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GROWTH OF THE INVASIVE COCKLE *FULVIA FRAGILIS* (MOLLUSCA: BIVALVIA) IN NORTHERN TUNISIA (CENTRAL MEDITERRANEAN)

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ABSTRACT

Fulvia fragilis *(Forsskål in Niebuhr, 1775), a non-indigenous species (NIS), has occurred in Tunisian coasts since 1994. Monthly and bimonthly sampling was conducted in marine and lagoon waters (of the Bay of Tunis and the Bizerte Lagoon, respectively) in Northern Tunisia. A total of 4,534 specimens were examined. Growth data were studied against environmental parameters (temperature, salinity, pH, dissolved oxygen and chlorophyll* a *concentration) and biotic parameters (reproductive cycle). This study showed significant differences between specimens from the two studied sites. Morphological differences were observed, with the specimens from the Bay of Tunis exhibiting a triangular shape as opposed to the elongated form featured in the specimens from the Bizerte Lagoon. Mass gain in the Bay of Tunis has been linked to the reproductive cycle and found at a disadvantage with respect to the shellfish length. In the Bizerte Lagoon, shell growth showed a reverse trend, probably due to pollution.*

Key words: *Fulvia fragilis*, growth, pollution, Bay of Tunis, Bizerte Lagoon

CRESCITA DEL CARDIDE INVASIVO *FULVIA FRAGILIS* (MOLLUSCA: BIVALVIA) NELLA TUNISIA SETTENTRIONALE (MEDITERRANEO CENTRALE)

SINTESI

Fulvia fragilis *(Forsskål in Niebuhr, 1775), specie non indigena (NIS), è presente lungo la costa tunisina dal 1994. Campionamenti mensili e bimestrali sono stati effettuati in acque marine (baia di Tunisi) e lagunari (Laguna di Biserta) nella Tunisia settentrionale. È stato esaminato un totale di 4534 individui. I dati riguardanti la crescita sono stati studiati in relazione ai parametri ambientali (temperatura, salinità, pH, ossigeno disciolto e concentrazione della clorofilla* a*) e a quelli biotici (ciclo riproduttivo). Questo studio ha evidenziato differenze significative tra gli individui dei due siti studiati. Tra le differenze morfologiche gli autori riportano una forma triangolare degli esemplari nella baia di Tunisi e una forma allungata di quelli nella Laguna di Biserta. L'aumento della massa nella baia di Tunisi è risultato legato al ciclo riproduttivo ed è stato svantaggiato rispetto alla lunghezza della conchiglia. Nella Laguna di Biserta, invece, la crescita della conchiglia ha mostrato un'inversione di tendenza, probabilmente a causa dell'inquinamento.*

Parole chiave: *Fulvia fragilis*, crescita, inquinamento, baia di Tunisi, Laguna di Biserta

INTRODUCTION

The invasive cockle *Fulvia fragilis* (Forsskål in Niebuhr, 1775), originating from the Indo-Pacific and commonly found in the Red Sea, has been observed in the Mediterranean since the beginning of the 20th century or, more precisely, since it was first collected in Port Said (Egypt) in 1939 (Moazzo, 1939). *F. fragilis* has been classified among the most widespread non-indigenous species (NIS) (Occhipinti-Ambrogi, 2014) and ranks among the worst invasive species (Galil *et al*., 2014) in the Mediterranean Sea. In Tunisia, the species was first discovered in the south, in the Gulf of Gabès (Passamonti, 1996), and has since spread northwards as far as the Bay of Tunis (Ben Souissi *et al*., 2003) and the Bizerte Lagoon (Zaouali, 2004).

The *F. fragilis'* relative growth was studied in the two mentioned sites, which are characterised by different ecological properties. The Bay of Tunis displays a satisfactory ecological status (Ayari & Afli, 2003), whereas the Bizerte Lagoon is heavily polluted (Yoshida *et al*., 2003; Trabelsi & Driss, 2009). The studies conducted both in the species' natural range and in its new habitats focussed on the biology of the species (Ozturk & Poutiers, 2005; Mohammad *et al.*, 2006; Rifi *et al*., 2011, 2012, *2015*), as well as its use as biomarker in the lagoon of Bizerte (Mahmoud et *al*., 2010). The morphometric variables identified have been correlated with endogenous (reproductive cycle) and exogenous (environmental parameters) factors at the two sampling sites.

This work was conducted in order to evaluate the acclimatization of this non-indigenous species in two different habitats (the Bay of Tunis and the Bizerte Lagoon) by studying its relative growth.

MATERIAL AND METHODS

Sampling

Preliminary investigations were carried out between 2004 and 2005 in 13 sites throughout the Tunisian coast (Fig. 1). Surveys conducted in shallow coastal waters (between 0 and 30 m of depth) were aimed at determining the distribution and the frequency of *Fulvia fragilis* in Tunisia. A seasonal density survey showed that *F. fragilis* was abundantly present throughout the year and therefore suitable for regular biological monitoring in two sites – the Bizerte Lagoon (site 3) and the Bay of Tunis (site 5) – and the two locations were then selected for this study.

The Bay of Tunis (Fig. 1) is located between 36° 42′ and 37° 10′ N, and 10° 17′ and 11° 37′ E, and represents the southern limit of the Strait of Sicily (Pérès, 1967). Also known as the 'small Gulf of Tunis', it covers a total area of 350 km² with an average depth of 15 m (Souissi *et al.,* 2000). Although the coastline of the

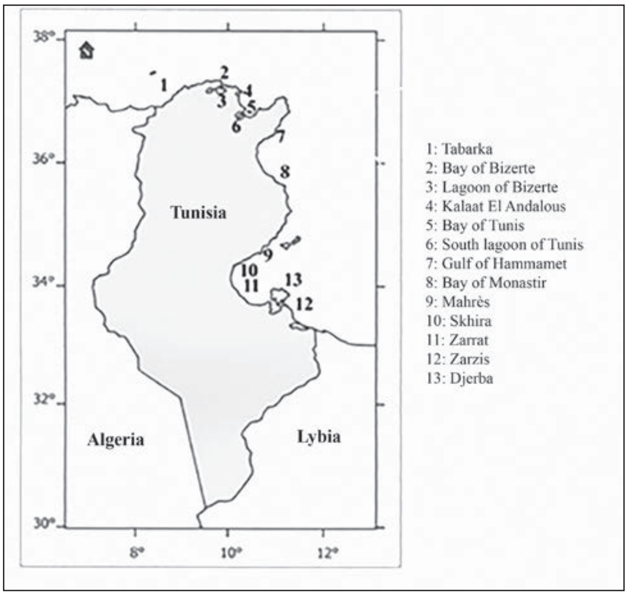

Fig. 1: Sampling sites
Sl. 1: Vzorčevalne postaje

Gulf of Tunis is exposed to anthropogenic pressures of various types (fishing, industry, urbanization, tourism, etc.), Ayari & Afli (2003), based on macrozoobenthos analysis, revealed it nevertheless remains a location of environmental value.

The Bizerte Lagoon (Fig. 1) is located in northern Tunisia between 37° 08′ and 37°14′ N and 9° 46′ and 9° 56′ E. This lagoon communicates with the Mediterranean Sea through an artificial channel, an elliptical depression of 128 km² with a maximum width of 11 km, a maximum length of 13 km and a 7 m average depth. It is surrounded by the cities of Bizerte, Zarzouna, Menzel Aberrahmen, Menzel Jemil and Menzel Bourguiba and is polluted because of several anthropogenic pressures. Organic pollution through chemical fertilizers and heavy metal contamination are mainly associated with disturbances to fauna and flora (Aissa, 1991) and biogeochemical cycles (Yoshida *et al*., 2002a, 2002b, 2003; Ben Garali *et al*., 2009, 2010, 2011).

In the Bay of Tunis, *F. fragilis* was sampled in the intertidal zone at very shallow depths (between 0.5 and 1.5 m) in sandy mud sediment. Samples were collected using dredges and scuba divers. Monthly and bimonthly samples were collected from January 2006 to October 2007, except in July, August and September 2006 due to summer mortality (Rifi *et al.,* 2012). A total of 2,893 specimens of *F. fragilis* were examined for the purpose of monitoring growth. In the Bizerte Lagoon, samples were collected in a muddy sediment at a depth of 5 m, employing experimental dredges hauled by a motorboat. Monthly and bimonthly surveys were conducted from June 2006 to September 2007, and 1,641 specimens were measured for the purpose of studying growth.

Environmental variables

The temperature of the sea surface was recorded by a thermometer with an accuracy of 0.1 °C and by a multi-type Lab (WTW, Multi/340i/SET) developed for measurements of other parameters, such as pH, salinity and dissolved oxygen. Seawater samples were kept in 1.5-litre opaque plastic bottles and transferred to the laboratory for a chlorophyll *a* (Chl *a*) concentration measurement employing the Aminot and Chaussepied method (Aminot & Chaussepied, 1983).

Relative growth

Specimens were measured for shell length (SL), shell height (SH) and shell width (SW) by a digital calliper to the nearest 0.01 mm. Moreover, total mass (TM), fresh meat mass (FMM) and dry meat mass (DMM) (obtained after oven drying at 60 °C for 72 hours) were measured with an electronic scale to the nearest 0.01 g.

Allometric relationships linking weight parameters to shell length were investigated. Linear regressions using the least-squares method with a logarithmic transformation were performed. The regression equation reads as follows:

$$log(y) = log(a) + b\ log(x)$$

where y is a dependent variable representing the size or mass of some part or the entire cockle, x is an independent variable representing the reference parameter, a is the intercept and b is the slope.

To analyse the allometry, slope b was compared to the theoretical value of 1 when two linear measurements were analysed, and to the theoretical value of 3 when linear and mass parameters were considered.

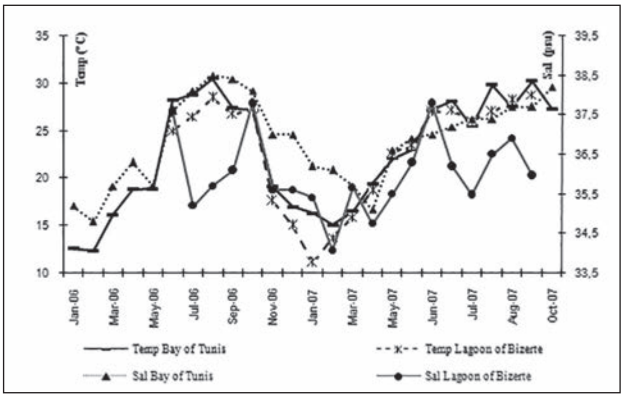

Fig. 2: Monthly evolution of the sea surface temperature (°C) and salinity (psu) in the Bay of Tunis (January 2006–October 2007) and in the Bizerte Lagoon (June 2006–September 2007).
Sl. 2: Površinska temperatura (°C) in slanost (psu) v Tuniškem zalivu (januar 2006–oktober 2007) in v Bizertski laguni (junij 2006–september 2007)

Data analysis

Stepwise regression was used to evaluate potential relationships between hydro-biological parameters (*i.e.*, temperature, Chl *a*, dissolved oxygen, salinity and pH) and the growth descriptors of *F. fragilis*. The differences in the environmental variables of the two sampling sites were tested by analysis of variance (ANOVA) ($p < 0.05$). The significance of the allometries was determined by a Student's *t*-test. All data analyses were carried out using Statgraphics Centurion software.

RESULTS

Environmental parameters

In the Bay of Tunis, the average sea surface temperature was 22.6±5.8 °C (between 12.4 °C and 30.5 °C). In the Bizerte Lagoon, this parameter ranged between 11.1 °C and 28.8 °C with an average of 23.0±5.7 °C. The mean salinity values were 36.4 ± 1.6 and 36±0.98 psu in the Bay of Tunis and in the Bizerte Lagoon, respectively (Fig. 2). Greater variations in salinity were observed in the Bizerte Lagoon due to high summer evaporation and freshwater inputs.

The recorded values of Chl *a* concentration in the Bay of Tunis were highly variable, with an average value of 3.03 μg/L and the lowest values registered in winter and early spring (Fig. 3). In the Bizerte Lagoon, this parameter varied less in the first months of the sampling, but from April 2007 onwards, there were significant increases, with a peak value (6.77 μg/L) reached in August 2007 (Fig. 3).

Average dissolved oxygen concentrations in the Bay of Tunis and the Bizerte Lagoon were 5.75 and 4.46 mg/L, respectively, with the lagoon being less oxygenated than the bay (Fig. 4). In the Bay of Tunis, the average pH was 8.20 (between 7.89 and 8.34), whereas in the Bizerte Lagoon this pollution indicator parameter ranged between 7.31 and 8.42, showing major environmental disruption (Fig. 4).

Statistical analysis showed significant differences between the salinity, the dissolved oxygen concentration and the pH of the two sampling sites, with a confidence level of 95 % (ANOVA, $p < 0.05$).

Relative growth

In the Bay of Tunis, fresh and dry meat mass were positively correlated with the Chl *a* concentration, while in the Bizerte Lagoon, the shell thickness and dry meat mass were negatively correlated with pH (Tab. 1).

The global allometry combining SH and SL was negative (b < 1) for the entire sample from the Bay of

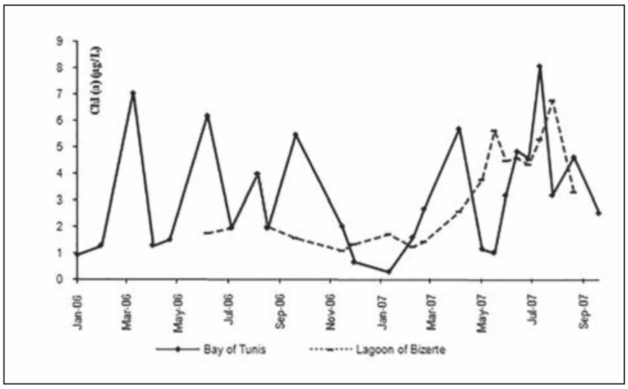

Fig. 3: Monthly evolution of Chl** a **concentration (µg/L) in the Bay of Tunis (January 2006–October 2007) and in the Bizerte Lagoon (June 2006–September 2007).
Sl. 3: Koncentracije klorofila** a **(µg/L) v Tuniškem zalivu (januar 2006–oktober 2007) in v Bizertski laguni (junij 2006–september 2007)

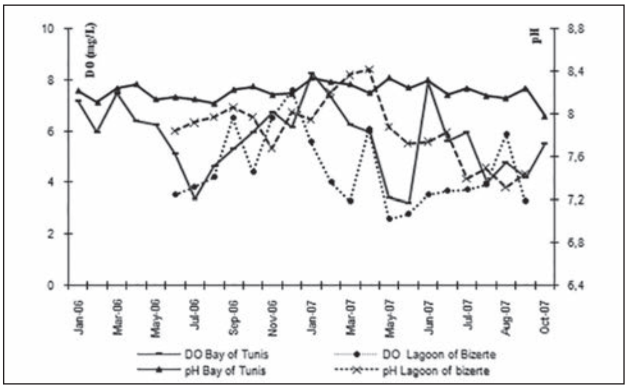

Fig. 4: Monthly variations of dissolved oxygen concentration (mg/L) and pH in the Bay of Tunis (January 2006–October 2007) and in the Bizerte Lagoon (June 2006–September 2007).
Sl. 4: Mesečna nihanja koncentracije raztopljenega kisika (mg/L) in pH v Tuniškem zalivu (januar 2006–oktober 2007) in v Bizertski laguni (junij 2006–september 2007)

Tunis and positive (b > 1) in the Bizerte Lagoon cockles. These results showed that the growth at the first site was generally faster in length, while at the second it was usually faster in height (Tab. 2). Regressions involving ST and SH to SL indicated that the shell grew more in length and height than in thickness in both sites (Tab. 2). The coefficient of determination R^2 for these three relationships displayed high values.

Tab. 1: Parameters of multilinear regression between morphometric parameters of** F. fragilis **and environmental variables in the two sampling sites (Bay of Tunis and Bizerte Lagoon). Legend: Chl** a **- chlorophyll** a **(µg/L), DMM - Dry Meat Mass (mg), FMM - Fresh Meat Mass (mg), DSM - Dry Shell Mass (mg), ST - Shell Thickness (mm), Temp - temperature (°C).
Tab. 1: Multilinearna regresija med morfometričnimi parametri školjke** F. fragilis **in okoljskimi spremenljivkami na dveh vzorčevalnih lokalitetah (Tuniški zaliv, Bizertska laguna). Legenda: Chl** a **- klorofil** a **(µg/L), DMM - suha masa mesa (mg), FMM - sveža masa mesa (mg), DSM - suha masa lupine (mg), ST - debelina lupine (mm), Temp - temperatura (°C).

Sampling site	Descriptor	Model
Bay of Tunis	FMM	FMM = cte + 0.27 Chl *a*
	DMM	DMM = cte + 0.04 Chl *a*
	DSM	DSM= cte + 0.15 Temp
Lagoon of Bizerte	ST	ST = cte - 4.00 pH
	DMM	DMM = cte - 0.14 pH
	DSM	DSM = cte - 2.14 pH

Regressions linking mass parameters to SL revealed negative allometries in the Bay of Tunis. Thus, *F. fragilis'* increase in shell length was less rapid than its mass gain (total and different parts) (Tab. 3). In the Bizerte Lagoon, the global regressions between TM, FMM, DMM and SL showed negative allometries (Tab. 3).

In cockles from the Bay of Tunis, the monthly regressions combining mass parameters to length presented mainly positive allometries reflecting a faster shell length growth than mass gain (total mass and different parts) (Tab. 4). The monthly coefficient of determination R^2 relating the total mass, the fresh and dry soft tissue mass to shell length showed low values in the months of high gonadal activity. It increased in months characterized by gametic emissions, especially in May and November 2006 (Rifi *et al*, 2011) (Tab. 4).

In the Bizerte Lagoon, monthly allometries between total mass and shell length suggested a faster SL growth than total mass gain (Tab. 5). Moreover, the allometries linking the soft tissue masses (fresh and dry) to shell length were generally positive, indicating a slower shell length growth than soft tissue mass gain (Tab. 5). The coefficient of determination R^2 was often relatively high, reflecting strong inter-individual variations (Tab. 5).

DISCUSSION

Growth is one of the most used measures of animal vitality. In this context, Dame (1972) suggested that '*Allometric relationships are often developed between shell parameters and body weight in order to nondestructively*

Tab. 2: Parameters of allometric regression models (Shell Height (SH) – Shell Length (SL), Shell Thickness (ST) – Shell Length (SL), Shell Thickness (ST) – Shell Height (SH) measured in mm) corresponding to the samples of* F. fragilis *collected from the Bay of Tunis and the Bizerte Lagoon. R^2: coefficient of determination;* t*-test, **: significant, NS: not significant for the confidence interval of 95 %.

Tab. 2: Modeli alometrične regresije (višina lupine (SH) – dolžina lupine (SL), debelina lupine (ST) – dolžina lupine (SL), debelina lupine (ST) – višina lupine (SH), izražene v mm) vzorcev školjke* F. fragilis *iz Tuniškega zaliva in Bizertske lagune. R^2: koeficient determinacije;* t*-test, **: značilna razlika, NS: razlika ni značilna na nivoju 95-% intervala zaupanja.

Sampling site	Relation	N	log(a)	b	R²	t-test	Allometry
Bay of Tunis	SH-SL	2893	0.38	0.88	0.83	**	negative
	ST-SL		0.01	0.88	0.74	**	negative
	ST-SH		-0.08	0.91	0.75	**	negative
Lagoon of Bizerte	SH-SL	1641	-0.20	1.04	0.94	**	positive
	ST-SL		0.11	0.86	0.77	**	negative
	ST-SH		0.33	0.80	0.79	**	negative

estimate soft body biomass in living bivalves'. The study of the *Fulvia fragilis*' relative growth is crucial to understanding the growth of the different parts of the cockle, in relation to environmental variables (hydro-biological conditions, pollution, etc.) and during its reproductive cycle. Our results showed remarkable differences by site. This method has been used for many decades in bivalves because of its reproducibility that allows a comparison between multiple sampling sites (*e.g.*, Seed, 1973; Bejaoui, 1998; Gimin *et al.*, 2004; Aragon-Noriega *et al.*, 2007). Such results can contribute to the management of this potentially exploitable species and to a better understanding of its bioinvasion.

Morphometric allometries in *F. fragilis* at the two sampling sites attested that the cockle shell growth was different. The global regression of height-length was

Tab. 3: Parameters of allometric regression models (Total Mass (TM) – Shell Length (SL), Fresh Meat Mass (FMM – Shell Length (SL), Dry Meat Mass (DMM) – Shell Length (SL), Dry Shell Mass (DSM) – Shell Length (SL)) corresponding to the samples of* F.fragilis *collected from the Bay of Tunis and the Bizerte Lagoon. R^2: coefficient of determination;* t*-test, **: significant, NS: not significant for the confidence interval of 95 %.

Tab. 3: Modeli alometrične regresije (celokupna masa (TM) – dolžina lupine (SL), sveža masa mesa (FMM) – dolžina lupine (SL), suha masa mesa (DMM) – dolžina lupine (SL), suha masa lupine (DSM) – dolžina lupine (SL)) vzorcev školjke* F. fragilis *iz Tuniškega zaliva in Bizertske lagune. R^2: koeficient determinacije;* t*-test, **: značilna razlika, NS: razlika ni značilna na nivoju 95-% intervala zaupanja.

Sampling site	Biometric relationships	log(a)	b	R²	t-test	Allometry
Bay of Tunis	TM-SL	-5.85	2.33	0.62	**	negative
	FMM-SL	-7.93	2.54	0.62	**	negative
	DMM-SL	-10.12	2.59	0.42	**	negative
	DSM-SL	-7.78	2.55	0.71	**	negative
Lagoon of Bizerte	TM-SL	-7.396	2.72	0.70	**	negative
	FMM-SL	-7.975	2.504	0.68	**	negative
	DMM-SL	-9.375	2.266	0.44	**	negative
	DSM-SL	-9.792	3.060	0.84	**	positive

negative in the Bay of Tunis and positive in the Bizerte Lagoon. *F. fragilis'* shell presents a triangular shape in the Bay of Tunis samples and an elongated form in the Bizerte Lagoon specimens. This morphological difference could be explained by endogenous (gametogenesis) and exogenous (nature of the sediment) factors. Previous work conducted by Rifi *et al*. (2011) confirmed that *F. fragilis* is a simultaneous hermaphroditic species with a diffuse gonad extending between the digestive gland and the pedal constriction. These authors described a maturation scale partitioned into eight stages: sexual rest (0), initiation of gametogenesis (1), advanced ga-

Tab. 4: Monthly parameters of allometric regression models (Total Mass (TM) – Shell Length (SL), Fresh Meat Mass (FMM) – Shell Length (SL), Dry Meat Mass (DMM) – Shell Length (SL)), Bay of Tunis, January 2006–October 2007. All morphometric parameter ranges are in mm and all masses are in mg. In bold are values, where b > 3. I: first half of the month; II: second half of the month; N: monthly individual number; R^2: coefficient of determination; t-test, **: significant, NS: not significant for the confidence interval of 95 %.

Tab. 4: Mesečna nihanja modelov alometrične regresije (celokupna masa (TM) – dolžina lupine (SL), sveža masa mesa (FMM) – dolžina lupine (SL), suha masa mesa (DMM) – dolžina lupine (SL)) vzorcev školjke *F. fragilis* ***iz Tuniškega zaliva (januar 2006–oktober 2007). Vsi morfometrični parametri so v mm in vse mase v mg. Vrednosti b > 3 so v krepkem tekstu. I: prva polovica meseca; II: druga polovica meseca; N: število osebkov na mesec; R^2: koeficient determinacije; t-test, **: značilna razlika, NS: razlika ni značilna na nivoju 95-% intervala zaupanja.***

Month	TM-SL				FMM-SL				DMM-SL			
	log(a)	b	R^2	*t*-test	log(a)	b	R^2	*t*-test	log(a)	b	R^2	*t*-test
Jan 06	-5.35	2.23	0.61	**	-4.90	1.70	0.49	**	-6.87	1.67	0.20	**
Feb 06	-6.93	2.64	0.60	**	-8.97	2.84	0.60	**	-8.89	2.18	0.38	**
Mar 06	-7.42	2.77	0.83	**	-7.66	2.53	0.81	**	-9.88	2.55	0.57	**
Apr 06	-5.97	2.30	0.31	**	-5.77	1.91	0.28	**	-6.63	1.54	0.10	**
May 06	-9.86	**3.42**	0.89	**	-12.5	**3.80**	0.92	**	-14.4	**3.72**	0.83	**
June 06	-4.71	2.02	0.29	**	-5.51	1.95	0.42	**	-9.49	2.48	0.31	**
Oct 06	-7.96	2.92	0.93	**	-10.8	**3.40**	0.96	**	-14.05	**3.79**	0.87	**
Nov 06	-7.839	2.82	0.89	**	-10.3	**3.25**	0.91	**	-13.58	**3.62**	0.80	**
Dec 06	-8.16	2.99	0.62	**	-11.04	**3.43**	0.83	**	-13.95	**3.66**	0.72	**
Jan 07	-5.35	2.23	0.61	**	-6.48	2.04	0.40	**	-8.95	2.15	0.40	**
Feb 07	-3.30	1.55	0.22	**	-8.97	2.84	0.60	**	-8.74	2.11	0.30	**
Mar 07	-6.104	2.40	0.63	**	-8.20	2.64	0.64	**	-9.88	2.55	0.57	**
Apr 07	-4.035	1.87	0.46	**	-5.08	1.83	0.40	**	-7.58	2.00	0.28	**
May I 07	-8.043	2.97	0.79	**	-10.2	**3.20**	0.67	**	-13.60	**3.58**	0.50	**
May II 07	-6.45	2.51	0.69	**	-9.15	2.88	0.58	**	-12.04	**3.14**	0.45	**
June I 07	-8.377	**3.03**	0.74	**	-10.7	**3.28**	0.68	**	-11.49	**3.03**	0.39	**
June II 07	-1.986	1.22	0.23	**	-3.30	1.27	0.19	**	-5.80	1.40	0.14	**
July I 07	-7.98	0.99	0.22	**	-2.18	0.97	0.20	**	-6.14	1.57	0.20	**
July II 07	0.100	0.78	0.27	**	-1.38	0.82	0.20	**	-3.97	1.00	0.17	**
Aug 07	-5.79	2.35	0.55	**	-8.15	2.60	0.49	**	-10.16	2.62	0.19	**
Sept 07	-6.78	2.52	0.52	**	-9.39	2.89	0.65	**	-2.22	0.39	0.11	N.S
Oct 07	-0.70	0.91	0.11	N.S	-1.00	0.69	0.32	N.S	-3.26	0.56	0.11	N.S

metogenesis (2), maturity (3A), partial spawning (3B1), advanced spawning (3B2), restoration (3C) and spent (3D). Moreover, the species breed differently in the two study sites. In the Bay of Tunis, where conditions were favourable, *F. fragilis* showed a continuous spawning activity, rare in winter and with seasonal peaks the rest of the year. Spring peaks were thus noted in May 2006 and May 2007, summer peaks in June 2006, June 2007 and August 2007, and an autumn peak in November 2006 (Rifi *et al.,* 2011, 2015). Conversely, in the Bizerte Lagoon, a very low gonadic activity with a prevalence of the sexual rest stage was observed (Rifi *et al.*, 2015). These reproductive abnormalities could be explained by the vast extent of pollution (Rifi *et al.*, 2015). Indeed, in the Bay of Tunis, this species displays a continuous reproductive activity and the position of the gonad in the animal's foot requires the shell to grow in length. The nature of the sediment could also explain this morphological difference between the two sampling sites. The sandy-mud sediment in the Bay of Tunis allows for the *F. fragilis* surface and sub-surface alimentation. Conversely, the muddy sediment of the Bizerte Lagoon explains the shell's height growth, which facilitates the animal's alimentation with its short siphons. Some authors had already highlighted similar morphological adaptations of some bivalves, such as *Donax trunculus* and *Panopea globosa*, to their biotopes (Gaspar *et al.*, 2002; Aragon-Noriega *et al.*, 2007).

In the Bay of Tunis, allometries linking soft tissue mass (fresh or dry) to shellfish length revealed a less

Tab. 5: Monthly parameters of allometric regression models (Total Mass (TM) – Shell Length (SL), Fresh Meat Mass (FMM) – Shell Length (SL), Dry Meat Mass (DMM) – Shell Length (SL)), Bizerte Lagoon, June 2006–September 2007. All morphometric parameter ranges are in mm and all masses are in mg. In bold are values, where b > 3. N: monthly individual number; R²: coefficient of determination; t-test, **: significant, NS: not significant for the confidence interval of 95 %.

Tab. 5: Mesečna nihanja modelov alometrične regresije (celokupna masa (TM) – dolžina lupine (SL), sveža masa mesa (FMM) – dolžina lupine (SL), suha masa mesa (DMM) – dolžina lupine (SL)) vzorcev školjke *F. fragilis* ***iz Bizertske lagune (junij 2006–september 2007). Vsi morfometrični parametri so v mm in vse mase v mg. Vrednosti b > 3 so v krepkem tekstu. N: število osebkov na mesec; R²: koeficient determinacije; t-test, **: značilna razlika, NS: razlika ni značilna na nivoju 95-% intervala zaupanja.***

Month	TM-SL				FMM-SL				DMM-SL			
	log(a)	b	R²	t-test	log(a)	b	R²	t-test	log(a)	b	R²	t-test
June 06	-7.49	2.73	0.63	**	-7.06	2.20	0.43	**	-10.73	2.66	0.43	**
July 06	-4.22	1.82	0.36	**	-5.96	1.92	0.57	**	-5.21	1.80	0.46	**
Aug 06	-7.14	2.64	0.43	**	-10.66	**3.31**	0.73	**	-11.14	2.81	0.42	**
Sept 06	-8.99	**3.16**	0.69	**	-10.69	**3.28**	0.75	**	-12.04	**3.06**	0.60	**
Oct 06	-9.16	**3.23**	0.80	**	-10.25	**3.18**	0.71	**	-15.25	**3.96**	0.74	**
Nov 06	-8.68	**3.11**	0.82	**	-10.66	**3.28**	0.73	**	-12.50	**3.24**	0.58	**
Dec 06	-8.28	2.98	0.79	**	-11.54	**3.51**	0.72	**	-15.22	**3.90**	0.64	**
Jan 07	-9.35	**3.28**	0.65	**	-10.88	**3.30**	0.78	**	-15.48	**3.88**	0.58	**
Feb 07	-8.30	2.97	0.53	**	-10.77	**3.26**	0.73	**	-13.82	**3.41**	0.63	**
Mar 07	-7.14	2.65	0.60	**	-8.77	2.70	0.57	**	-10.02	2.39	0.49	**
Apr 07	-7.81	2.81	0.39	**	-10.04	**3.02**	0.62	**	-13.76	**3.40**	0.55	**
May 07	-8.75	**3.10**	0.60	**	-9.965	**3.02**	0.59	**	-9.53	2.30	0.27	**
June 07	-8.16	2.93	0.44	**	-11.14	**3.31**	0.49	**	-15.55	**3.88**	0.48	**
July 07	-9.18	**3.08**	0.61	**	-11.05	**3.25**	0.60	**	-17.44	**4.36**	0.45	**
Aug 07	-5.71	2.32	0.40	**	-8.58	2.74	0.58	**	-8.56	2.08	0.32	**
Sept 07	-5.29	2.16	0.70	**	-9.105	2.82	0.60	**	-9.12	2.19	0.36	**

important mass gain compared to shell length. However, an opposite trend coinciding with gamete production (at spawning stages, restoration and initiation of gametogenesis) and the sexual rest period was observed. It was demonstrated that mass increase in some bivalves was related to gonadic mass, which represents a major share of the visceral mass (Bayne & Worrall, 1980; Alunno-Bruscia *et al.*, 2001). Otherwise, in *F. fragilis*, during the sexual rest and especially in January and February 2007, the tissue growth probably resulted from gametes transforming to food reserves (Rifi *et al.*, 2011). This phenomenon has already been described in some bivalves (Thompson, 1979; D'Orange *et al.*, 1989; Rodríguez *et al.*, 2003). In addition, throughout our study period, except for winter months (from December to February), we recorded relatively high Chl *a* concentrations, which in part explained the growth of soft tissue. This observation was verified through stepwise regression and corroborated a positive correlation between flesh mass and Chl *a* concentration in samples from the Bay of Tunis. This phenomenon has already been described in other bivalve species (Ansell, 1974; Brown, 1988; Dridi *et al.*, 2008).

In the bay of Tunis, during gamete emission periods, *F. fragilis* has a synchronous growth in soft tissue and shell. In bivalves, the shell and flesh growth depend on different nutrient sources. The soft tissue growth depends on the seasonal nutrient cycle and reproduction strategies of storing food reserves, while the shell growth depends partially on metabolic carbon and occurs mainly during the deposition of materials in the water column (Borrero & Hilbish, 1988; Alunno-Bruscia *et al.,* 2001). In general, bivalves have a delayed growth of flesh and shell. Besides, in some species of bivalves (as *Mytilus edulis* and *Geukensia demissa*), the shell and flesh growths were not synchronous (Hilbish, 1986; Borrero & Hilbish, 1988; Alunno-Bruscia *et al.*, 2001). Hilbish (1986) reported that *M. edulis* shell growth preceded the flesh gain. Thompson (1979) explained that this phenomenon was an adaptive strategy to increase the volume in anticipation of the flesh growth.

The coefficient of determination R^2 between the fresh and dry flesh masses versus shell length has generally high values, indicating a strong relationship. However, this ratio decreased during spring and summer successive spawn periods extending from March 2007 till the end of August 2007 (Rifi *et al.*, 2011). The same trend has been described in *Crassostrea gigas* (Dridi *et al.*, 2008). High inter-individual variations were also observed in October 2007, probably due to high mortalities. The large inter-individual variation in *F. fragilis* was probably accentuated by its weakness after successive spawning episodes.

In the Bizerte Lagoon, regressions between flesh masses (fresh and dry) and shell length revealed that the *F. fragilis'* flesh mass usually developed faster than shellfish length. These results show that the growth of the non-native cockle at this location is directly opposed to that registered at the Bay of Tunis site. The differences in growth could be attributed to environmental factors; they are likely related to pH values being statistically lower than in the Bay of Tunis (ANOVA, $p < 0.05$). Indeed, the shellfish growth was probably affected by pollution. Several authors (Gazeau *et al.*, 2007; Kurihara *et al.*, 2007; Guinotte & Fabry, 2008; Portner, 2008) have shown that low pH values have several negative effects, particularly inhibition of shell calcification. In addition, in some species a decline in shell growth was explained by chemical pollution (Thain, 1984).

The monthly coefficients of determination on regressions between the total mass, fresh and dry flesh mass to shellfish length in the population of *F. fragilis* from the Bizerte Lagoon were relatively low in the warmer period, reflecting high inter-individual variations. These variations could be explained by increased levels of pollutants, especially chemical contaminants, and low dissolved oxygen concentrations. Several studies have showed that the availability of dissolved oxygen in water is a limiting factor for molluscs' growth (Baker & Mann, 1992; Harris *et al.*, 1999; McDowell *et al.*, 1999; Wilson & Burnett, 2000). McDowell *et al.* (1999) demonstrated that some bivalves have biological reactions, including allocation of nutrients and biosynthetic processes following exposure to certain contaminants.

To conclude, the growth of the allochthonous cockle *F. fragilis* at the two selected sites revealed major differences. The nature of the allometric regression associated with metric variables changing from one site to another demonstrates a more elongated shellfish in the Bizerte Lagoon. In specimens of *F. fragilis* collected in the Bay of Tunis, monthly relationships involving masses with shell length depend on the progress of gametogenesis. Indeed, the growth in mass is higher in the months of sexual activity. Moreover, the growth in shellfish and flesh masses was synchronous in favourable conditions. In the Bizerte Lagoon, the sampling site characterized by a very low reproductive activity, the fresh and dry flesh mass growth depended essentially on the availability of nutrients. In this lagoon, the increase in shellfish length could have been affected by the "acidification" of water. This phenomenon, caused by pollution, compromised the shell calcification (Gazeau *et al.*, 2007; Guinotte & Fabry, 2008; Kurihara, 2008; Portner, 2008).

In the Bay of Tunis and the Bizerte Lagoon, the high inter-individual variations in mass and length in *F. fragilis* implied by the low coefficients of determination occur in the months of high sexual activity (gametic production) and in warmer months, which correspond to peak pollution period, respectively.

These results imply that the mode of reproduction of *F. fragilis* facilitated its spreading beyond its geographical area, but this cockle shows signs of vulnerability especially in highly polluted environments, such as the Bizerte Lagoon. It is noteworthy that we were forced to stop our sampling in October 2007 in the Bay of Tunis and in September 2007 in the Bizerte Lagoon following massive mortality and scarcity of the studied species. Recent sampling has shown, on the one hand, a massive reappearance of this species in the Bay of Tunis, and on the other, its absence from the Bizerte Lagoon.

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RAST INVAZIVNE ŠKOLJKE *FULVIA FRAGILIS* (MOLLUSCA: BIVALVIA) IZ SEVERNE TUNIZIJE (OSREDNJI MEDITERAN)

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POVZETEK

Tujerodna vrsta školjke Fulvia fragilis *(Forsskål in Niebuhr, 1775) se vzdolž tunizijske obale pojavlja že od leta 1994. Mesečna in dvomesečna vzorčenja te vrste so bila opravljena v morskih (Tuniški zaliv) in lagunskih vodah (Bizerta) v severni Tuniziji. Avtorji so pregledali skupno 4.534 osebkov. Raziskovali so odnos med rastnimi podatki in okoljskimi parametri (temperatura, slanost, pH, raztopljeni kisik in koncentracija klorofila* a*) ter biotskimi parametri (razmnoževalni cikel). Pokazale so se značilne razlike med obema obravnavanima lokalitetama. Očitne so bile tudi morfološke razlike med obema lokalitetama, saj so bile lupine trikotne v tuniškem zalivu in podolgovate v Bizertski laguni. Biomasni prirastek v Tuniškem zalivu je bil povezan z razmnoževalnim ciklom in je bil nižji v primerjavi z dolžino lupine. V Bizertski laguni pa je bil obraten trend rasti školjk, najverjetneje zaradi onesnaževanja okolja.*

Ključne besede: *Fulvia fragilis*, rast, onesnaževanje, Tuniški zaliv, Bizertska laguna

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