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Population study of the protected bivalve *Pinna nobilis* (Linnaeus, 1758) in Thermaikos Gulf (North Aegean Sea)

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The population structure and the age and growth of the protected bivalve *Pinna nobilis* were studied in the Thermaikos Gulf (North Aegean Sea). The density was 1.04 ± 0.17 ind m^{-2}, the highest reported until now in the Mediterranean Sea. Mean length was 34.35 ± 11.78 cm and maximum length (L_{max}) was 69.10 cm, which indicated an undisturbed natural population. Allometric relations between morphometric and/or weight parameters were calculated and they indicated that *P. nobilis* has the priority to ensure the living space for its body growth and protection. Length frequency distribution and the observed age structure indicated that the *P. nobilis* population studied was constructed mainly of small and medium sized/aged individuals. In comparison with other Mediterranean populations of *P. nobilis*, the growth rate of the East Thermaikos population was among the smallest ones (k = 0.063), while the maximum length (L_∞ = 73.77) was among the largest ones.

Key words: *Pinna nobilis*, population structure, age, von Bertalanffy growth equation, North Aegean Sea.

INTRODUCTION

Pinna nobilis (the fan mussel) is the largest bivalve in the Mediterranean Sea with a maximum length of 108 cm (FAO, 1987). There are only a few studies regarding the age and growth of the fan mussel in France (Moreteau & Vicente, 1982), Spain (Richardson *et al*., 1999), Croatia (Richardson *et al*., 2004) and the Adriatic Sea (Siletic & Peharda, 2003). *Pinna nobilis* studies in Greece concerning its morphometry and ecology have been performed in North Aegean (Thermaikos Gulf) by Galinou-Mitsoudi & Petridis (2001). Also, Hames *et al*. (2001) and Anonymous (2002) studied the population dynamics of this species in the Ionian Sea (north-eastern Kefalonia), while the fan mussel population ecology was studied in the Korinthiakos Gulf by Katsanevakis (2005). The species is protected by European (Directive 92/43/EEC) and local legislation (GD 227/2003/FEK A' 198).

The aim of the present study was to provide information about this protected species, regarding, for the first time, relationships of shell dimensions and weights so that the removal of shells could be avoided in relevant future studies. The population structure, age and growth of *P. nobilis* in North Aegean Sea (eastern Mediterranean) were also studied for the first time in this area.

MATERIALS AND METHODS

This study took place in the eastern coasts of the Thermaikos Gulf, north of the Epanomi port, a small scale fishing area with slight tourist disturbance. The hydrodynamics of the area have been altered by the construction of the port's north jetty during the winter of 1999-2000. Sampling was carried out once in May 2004 at depths of 2-3 m. A total of 73 fan mussels were collected with scuba diving from 7 sampling units, each covering an area of 1 × 10 m. Additionally, 39 individuals were collected randomly from a nearby broader area (8th sampling area) (Fig. 1). All mussels were preserved in 7% formaldehyde

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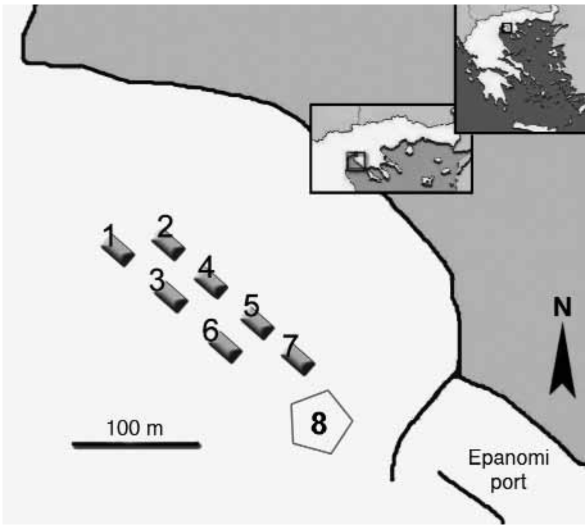

FIG. 1. Study area in East Thermaikos Gulf.

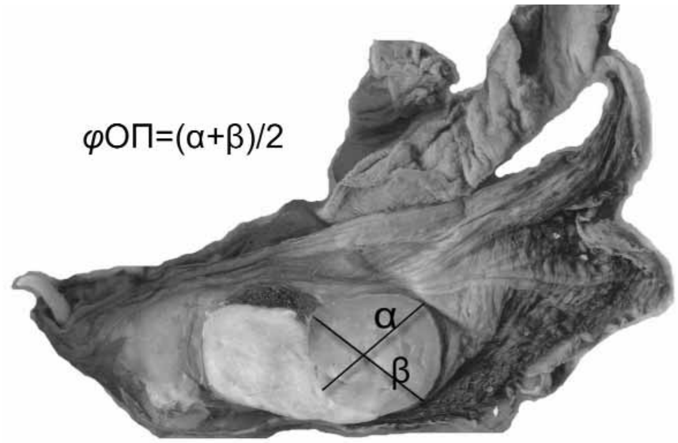

FIG. 2. Measurements and calculation of the posterior adductor muscle (φΟΠ) mean diameter.

FIG. 3. The inner surface (left) with scars of posterior adductor muscles and the outer surface (right) of *P. nobilis* with arrows in the annual rings. L: shell length.

solution.

Fan mussel valve morphometry (length L, height H, width W) was measured with an accuracy of 1 mm. Posterior adductor muscle dimensions (min = α, max = β, $\varphi = (\alpha + \beta)/2$, Fig. 2) were measured using a vernier caliper with an accuracy of 0.02 mm. The fan mussel body and the valves' wet and dry weights were measured separately using a digital balance with an accuracy of 0.01 g (wet weights) and 0.001 g (dry weights). Dry weight measurements were made after the samples were dried at 120°C for 24 h. The total weights did not include the byssus and intervalve water weights.

Fan mussel age was determined from the posterior adductor muscle scars (Richardson *et al.*, 1999) and the low growth rate zones on the valves' outer surface for the mussels with a length of < 20 cm (Fig. 3). The fan mussel length frequency distribution was also taken into account during age determination.

Analysis of variance (ANOVA) on log-transformed data was used for mean length comparisons between all sampling units. The regression equations between all shell dimensions and weights were also calculated using log-transformed data.

RESULTS

In the 7 sampling units, the lowest population density was 0.80 ind m^{-2} while the highest was 1.30 ind m^{-2} and the mean density (± standard deviation) was 1.04 ± 0.17 ind m^{-2}. The smallest fan mussel length was 15.80 cm and the largest one was 69.10 cm (Table 1) sampled from units 7 and 3 respectively, while overall the smallest fan mussel length was 14.00 cm sampled from the 8th sampling area. The median length was 32.45 cm and the mean length was 34.35 ± 11.78 cm. The median and mean lengths varied among the sampling units from 22.05 to 49.20 and 25.13 to 46.05 cm, respectively (Fig. 4), with the northern sampling units being represented by the longest fan mussels (ANOVA, N = 73, $F = 4.79$, $p = 0.000$).

The length frequency distribution is shown in Fig. 5. It can be seen that all length groups are present in the study population and that most individuals were small (< 30 cm) and medium (30–45 cm) sized.

The mean wet and dry body weights for all individuals (of all ages and lengths) were 88.25 ± 70.14 and 16.61 ± 15.00 g, respectively, while the wet and dry shell weights were 284.7 ± 280.1 and 254.5 ± 265.7 g, respectively. The minimum and maximum body and shell weights as well as the median values are displayed in Table 2. During the sampling period (May) the wet body weight represented 23.7% of the total (shell + body) wet weight and the dry body weight represented 6.1% of the total dry weight.

Linear regressions using the fan mussel lengths, heights, widths and weights (body, shell and total, wet and dry) were calculated and the allometric relationships between them were determined (Table 3).

Fan mussel age varied from 0 to 27 years, with most individuals being in the younger age groups. The theoretical growth curve (von Bertalanffy) was calculated using the average length of the individuals. By using the Ford-Walfort method, the maximum length L_∞ was calculated to be 73.77 cm, the growth

TABLE 1. Population density and mean length (± SD) of *P. nobilis* in the Mediterranean Sea

Area	**N**	**Density (ind m^{-2})**	**Min–Max length / Mean Length ± SD (cm)**	**Reference**
North Adriatic	61	–	10–68	Zavodnik (1967)
Corsica	3 samples / 15 days for a year	–	20–71	de Gaulejac (1995)
South-East Spain (4 sites)	45	0.040–0.300	~ 10–58	Richardson *et al.* (1999)
Ionian Sea	–	0.002–0.080	22.50*	Hames *et al.* (2001)
Ionian Sea	–	0.080	–	Anonymous (2002)
East Adriatic Sea	47	0.020–0.200	43.88 ± 13.21	Siletic & Peharda (2003)
Korinthiakos Gulf	–	0.047	7.40–75.10	Katsanevakis (2005)
East Thermaikos Gulf	137	–	17.50–62.50 45.20 ± 8.25	Galinou-Mitsoudi & Petridis (2001)
East Thermaikos Gulf	73	0.800–1.300	15.80–69.10 34.35 ± 11.78	Present Study

* No SD value was provided

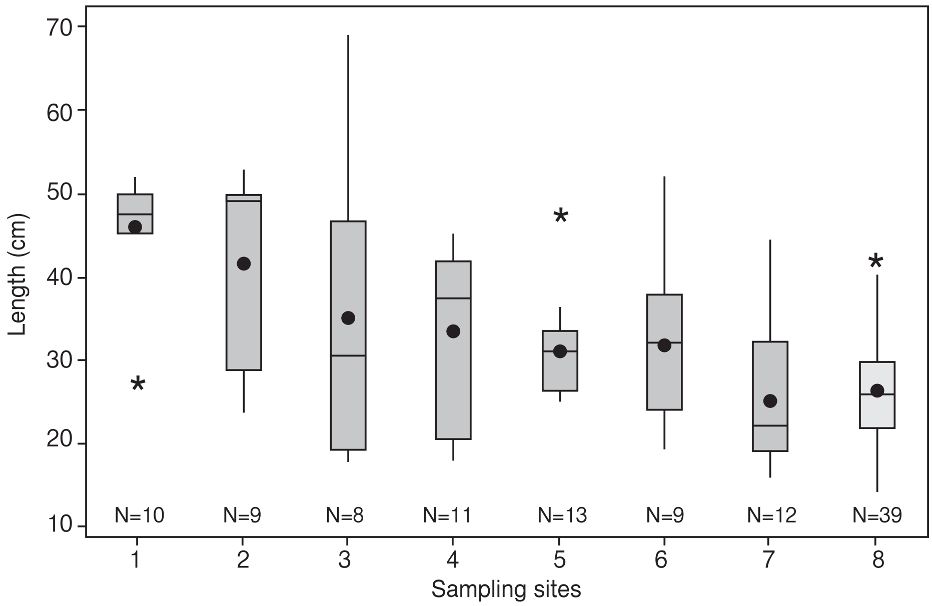

FIG. 4. Box plots of shell length (L) in sampling areas. (•) mean value; (–) median; (*) extreme value.

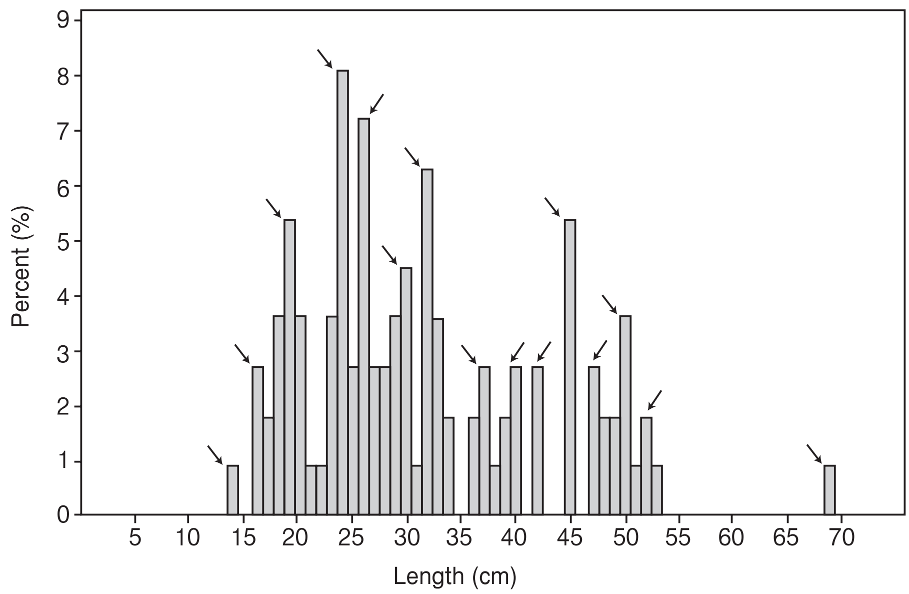

FIG. 5. Length frequency distribution (%) of N = 112 fan mussels. Arrows indicate age classes.

TABLE 2. Wet (Ww) and dry (Dw) body (B) and shell (S) weights of *P. nobilis* (May 2004)

Weights (g)	N	Mean ± SD	Median	Minimum	Maximum
BWw	112	88.25 ± 70.14	64.96	11.28	374.00
BDw	112	16.61 ± 15.00	10.60	1.70	74.43
SWw	111	284.73 ± 280.07	180.23	32.45	1676.00
SDw	111	254.53 ± 265.68	155.26	24.82	1602.00

TABLE 3. Linear regressions of morphometric parameters (L = length, H = height, W = width) and body (B), shell (S) and total (T) weights [wet (Ww), dry (Dw)] as well as mean diameter of posterior adductor muscle (φΟΠ) of fan mussels. R^2: determination coefficient (%); C.I.: confidence intervals of b with 95% probability; Allometry (+/-/0): positive/negative/isometric

N	Linear regression logy = loga + blogx	R^2 (%)	ANOVA Probability (p)	Standard error of b (95% C.I. of b)	Allometry (+/–/0)
109	logL = 0.05 + 1.29 logH	88.5	0.000	0.045 (1.20–1.38)	+
109	logL = 0.73 + 1.19 logW	91.5	0.000	0.024 (1.14–1.24)	+
109	logW = -0.64 + 1.14 logH	88.9	0.000	0.039 (1.06–1.21)	+
110	log(φΟΠ) = -1.01 + 0.91 logL	91.2	0.000	0.027 (0.85–0.96)	–
109	log(φΟΠ) = -1.04 + 1.23 logH	86.8	0.000	0.047 (1.14–1.32)	+
110	log(φΟΠ) = -0.30 + 1.01 logW	87.6	0.000	0.036 (0.94–1.08)	0
112	log(BDw) = -1.01 + 1.13 log(BWw)	99.3	0.000	0.009 (1.11–1.15)	+
110	log(BDw) = -2.91 + 2.69 logL	95.4	0.000	0.056 (2.58–2.80)	–
110	log(BDw) = -2.98 + 3.64 logH	88.8	0.000	0.124 (3.39–3.89)	+
110	log(BDw) = -0.84 + 3.00 logW	93.0	0.000	0.078 (2.84–3.16)	0
107	log(BWw) = -1.67 + 2.37 logL	94.8	0.000	0.053 (2.26–2.48)	–
109	log(BWw) = -1.73 + 3.19 logH	89.8	0.000	0.104 (2.98–3.40)	0
110	log(BWw) = 0.15 + 2.63 logW	92.7	0.000	0.071 (2.49–2.77)	–
110	log(SDw) = -0.24 + 1.07 log(SWw)	99.8	0.000	0.004 (1.06–1.08)	+
109	log(SDw) = -1.97 + 2.83 logL	97.7	0.000	0.042 (2.75–2.91)	–
109	log(SDw) = -1.95 + 3.75 logH	90.6	0.000	0.116 (3.52–3.98)	+
109	log(SDw) = 0.24 + 3.12 logW	93.1	0.000	0.082 (2.96–3.28)	0
110	log(SWw) = -1.54 + 2.59 logL	96.5	0.000	0.047 (2.47–2.68)	–
110	log(SWw) = -1.61 + 3.51 logH	91.1	0.000	0.106 (3.30–3.72)	+
109	log(SWw) = 0.459 + 2.89 logW	92.7	0.000	0.078 (2.73–3.05)	0
111	log(TDw) = -0.41 + 1.10 log(TWw)	99.8	0.000	0.005 (1.09–1.11)	+
109	log(TDw) = -1.92 + 2.82 logL	97.7	0.000	0.042 (2.74–2.90)	–
110	log(TDw) = -1.94 + 3.77 logH	91.0	0.000	0.114 (3.65–3.99)	+
109	log(TDw) = 0.28 + 3.11 logW	93.2	0.000	0.081 (2.95–3.27)	0
110	log(TWw) = -1.37 + 2.56 logL	96.9	0.000	0.044 (2.47–2.65)	–
110	log(TWw) = -1.39 + 3.43 logH	91.3	0.000	0.102 (3.23–3.63)	+
109	log(TWw) = 0.62 + 2.83 logW	93.3	0.000	0.073 (2.68–2.98)	–

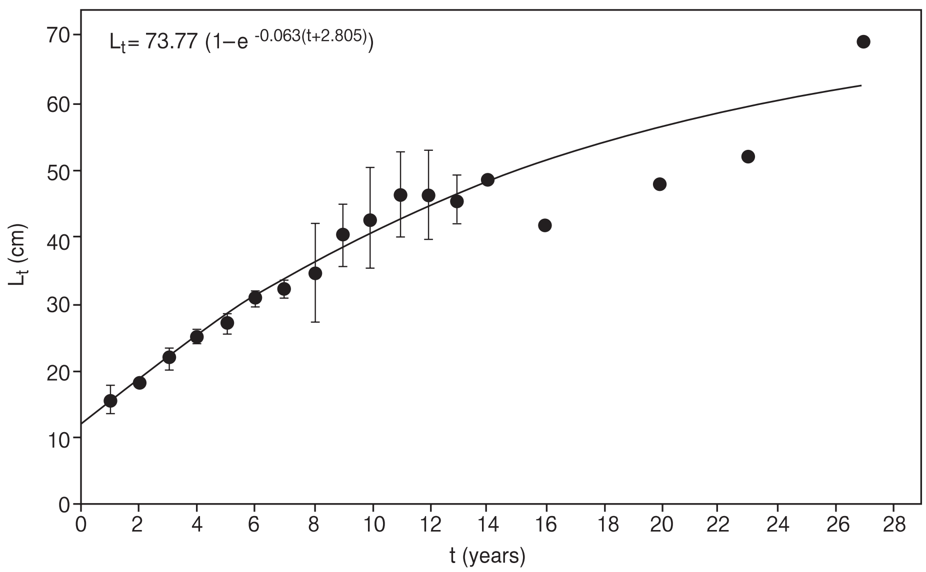

FIG. 6. Observed age for N = 112 individuals and theoretical curve (with 95% confidence intervals) according to the von Bertalanffy equation.

rate $k = 0.063$ and $t_0 = -2.805$. Substituting these values, the von Bertalanffy equation (Fig. 6) is:

$$L_t = 73.77\,[1 - e^{-0.063\,(t\,+\,2.805)}]$$

DISCUSSION

The population density of *P. nobilis* is the highest in Greece and also in the Mediterranean when compared with previous studies, while the maximum length for *P. nobilis* is among the highest in the Mediterranean (Table 1). These could be attributed to the absence of human impact such as fishing and anchoring in the study area. The mean shell length was different among the sampling units (Fig. 4) and it was higher in the more exposed northern areas. The more protected southern and central areas were inhabited by smaller individuals. The construction of the port's north jetty during the winter of 1999–2000 and the resulting environmental disturbance probably have caused older populations to disappear following a new settlement of only younger and smaller individuals (Fig. 1).

All linear regressions between morphometric parameters and weights (Table 3) had a very good predictability with R^2 values being always > 86.8%. The linear regressions with the best R^2 were the ones connecting dry and wet weights ($R^2 \geq 99.3\%$). All relationships had always a higher R^2 value when the shell length was used as a predictor ($R^2 \geq 91.2\%$) followed by those where shell width ($R^2 \geq 87.6\%$) and height ($R^2 \geq 86.8\%$) were used as predictors. Shell length cannot be measured *in situ* without removing the fan mussels from the substrate. Measuring of shell width is less safe than measuring of shell height due to the large number and volume of the epibionts. Length can be predicted with very good accuracy ($R^2 = 88.5\%$) by measuring shell height. Nevertheless, the best linear regression among shell dimensions was length *vs* width with $R^2 = 91.5\%$. In any case, shell height of fan mussels could be used to predict all weight measurements with very good accuracy ($R^2 = 88.8$–91.3%).

Positive allometric relationships between shell dimensions showed that *P. nobilis* grows more in shell length than width and height. Shell width and height are the dimensions that mostly determine the available shell volume for body growth. All relationships calculated between body weight and shell length for mussels collected in May 2004 always showed a negative allometry, with b values similar to those of other pinnid species as *Atrina* (*Servatina*) *pinnata japonica* (Park & Oh, 2002). This corresponds to the finding that *P. nobilis* has one of the heaviest valves compared with other bivalves. Its total wet weight consists of 23.7% body weight and 76.3% shell weight, similar to *Gibbula divaricata* (76%) and *Venus gallina* (74%) (Alyakrinskaya, 2005). Therefore, it seems that the priority of *P. nobilis* is to ensure the living space for its body growth and protection.

According to the length frequency distribution (Fig. 5), the fan mussel population mainly consists of small and medium individuals compared with other populations, such as those in the Adriatic Sea (Siletic & Peharda, 2003) and the Ionian Sea (Anonymous, 2002). Katsanevakis (2005) calculated a maximum length of 75.1 cm in the Korinthiakos Gulf, Greece, a value similar to that measured in the present study (73.77 cm).

TABLE 4. Comparative presentation of the time t_0, growth rate k and maximum length L_∞ from the von Bertalanffy equation for *P. nobilis*

Area	N	t_0	k	L_∞	Reference
South-East Spain	22	0.381	0.210	49.41	Richardson *et al.* (1999)
South-East Spain	6	0.250	0.280	45.27	Richardson *et al.* (1999)
South-East Spain	15	0.500	0.210	68.98	Richardson *et al.* (1999)
East Spain	85	*	0.006	67.13	García-March *et al.* (2002)
South-East France	122	-0.222	0.053	86.30	Moreteau & Vicente (1982)
East Adriatic Sea	47	*	0.160	72.31	Siletic & Peharda (2003)
East Adriatic Sea	6	-2.511	0.331	59.30	Richardson *et al.* (2004)
East Adriatic Sea	6	-2.136	0.369	49.50	Richardson *et al.* (2004)
East Adriatic Sea	6	-0.122	3.806	59.90	Richardson *et al.* (2004)
East Thermaikos Gulf	112	-2.805	0.063	73.77	Present Study

N = number of individuals; * = values not provided

From the age determination and the von Bertalanffy theoretical growth curve (Fig. 6), as well as from the length frequency distribution (Fig. 5), it is concluded that the fan mussels were aged up to 27 years while most individuals were younger than 15 years. *Pinna nobilis* found in the Thermaikos Gulf exhibits a large L_∞ value and rather low growth rate (k) and t_0 values compared with available literature data (Table 4). Similar L_∞ values have been given by Siletic & Peharda (2003) in East Adriatic Sea and by Richardson *et al*. (1999) and Garcia-March *et al*. (2002) in eastern and south-eastern Spain, while growth rates (k) given in these studies vary significantly. These differences could be attributed to differences in sample size between studies and environmental conditions. The highest L_∞ value in the Mediterranean was calculated by Moreteau & Vicente (1982) using measurements of 122 individuals. These measurements were made several decades ago (1969) which might suggest that the fan mussel beds were not disturbed by overfishing or other human activities. The growth rate (k) in that study was low, similar to that in the present study. In any case, the L_∞ value is considerably lower than the maximum length value (108 cm) provided by FAO (1987).

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