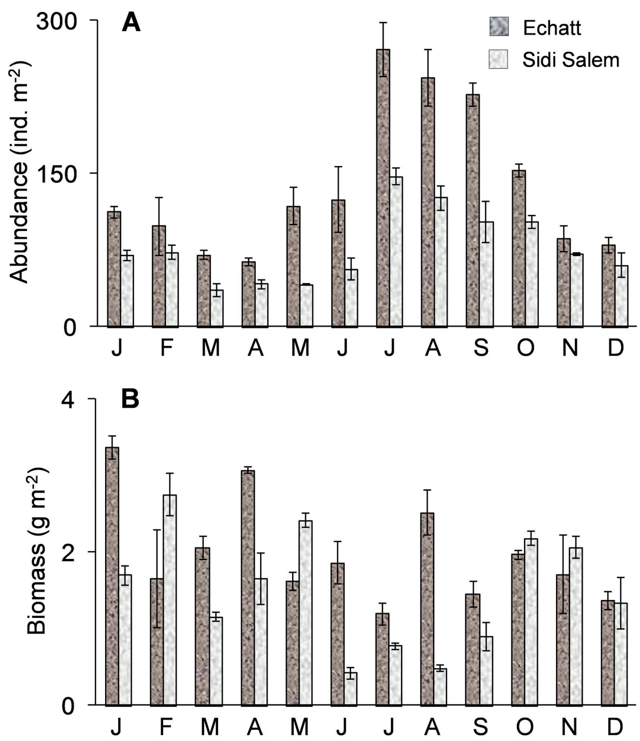

Fig. 2: Abundance (A) and biomass (g AFDM) (B) distribution of *D. trunculus* at the two study sites (Echatt and Sidi Salem) in the Gulf of Annaba in 2012.

Table 1. Results of ANOVA to test for differences between Sites and among Dates on the total number of individuals (N) and biomass of *D. trunculus*. In bold significant values of interest.

		N			Biomass		
	DF	MS	F	P	MS	F	P
Sites=S	1	43368.16	200.69	0.00	3.01	13.25	0.00
Dates=D	11	10964.96	50.74	0.00	1.07	4.69	0.00
S × D	11	1756.27	8.13	**0.00**	1.02	4.51	**0.00**
Residual[A]	24	216.09			0.23		
Total	47						
Transform:		none			none		
Cochran's Test		0.2 ($P > 0.05$)			0.3 ($P > 0.05$)		

[A] Denominator for S, D and S × D

(Fig. 4) and three couples of ages-lengths at both sites (Table 2). This enabled us to establish the equations for the model Von Bertalanffy (1938) at the two study sites (Table 3). At Echatt, the total length obtained during the first year was the highest (12.1 mm) and then decreased during the second and third years (6.4 and 9.1 mm, respectively). A similar pattern of growth was detected at Sidi Salem. Here, the total length during the first year was higher (13.1 mm) than that attained during the second and third years (8.2 and 6 mm, respectively).

The plots of shell length (Lt) vs. height (H) and Lt vs. thickness (w) revealed highly significant correlation for both Sidi Salem and Echatt populations (Figs. 5 and 6, Table 4). These linear parameters were characterized by a negative allometry type of growth. Also the correlation between the total wet weight and length was highly significant (Fig. 7). The allometric coefficient (b = 2.93; t_{obs} = 4.57 for Sidi Salem and b = 2.82; t_{obs} = 11.91 for Echatt), was less than 3 (Table 5), reflecting a growth of negative allometry, for which the size is growing faster than the weight.

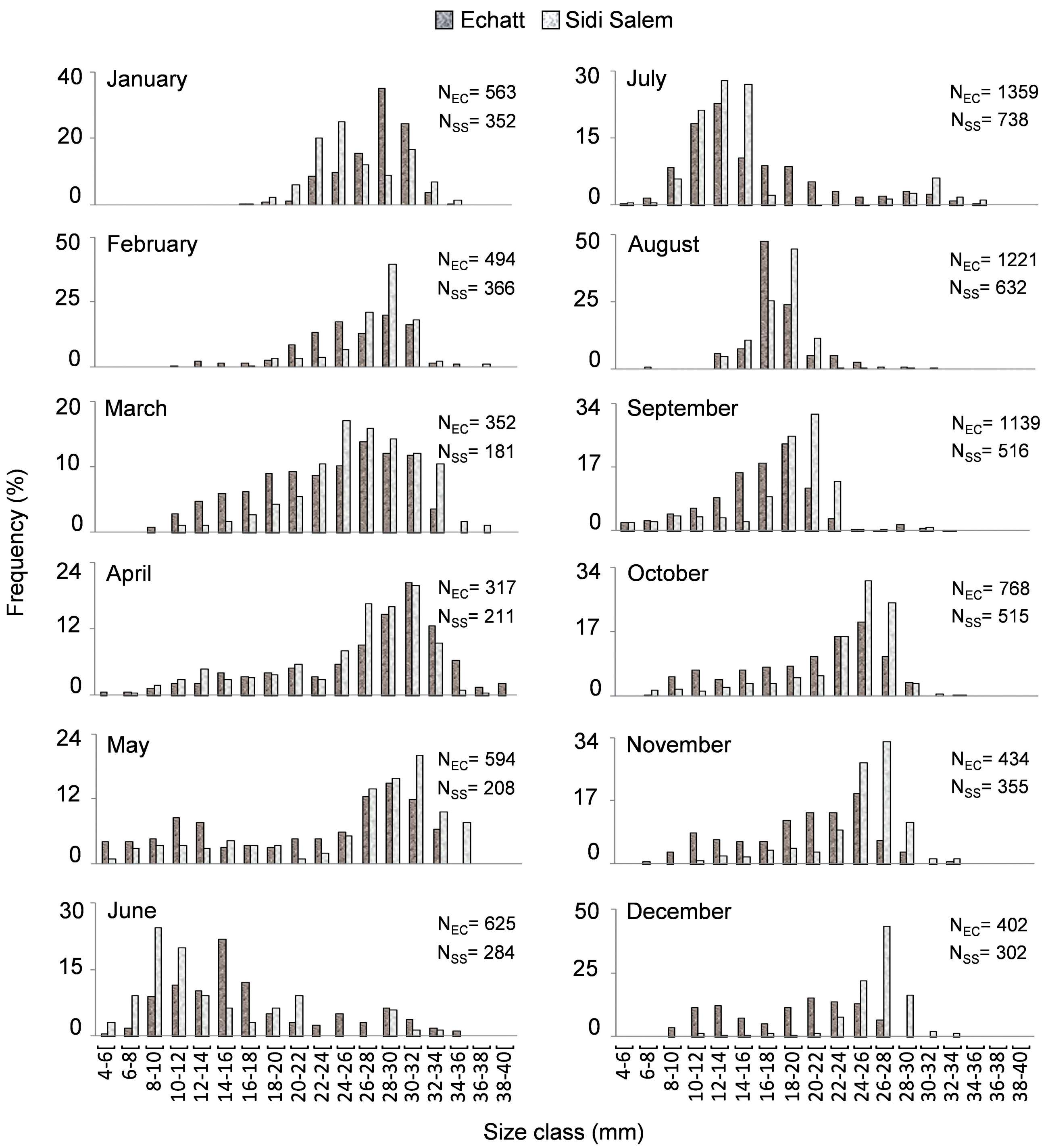

Fig. 3: Size frequency distribution of *D. truncus* at the two study sites [Echatt (EC) and Sidi Salem (SS)] in the Gulf of Annaba in 2012.

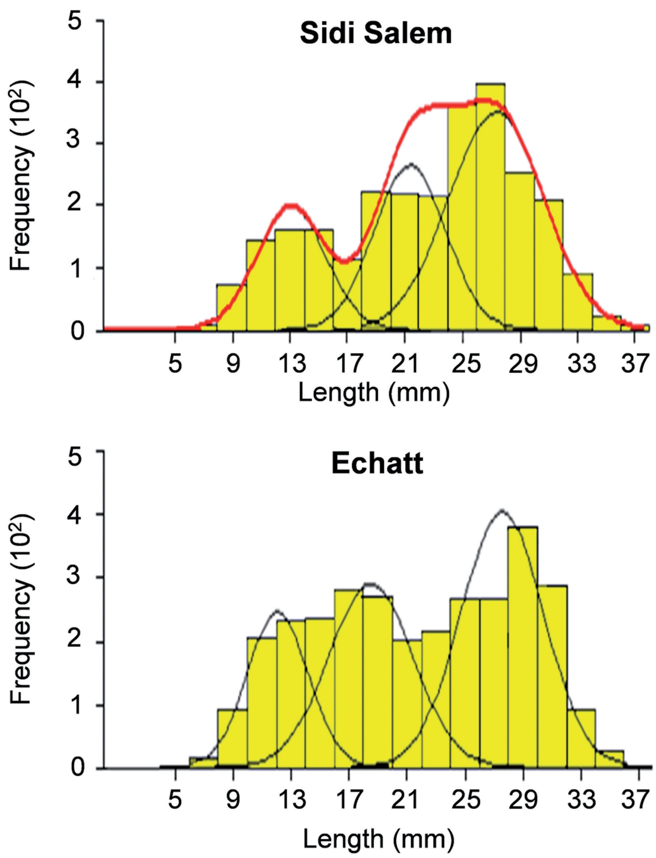

Fig. 4: Age group distribution of *D. trunculus* at the two study sites, Sidi Salem and Echatt, according to the Bhattacharya method (1967).

Table 2. Determination of the age groups in *D. trunculus* according to the Bhattacharya (1967) model at the two study sites (Sidi Salem and Echatt) in the Gulf of Annaba in 2012.

Site	Age (years)	Total length (mm)	Standard deviation
Sidi Salem	1	13.10	2.37
	2	21.35	2.47
(N = 2653)	3	27.35	3.31
Echatt	1	12.10	2.10
	2	18.52	2.90
(N = 3043)	3	27.61	2.85

Secondary production

Individual production of *D. trunculus* depended on the shell length and increased to the highest values between 30-40 mm (Sidi Salem-0.015, Echatt-0.013g AFDM m^{-2} yr^{-1}) (Fig. 9). Annual somatic production and biomass were lower at Sidi Salem (0.773 g AFDM m^{-2} yr^{-1} and, 1.642 g AFDM m^{-2}, respectively) that at Echatt (1.262 g AFDM m^{-2} yr^{-1} and 3.046 g AFDM m^{-2}, respectively). However the annual P/B ratio was similar between the two sites (i.e. 0.414 and 0.471 yr^{-1}, respectively).

Table 3. The growth parameters for *D. trunculus*, calculated from the Von Bertalanffy (1938) model at the two study sites (Sidi Salem and Echatt) in the Gulf of Annaba in 2012.

Site	L_{max} observed	L_∞	K	t_o	Equation	N
Sidi Salem	37.17	54.70	0.15	-1.24	$L_t = 54.70\ [1- e^{-0.15\ (t+1.24)}]$	2653
Echatt	39.67	55.22	0.14	-1.21	$L_t = 55.22\ [1- e^{-0.14\ (t+1.21)}]$	3043

The condition index (*CI*) differed significantly between sites and during the year at both sites ($P < 0.001$; Fig. 8). Three periods of significant increase in the value of *CI* were observed, i.e. March/April, June/July and October. The Sidi Salem population was characterized by slightly higher *CI* than the Echatt population.

Discussion

Within the Gulf of Annaba, we found some differences between the two study sites that are most likely related to different anthropogenic pressures. The total number of individuals and the annual somatic produc-

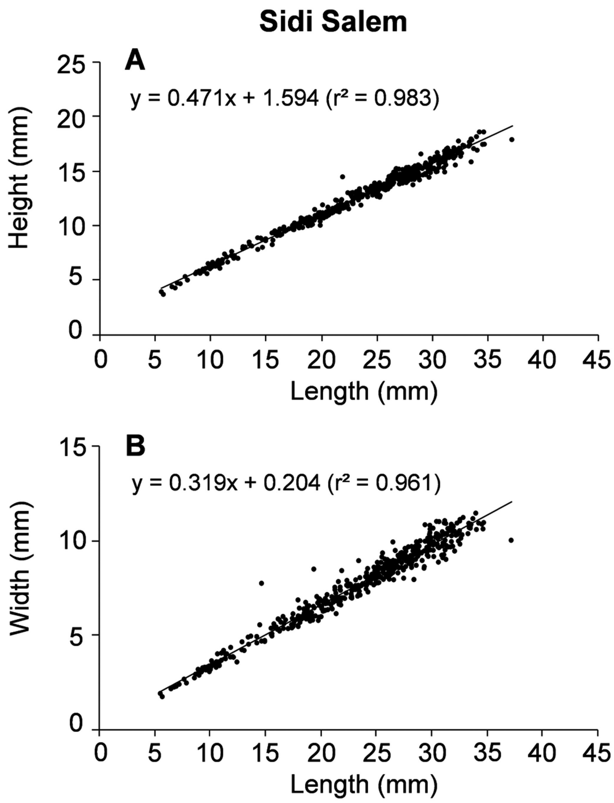

Fig. 5: Regression line of height vs. length (A) and width vs. length (B) in the Sidi Salem population of *D. trunculus*.

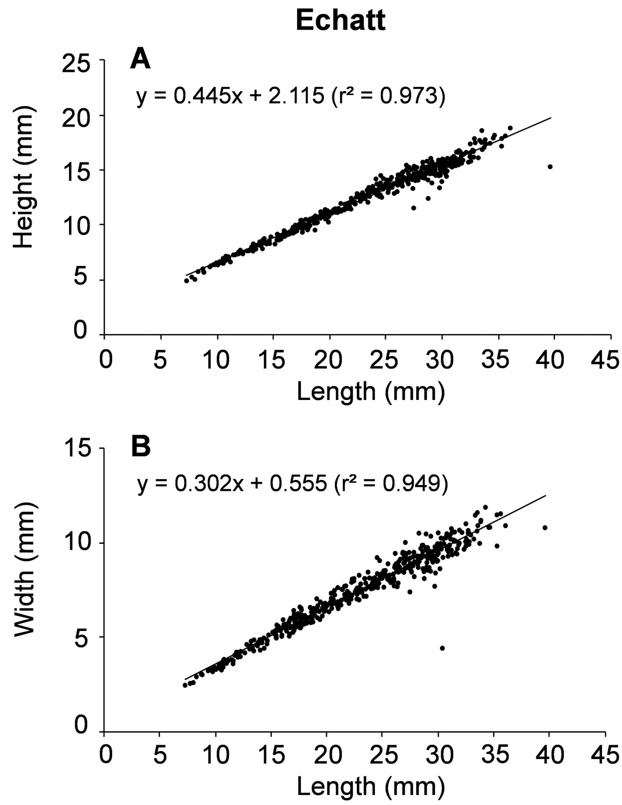

Fig. 6: Regression line of height vs. length (A) and width vs. length (B) in the Echatt population of *D. trunculus*.

Table 4. Equations and features of regressions linking the length (Lt) to the height (H) and width (w) at *D. trunculus* collected at the two study sites (Sidi Salem and Echatt) in the Gulf of Annaba in 2012.

Sites	X	Y	Equation	R	*p*	N	Allometric type
Sidi	Lt	H	$Y = 0.89X^{0.84}$	0.99	< 0.001	480	- allometry
Salem	Lt	w	$Y = 0.35X^{0.97}$	0.98	< 0.001	480	- allometry
Echatt	Lt	H	$Y = 0.98X^{0.80}$	0.99	< 0.001	480	- allometry
	Lt	w	$Y = 0.40X^{0.93}$	0.98	< 0.001	480	- allometry

tion of *D. trunculus* were lower at Sidi Salem than at Echatt. This seems to be consistent with the proximity of Sidi Salem to the Seybouse River, the industrial Port of Annaba, and the relatively low hydrodynamic conditions at this site, which may favor the accumulation of pollutants (Abdennour *et al.*, 2000; Djabri *et al.*, 2003; Belabed *et al.*, 2013). Differences in the condition index (*CI*) of *D. trunculus*, found to be slightly higher at Sidi Salem than at Echatt, may also be related to oil exposure of clams at Sidi Salem, rather than to variations in individual biomass between the two study sites. Similarly to our results, Stekoll *et al.* (1980) showed a decrease in the rate of shell growth and consequently an increase in the *CI* index of *Macoma balthica* exposed to low oil concentrations (0.03 mg l^{-1}) as compared to individuals not exposed to oil. Furthermore, while pollution is likely to be the most important factor explaining the low number of individuals and the low production of *D. trunculus* at Sidi Salem, we infer that excessive harvesting of *D. trunculus* is the primary cause for the impoverishment of the natural stock of the clam at Echatt. At this site, uncontrolled exploitation of *D. trunculus* has been exercised by dozens of fishermen over the past ten years, not subjected to any specific regulations or guardianship by the local authorities. This management and conservation problem is also found in other Mediterranean areas for endangered molluscs such as *Patella ferruginea* (Coppa *et al.*, 2012) and *Pinna nobilis* (Coppa *et al.*, 2013). As a result, at both Sidi Salem and Echatt, the total number in individuals and the production of *D. trunculus* were lower than those reported in several other sites along the Atlantic and Mediterranean shores. For instance, Lucas (1965) found values of 600-700 ind m^{-2} in Brittany (France), while Fishelson *et al*. (1999) in the Bay of Haifa (Israel)

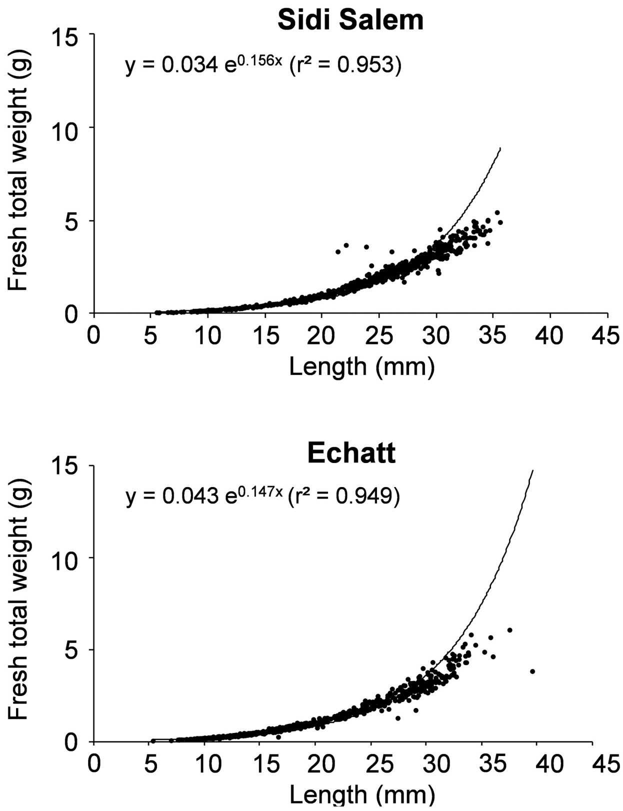

Fig. 7: Exponential curve of the total wet weight (g) depending on the length (mm) in *D. trunculus* collected at the two sites (Sidi Salem and Echatt).

and Marobin *et al*. (2007) in the natural park of the Camargue (France) reported peaks of abundance up to 1000 ind m^{-2}. For the congener *D. variabilis*, El-Ghobashy *et al*. (2011) also reported values of 624-1945 ind m^{-2} in New Damietta (Egypt). Similarly, Mazé (1990) estimated values of production of *D. trunculus* of 1.8-3.7 g AFDM m^{-2} yr^{-1} in the El Barquero estuary (Spain), whereas production amounted to 18.98-39.99 g AFDM m^{-2} yr^{-1} on the French Atlantic coast (Ansell & Lagardere, 1980) and to 16.05 g AFDM m^{-2} yr^{-1} in the West Marmara Sea (Colakoglu, 2014).At our study sites, *D. trunculus* showed three successive peaks in the *CI* values, i.e. March/April, June/July and October, irrespective of differences between sites. The first two peaks in the *CI* are due to the gonads development whereas the third peak on October follows the end of the reproductive period and represents an increase in the level of stored reserves. Our results are in accordance with Ansell & Bodoy (1979) who described three successive peaks in the *CI* of *D. trunculus*, i.e. in April/May, August and November/December for populations along the French Atlantic coast. As related to the gonads development, the recruitment of *D. trunculus* occurred from April to October, with two major periods of recruits arrival in May and September, consistent with the work of Beldi (2007) in the Gulf of Annaba and that of Bakalem (1981) in the Bay of Algiers. Although a single recruitment peak of *D. trunculus* has been described (Voliani *et al*., 1997; Gaspar *et al*., 2002; Manca-Zeichen *et al*., 2002), many studies found two major periods of recruitment of young

Table 5. The size/weight relationship of *D. trunculus* at the two study sites (Sidi Salem and Echatt) in the Gulf of Annaba in 2012.

Site	N	R	b	t_{obs}	Equation	Allometric Type
Sidi Salem	720	0.99	2.93	4.57	$P = 0.0001\ L^{-2.93}$	- allometry
Echatt	720	0.99	2.82	11.91	$P = 0.0002\ L^{-2.82}$	- allometry

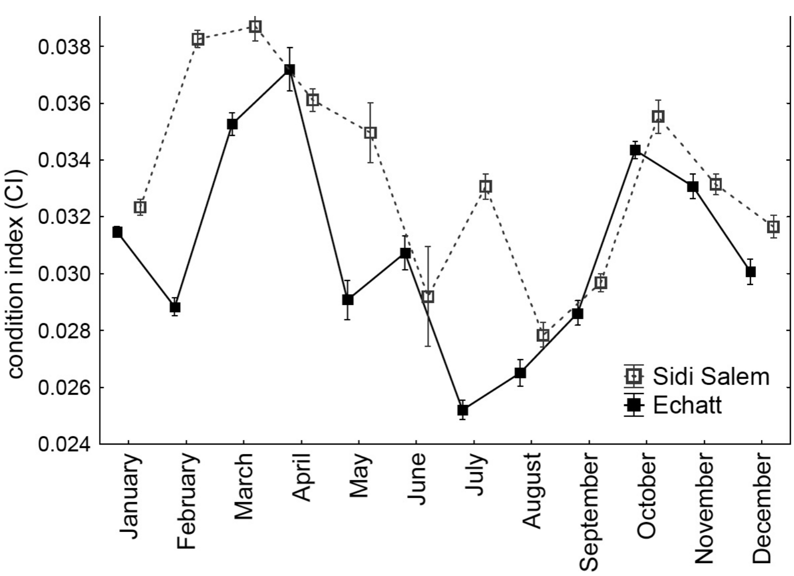

Fig. 8: Seasonal changes in the condition index (CI) at the two study sites (Sidi Salem and Echatt) in the Gulf of Annaba in 2012 (mean ± standard error).

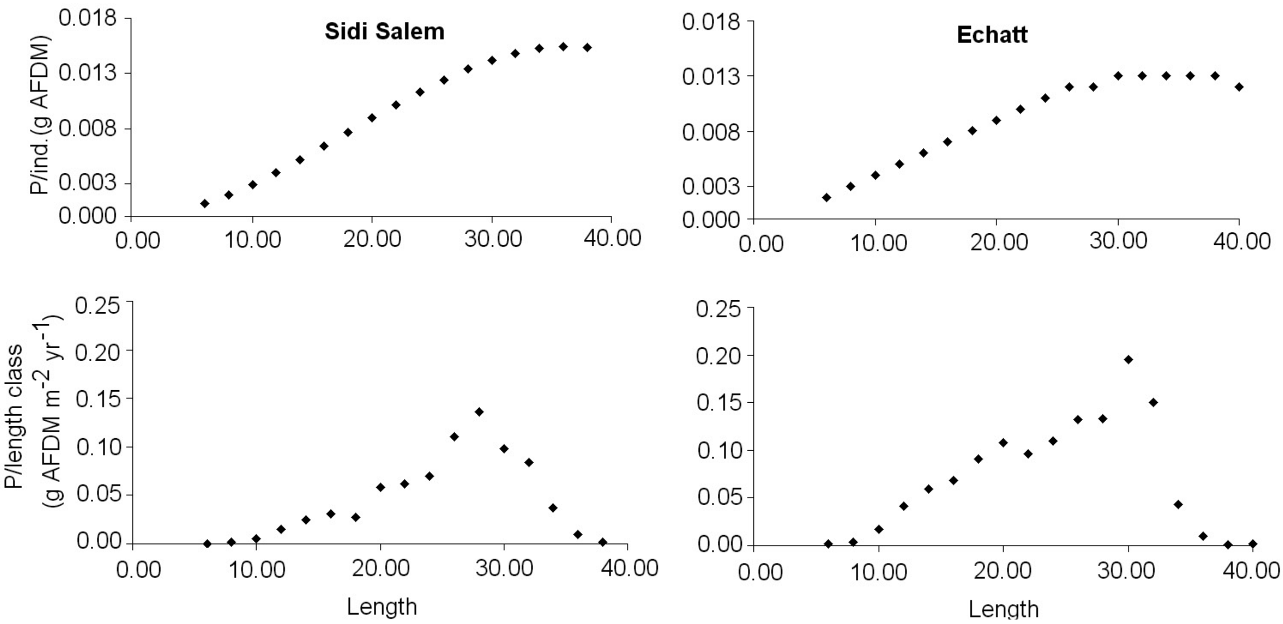

Fig. 9: Annual individual (upper panels) and population (lower panels) somatic production of *D. trunculus* at the two study sites (Sidi Salem and Echatt) in the Gulf of Annaba in 2012.

individuals of *D. trunculus* both in the Mediterranean Sea (Ansell *et al.,* 1980; Mazé & Laborda, 1990; Ramón *et al*., 1995) and the Atlantic (Bayed & Guillou, 1985; Bayed, 1990; Guillou & Bayed, 1991).

The maximum size of *D. trunculus* recorded in the present study was larger than that mentioned by Beldi (2007) in the same study area, by Mouëza (1971) in the Bay of Algiers and by several other authors on the Moroccan (Bayed, 1991), French (Bodoy & Massé, 1979), Italian (Manca-Zeichen *et al*., 2002) and Israeli (Fishelson *et al*., 1999) coasts. However, similar or higher values have been reported in other sites, such as in the Island of Oléron (Ansell & Lagardère, 1980) and the bay of Douarnenez (Guillou & Le Moal, 1980) in France, in Spain (Ramón *et al*., 1995; De la Huz *et al*., 2002) and in the Marmara Sea, Turkey (Deval, 2009; Çolakoğlu & Tokaç, 2011; Çolakoğlu, 2014). The estimated maximum age for the Echatt and Sidi Salem populations using the indirect method of Bhattacharya (1967) showed that *D. trunculus* in the Gulf of Annaba can live up to 3 years. This age is similar to that described for many Mediterranean populations, such as those on the Spanish (Mazé & Laborda, 1988; Ramón *et al*., 1995; Voliani *et al.,* 1997) and the Israeli (Neuberger-Cywiak *et al*., 1990) coast as well as the age described for Atlantic populations, such as those on the Moroccan coast (Bayed & Guillou, 1985). Older populations, however, have often been described, with a maximum age of 4 years on the Italian coast (Manca-Zeichen *et al*., 2002) and in the west of the Marmara Sea in Turkey (Çolakoğlu & Tokaç, 2011; Çolakoğlu, 2014), 5 years on the French coast (Ansell & Lagardère, 1980; Guillou & Le Moal, 1980) and 6 years in the north of the Marmara Sea (Deval, 2009). For other species of *Donax*, such as *D. striatus* (McLachlan *et al*., 1996) and *D. denticulatus* (Vélez *et al*., 1985) on the Venezuelan coast and *D. hanleyanus* on the Brazilian coast (Cardoso & Veloso, 2003), maximum age is reported up to 1.5 years only. For *D. hanleyanus* on the Argentinean coast, longevity varies between 3 (Penchaszadeh & Olivier, 1975) and 5 years (Herrmann *et al*., 2009), while the population of *D. serra* in South Africa can live up to 5 years (De Villiers, 1975).

The relationship between linear biometric parameters (H/L and w/L) for *D. trunculus* showed a negative allometry growth at our study sites. Our results are consistent with the work of Salas (1987) in Málaga (Spain), Ramón (1993) in Valencia (Spain) and Gaspar *et al*. (2002) in Portugal. Differently, Mouëza (1971) indicated an isometric growth between the two linear parameters in the population colonizing the Bay of Bou Ismail (Algeria). The positive allometry between these two linear parameters for *D. trunculus* is rare; it was reported by Fernández *et al*. (1984) in Galicia (Spain) and Bayed (1998) between Tangier and Massa (Moroccan Atlantic coast). Furthermore, the w/L relationship showed a negative allometry growth for the Echatt population and isometric type of growth for the Sidi Salem population, the latter already reported by Mouëza (1971) in the Bay of Bou Ismail (Algeria), by Bayed (1998) in the Atlantic coast of Morocco and by Gaspar *et al*. (2002) in Portugal. The growth rate (K) for the Echatt and Sidi Salem populations using the method of Von Bertalanffy (1938) was low (0.14 to 0.15), with L_∞ values ranging between 54.70 and 55.22 mm. The population growth of *D. trunculus* in the Gulf of Annaba was low compared to other studies both in the Mediterranean and the Atlantic coasts. This slowdown in growth may be due to physical and chemical conditions, such as high thermal and saline changes in the south of the Gulf subject to continental inputs from rivers and low thermal inertia in the water column that does not exceed 1.5 m, not to mention the negative impact of pollution. The highest value of L_∞ (52.84 mm) has been found in the Atlantic coast (Mazé & Laborda, 1988), while the lowest (35.9 mm) in the Mediterranean Sea (Bodoy, 1982). Similarly, the lowest growth rate (K = 0.30) is encountered in the Mediterranean (Manca-Zeichen *et al*., 2002), while it reaches 0.97 in the Atlantic (Fernández *et al*., 1984). Finally, the negative allometric growth (b<3) found in the present study is in accordance with several other studies conducted on the same species at several sites (Ansell & Lagardère, 1980; Guillou, 1980; Bayed, 1990; Mazé & Laborda, 1990; Ramón, 1993; Tlili *et al*., 2010; Deval, 2009; Çolakoğlu & Tokaç, 2011).

Conclusions

The present study provides the first insight into the population dynamics and secondary production of *D. trunculus* on the North African coast, most of such work being conducted in the Atlantic and Northern Mediterranean regions. Although the population dynamics in our study area was similar to that found elsewhere, the total abundance and production were in the moderate-low range reported for this species. Pollution is likely to be the most important factor explaining the low number of individuals and production of *D. trunculus* in Sidi Salem, whereas harvesting is the primary cause of the impoverishment of the natural stock in Echatt. We conclude that the low secondary production described in the present study should be taken into account for the development of sustainable strategies of clam exploitation in the Gulf of Annaba. In particular, efforts should be made to reduce land-based pollution and to regulate the collection of *D. trunculus* according to the local environmental conditions, and the life cycle and production potential of this species.

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