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Population Structure, Growth and Production of the Wedge Clam *Donax trunculus* (Bivalvia, Donacidae) in the West Marmara Sea, Turkey

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Abstract

Population structure, growth, mortality and productivity of the wedge clam, *Donax trunculus* (Bivalvia, Donacidae), were investigated on high-density sandy beaches (0.5–2 m) west of the Marmara Sea between May 2011 and April 2012. From length – frequency distribution, the parameters of the von Bertalanffy growth function (VBGF) were estimated to be L_∞= 44.10 mm and K= 0.76 year^{-1}. The growth performance index ($Ø'$) and the longevity (t_{max}) derived from VBGF parameters were 3.17 and 3.95 years, respectively. Growth pattern showed negative allometric growth (b = 2.69). Estimated natural mortality rate (M) was 1.071 year^{-1}, whereas average mortality (Z) was 1.082 year^{-1}. Mean abundance and biomass of the studied population were 14.45 ind. m^{-2} and 92.95 g *SFWM* m^{-2} (shell-free wet mass), respectively. Individual production was maximal for 0.66 g *SFWM* at 28 mm shell length. Annual production of the population was 96.66 g SFWM m^{-2}year^{-1}. The annual $P/\overline{B}$ ratio was estimated to be 1.04 year^{-1}. The findings of this study will facilitate adequate stock management during potential commercial exploitation of the wedge clam.

Keywords: *Donax trunculus*, Population dynamics, growth, mortality, production, Marmara Sea.

Batı Marmara Kum Şırlanının *Donax trunculus* (Bivalvia, Donacidae) Populasyon Yapısı, Büyüme ve Üretimi

Özet

Marmara Denizi'nin batısında yüksek yoğunluklu kumsal alanlarda (0,5–2 m), mayıs 2011–nisan 2012 yılları arasında *Donax trunculus*'un populasyon yapısı, büyüme, ölüm ve üretimi araştırılmıştır. Von Bertalanffy büyüme parametreleri boy–frekans dağılımları kullanılarak hesaplanmış, L_∞= 44,10 mm ve K= 0,76 yıl^{-1} olarak tahmin edilmiştir. Büyüme performansı indeksi (Ø') ve maksimum yaşam süresi (t_{max}) sırasıyla, 3,17 ve 3,95 yıl olarak belirlenmiştir. Büyümenin negatif allometrik (b = 2,69) olduğu tespit edilmiştir. Doğal ölüm oranı (M) 1,071, ortalama ölüm oranı (Z) 1,082 olarak tahmin edilmiştir. Populasyonun ortalama bolluk ve biyoması ise sırasıyla, 14.45 ind. m^{-2} ve 92,95 g *SFWM* m^{-2} olarak belirlenmiştir. Maksimal bireysel üretim 28 mm kabuk boyunda 0.66 g *SFWM*, populasyonun yıllık üretimi ise 96,66 g *SFWM* m^{-2}yıl^{-1}olarak tespit edilmiştir. Yıllık $P/\overline{B}$ oranı 1,04 yıl^{-1} olarak tahmin edilmiştir. Bu çalışmanın sonuçları, stokun potansiyel ticari kullanımı sırasında stok yönetimi açısından kolaylık sağlayacaktır.

Anahtar Kelimeler: *Donax trunculus*, populasyon dinamiği, büyüme, ölüm, üretim, Marmara Denizi

Introduction

Donax trunculus (Linnaeus, 1758), the "wedge clam", is an Atlantic–Mediterranean species distributed from Senegal to the Atlantic coast of France (Tebble, 1966), the Black Sea, the Mediterranean (Bayed and Guillou, 1985) and also in the Marmara Sea (Deval, 2009). This species can inhabit highly energetic environments on sandy beaches, where it is exposed to the tidal rhythm, intense wave action and sediment instability (Ansell *et al*., 1983; Brown and McLachlan, 1990; Gaspar *et al*., 2002a). In such environments, *Donax trunculus* populations are capable of reaching very high densities (Gaspar *et al*., 1999) and it occurs primarily in the intertidal zone (0–6 m) distributed by size or age (Gaspar *et al*., 2002a; Mazé and Laborda, 1988; Sales and Casonova, 1987).

Most of the studies on *D. trunculus* have been carried out in Italy, Portugal and France, particularly focusing on the Mediterranean Sea and North Atlantic populations. In Turkey, population structure and distribution, growth, reproduction of this species in several locations of the Marmara Sea were studied (Deval, 2009; Çolakoğlu and Tokaç, 2011). Additionally, there are a many studies on population dynamics of *D. trunculus* in different regions of the world. These include studies on the ecophysiology (Degiovanni and Mouëza, 1972; Mouëza, 1972; Ansell and Lagardere, 1980; Guillou and Bayed, 1991), reproductive cycle and population dynamic (Guillou, 1982; Mazé and Laborda, 1988; Mazé, 1990; Tirado and Salas, 1998) of *D. trunculus*. Otherwise, studies on the burrowing behavior of different species of *Donax* have been undertaken by Ansell and Trevallion (1969), Trueman (1971), Mouëza (1972), McLachlan and Young (1982), Donn and Els (1990), Ansell *et al*. (1998) and Huz *et al*. (2002). This paper deals with different aspects of population structure (growth, mortality) with production and biomass of a population of *D. trunculus* on the west coast of the Marmara Sea.

At present, there are no artisanal fisheries for *D. trunculus* along the Marmara Sea coastal waters. Therefore, this study was to determine the relationship of productivity indices to the biomass and population density of *D. trunculus* and whether it will generate adequate stock during future commercial fisheries.

Materials and Methods

Study Site and Sampling Methods

Sampling of *D. trunculus* was carried out with monthly intervals between May 2011 and April 2012 at situated in the west coast of the Marmara Sea (Misakça, Turkey) (40º19'37"N-027º37'17"E) (Figure 1). Samples were collected from infra littoral zone between 0.5 and 2 m depth contour. The tows were performed parallel to the shoreline and during low tide, with a duration of 5 minutes by hand dredge. The specifications of the hand dredge used to obtain samples are given in Table 1. In order to estimate the swept area for hand dredge, the towing distance was recorded with a DGPS. The total swept area was 143.35 m^2 in 12 surveys (Table 2).

The samples were sorted and all individuals were identified to the species level with the uttermost precision and the respective weights recorded in the laboratory. Annual seawater temperature, according to the data collected during the study varies between 8.8 °C in winter (February) and 24 °C in summer (July)

Data Analysis

The anterior-posterior length (*L*) and shell height (*H*) of each individual *D. trunculus* was measured to the nearest 0.01 mm using a digital caliper. Size–frequency distributions (1 mm intervals) were recorded for each month. For each of the individuals collected total mass (TM), shell mass (SM) and shell-free wet mass (SFWM) (precision±0.01 g) were determined.

Parameters of the relationships between length and mass of *D. trunculus* were estimated by regression analysis; $M= a\ L^b$, where M is the mass, *a* is the intercept and *b* is the slope. The coefficient of determination (r^2) was used as an indicator of the quality of linear regression (Scherrer 1984).

Growth

The von Bertalanffy growth function (Sparre and Venema, 1992) was used to find the lengths of *D. trunculus* at various ages. The von Bertalanffy growth

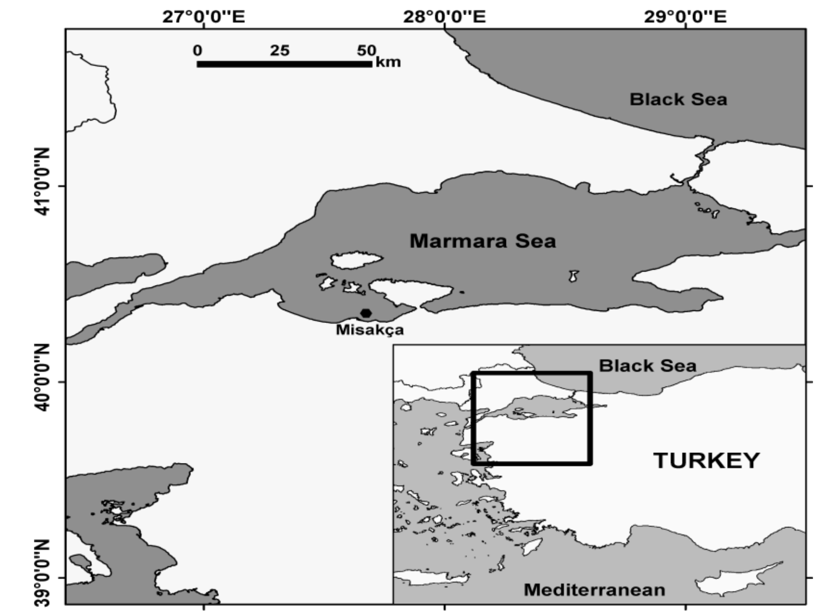

Figure 1. Sampling location (Misakça (40º19'37" N-027º37'17" E)).

Table 1. Specifications of the *Donax trunculus* hand dredge

Gear specifications	Size (cm)
Dredge Mouth:	
Width	65
Height	13
The Sieve:	
mesh size	0.8
Length	58
Other Dredge Features	
cutting edge	5
towing arm	135
rear width	35
Net Bag:	
net length	150
stretched mesh size	0.6

Table 2. Total catch, swept area and dredge hauls number in sampling location.

Year	Month	Depth (m)	Swept area (m^2)	Total Catch (g)
2011	May	0.5 – 1.5	12.38	15525.83
	June	1 – 2	11.37	5518.17
	July	1 – 1.5	12.75	1441.31
	August	1.5 – 2	10.13	1492.10
	September	0.5 – 1	10.50	4145.02
	October	1 – 2	12.52	12678.20
	November	1 – 2	11.35	11697.66
	December	0.5 – 1.5	11.63	10510.5
2012	January	0.5 – 1	13.40	1596.58
	February	1 – 1.5	11.38	1229.05
	March	1 – 1.5	13.41	1848.80
	April	1.5 – 2	12.53	10358.7
Total		0.5 – 2	143.35	78041.92

function was fitted to a growth-curve estimate using non-linear square estimation procedures. The von Bertalanffy growth function is defined by the equation:

$$L_t = L_\infty (1-e^{-K(t-to)})$$

where, L_t is total length at age t (mm), L_∞ is the asymptotic total length (mm) to which *D. trunculus* grows, K is the growth curvature parameter (year^{-1}), t_0 is the theoretical age at which the length is zero (year).

In order to compare different estimations of growth parameters, the empirical equation of growth performance, $Ø' = \log_{10} K + 2 \log_{10} L_\infty$, of Pauly and Munro (1984) was used. In addition, the reliability of these growth parameters made t-test analysis by Munro phi index ($Ø'$). Analyses of the length data were fitted to monthly length frequency distributions grouped into 1 mm total length size classes using the ELEFAN procedure in the computer program FISAT II (Gayanilo *et al*. 1995).

Mortality and Longevity

The natural mortality rate (M) was estimated using the method of Alverson and Carney (1975): $M = 3K / (e^{tmax*0.38*K} - 1)$. Commercial fishing does not take place in the study area and thus, the total mortality rate (Z) would be equal to M, as the rate of fishing mortality $F = 0$. The life-history model of Hoenig (1983) was also used to estimate the total mortality (Z): $\ln(Z) = 1.44 - 0.984 \ln(t_{max})$.

Longevity (t_{max}) was calculated as:

$$t_{max} \approx 3/K$$ (Pauly, 1980).

Biomass and Production

Total annual somatic production P was calculated for *D. trunculus* by the mass specific growth rate method (Crisp, 1984; Brey, 2001) from the size–mass relation, the size–frequency distribution obtained from all pooled samples and the von Bertalanffy growth function:

$$P = \sum N_i M_i G_i \text{ (g } SFWM \text{ m}^{-2} \text{ year}^{-1})$$

N_i and M_i are the average number of animals (N m^2) and mean individual *SFWM* in length class *i*, respectively, and G_i is the mass-specific growth rate:

$$G_i = bK((L_\infty / L_i) - 1)$$

where b is the exponent of the size–mass relation, K, L_∞ are parameters of the von Bertalanffy growth function and L_i is the mean size in class i.

Mean annual biomass $\overline{B}$ was computed by:

$$\overline{B} = \sum N_i M_i \text{ (g } SFWM \text{ m}^{-2}\text{)}$$

The annual P/ $\overline{B}$ ratio (productivity) of the *Donax trunculus* population was calculated from annual somatic total production P and annual mean biomass $\overline{B}$.

Results

Catch Composition and Size–Mass relationship

A total of 12 surveys (hand dredge tow) were conducted throughout the sampling period. It appears that a highest value 28502.11 g in autumn and the lowest 8451.58 g in summer, with total catch 78041.92 g (Table 3). Nine different bivalve species were captured during sampling. The following bivalve species were collected throughout this period; *Donax trunculus*, *Chamelea gallina*, *Donax variabilis*, *Tapes phillippinarum*, *Tapes decussatus*, *Venus verrucosa*, *Spisula subtruncata*, *Cardium edule* and *Mytilus galloprovincialis*. The catch composition comprised target species (*D. trunculus*) 69.34%, by-catch bivalve species 25.71%, and predator species 4.95% (Table 3). *C. gallina* was the most abundant by-catch bivalve species, representing 27.77% of the total catch.

Linear regression demonstrated significant relationships for H ($P < 0.05$), TM ($P < 0.05$), SM, and $SFWM$ with L (Table 4 and Figure 2). The slope (b=2.6855) of the regression indicated a negative allometric growth pattern. The observed relationship between length and $SFWM$ of *Donax trunculus* was used for production estimates.

Growth, Mortality and Longevity

The monthly length–frequency distributions of *D. trunculus* between May 2011 and April 2012 are shown in Figure 3. The shell length of individuals ranged from 10 to 42 mm (N= 2558). The smallest wedge clam (=10 mm) appeared in the population in March, April and June. Only 0.25% of the *D. trunculus* were larger than 40 mm. The length–frequency distributions of *D. trunculus* show that the young of the year appear in the population at the beginning of spring (March) and continue to appear during the summer (Figure 3).

Asymptotic length (L_∞) of *D. trunculus* was 44.10 mm; the growth coefficient (K) was 0.76 year^{-1}. The computed growth curve using these parameters is shown over the restructured length distribution in Figure 4.

The observed extreme length was 42 mm and the predicted extreme length was 43.35 mm (Figure 5). The range at 95% confidence interval was 41.48–45.23 mm. The growth performance index ($Ø'$) and the longevity (t_{max}) derived from VBGF parameters estimated for *D. trunculus* were 3.17 and 3.95 years, respectively.

Estimated natural mortality rate (M) was 1.071 year^{-1}, whereas total mortality (Z) was 1.092 year^{-1}. The two mortality rates were averaged for further

Table 3. The seasonal catch compositions (in number and weight) for the hand dredge (5 min tow)

Catch composition	Winter		Spring		Summer		Autumn		Total	
	TN	TW (g)	TN	TW (g)	TN	TW (g)	TN	TW (g)	W (g)	%
Bivalvia										
Target species (*Donax trunculus)*		9295.76		16630.69		5830,69		22357.72	54114.86	69.34
Chamelea gallina		3170.17		8714.68		2328.73	28	5116.61	19330.19	24.77
Donax variabilis	13	12.65	4	2.53	-	-	3	19.88	35.06	0.05
Tapes phillippinarum	7	136.94	2	10.95	-	-	-	58.14	206.03	0.26
Tapes decussatus	-	-	1	6.82	-	-	1	-	6.82	0.01
Venus verrucosa	-	-	-	-	-	-	77	21.23	21.23	0.03
Spisula subtruncata	14	15.21	32	33.16	7	10.45	1	90.01	148.83	0.19
Cardium edule	10	172.39	2	50.89	-	-	-	20.98	244.26	0.31
Mytilus galloprovicialis	2	46.41	4	15.3	1	5.04	110	-	66.75	0.09
Total	46	12849.53	45	25465.02	8	8174.91		27684.57	74174.03	95.05
Muricidae							1			
Rapana thomasiana	-	-	-	-	-	-	-	167.41	167.41	0.22
Murex trunculus	1	31.02	-	-	-	-		-	31.02	0.04
Crustacea										
Liocarcinus depurator	19	146.55	16	142.89	2	19.21	17	104.54	413.19	0.53
Cerithioidae										
Gaurmya vulgata	162	217.41	1254	1861.01	147	189.78	274	391.58	2659.78	3.41
Bittium reticulatum	2	0.68	7	21.19	-	-	-	-	21.87	0.03
Astropectinidae										
Astropecten spinulosus	1	1.69	4	48.69	1	5.67	-	-	56.05	0.07
Nassariidae										
Cyclope nerita	76	74.12	154	228.43	62	62.01	158	154.01	518.57	0.65
Total	261	471.47	1435	2302.21	212	276.67	450	817.54	3867.89	4.95
TOTAL	307	13321	1480	27767.23	220	8451.58	560	28502.11	78041.92	100

TN: Total Number, TW: Total Weight, W: Weight

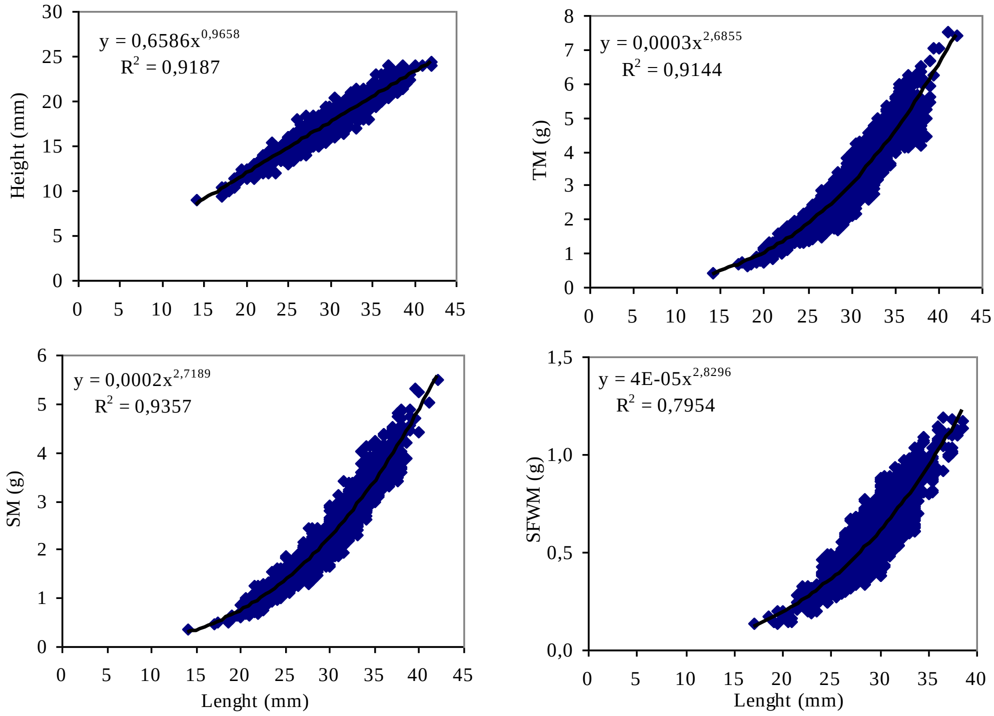

Figure 2. Relationships of *H*, *TM*, *SM*, and *SFWM* with *L* of *D. trunculus*.

computations to an average mortality value of 1.082 year^{-1}.

Biomass and Production

Individual somatic production of total soft tissues peaked with 0.66 g SFWM ind.$^{-1}$year^{-1} at 28 mm shell length, whereas SM production reached a maximum of 2.19 g SM ind.$^{-1}$year^{-1} at 27 mm shell length. Mean abundance of the studied population were 14.45 ind.m^{-2}. Annual biomass $\overline{B}$ was 92.95 g *SFWM* m^{-2}. Annual production *P* was 96.66 g SFWM m^{2} year^{1}, and annual $P/\overline{B}$ ratio was 1.04 year^{1}. Individuals between 22 and 32 mm shell length contributed most to somatic production of the population of *D. trunculus* (Figure 6).

The SFDM for comparison with *D. trunculus* species from different geographical regions was converted into ash free dry mass (AFDM*)* using the conversion factors of 0.166 taken from Brey, 2001. Annual production P and biomass $\overline{B}$ amounted to 16.05 g AFDM m^{2} year^{1} and 15.43 g AFDM m^{-2}, respectively.

Discussion

In the west of the Marmara Sea an unexploited population of *D. trunculus* was identified. The study area fauna were comprised of bivalves such as *Donax trunculus*, *Chamelea gallina*, *Donax variabilis*, *Tapes phillippinarum*, *Tapes decussatus* and *Spisula subtruncata;* gastropods like *Rapana thomasiana*, *Murex trunculus, Cyclope nerita* and *Gaurmya vulgata*; and crustaceans like *Liocarcinus depurator*. These species have been widely reported in coastal waters of the Mediterranean Sea (Dantart *et al*., 1990; Labourg and Desprez, 1997; Rueda *et al*., 2001).

In the present study, the maximum shell length of *D. trunculus* individuals was 42 mm. The investigations conducted into biometric parameters elsewhere reported a maximum shell length for *D. trunculus* of 45 mm in the Mediterranean Sea (Huz *et al*., 2002); 44 mm, 44.27 mm and 31 mm on the Atlantic coast (Gaspar *et al*., 2002b; 2003); 37 mm in the southern Adriatic Sea (Zeichen *et al*., 2002); 44.8 mm in the north (Deval, 2009) and 42 mm in the west of the Marmara Sea (Çolakoğlu and Tokaç, 2011).

The negative allometry observed for length (L) - total mass (TM) relationship is in agreement with the findings in the literature about the growth of *D. trunculus* in several different geographical areas. Negative allometries were found in the Mediterranean Sea (b=2.72; $2.709<b<3.247$; b=2.70 and b=2.80) (Ansell and Lagardère, 1980; Mazé and Laborda, 1990; Ramón, 1993; Gaspar *et al*., 2002b), in the Atlantic ($2.076\leq b\leq 2.972$; $2.698\leq b\leq 2.754$) (Bayed, 1990; Gaspar *et al*., 2002a) and in the Marmara Sea (b=2.90; 2.740) (Deval, 2009; Çolakoğlu and Tokaç, 2011). In the present study, this tendency had a value of b= 2.69.

The comparison with growth parameters obtained in other studies show differences in *D. trunculus* from different areas of the world (Table 5).

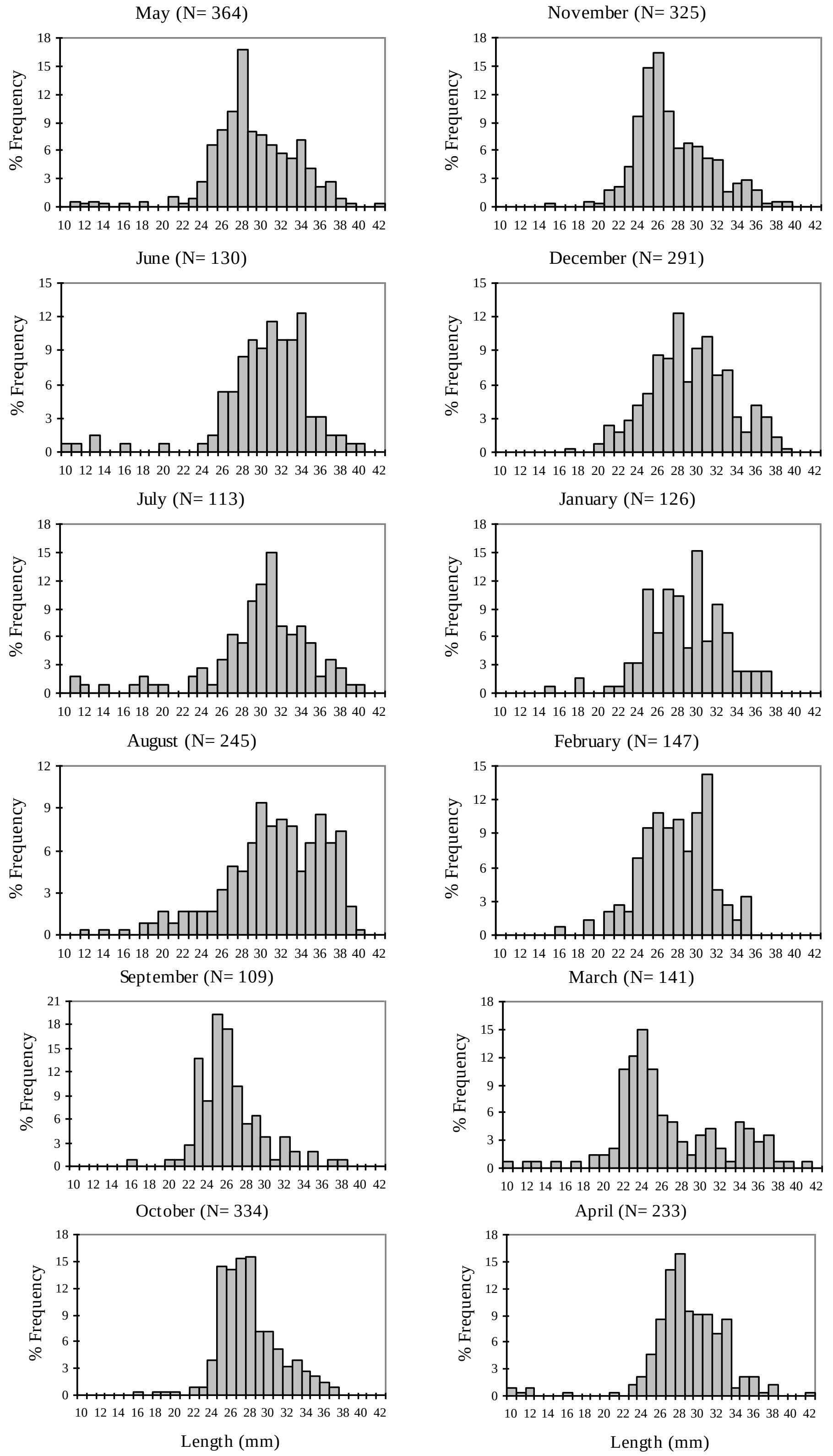

Figure 3. Monthly length–frequency distribution of *Donax trunculus* collected at Misakça (May 2011 to April 2012).

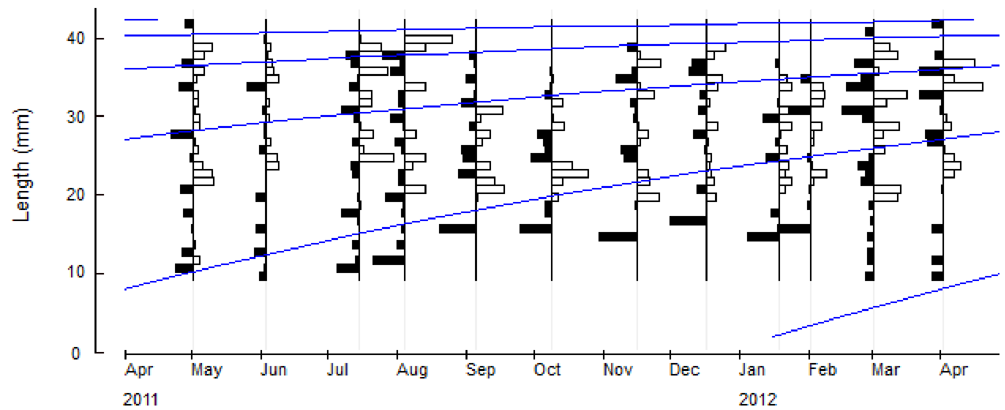

Figure 4. Restructured length frequency distribution with growth curves superimposed using ELEFAN I (L_∞= 44.10 mm, K= 0.76 year^{-1}).

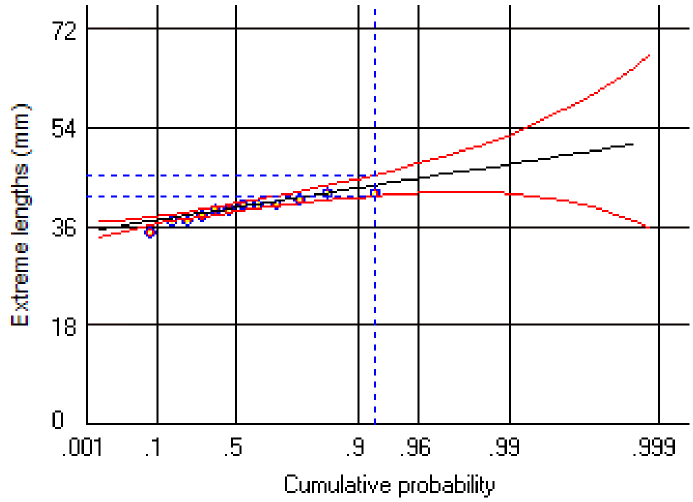

Figure 5. Estimation of maximum length of *D. trunculus*.

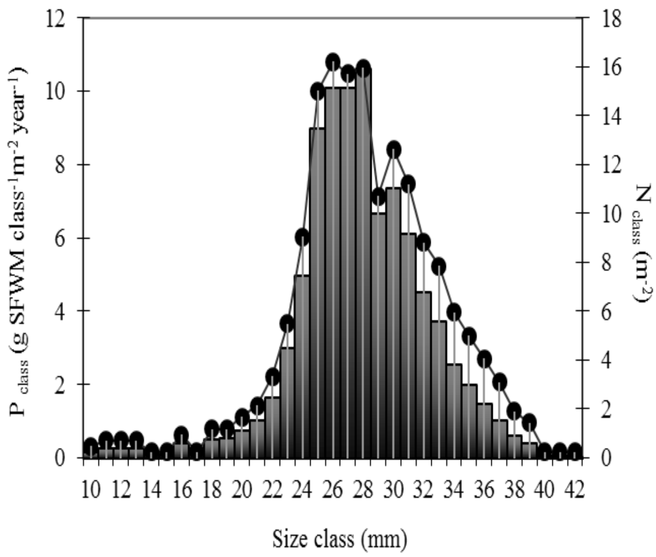

Figure 6. Length–frequency distribution and corresponding somatic production P_{class} distribution of *D. trunculus*.

The highest value of L_∞ (52.84 mm) is from the Atlantic coast (Mazè and Laborda, 1988) and the lowest value (35.9 mm) is in the Mediterranean Sea (Bodoy, 1982). In this study, the parameters of the von Bertalanffy growth function were estimated to be L_∞= 44.10 mm and K= 0.76 year^{-1}. The growth performance index (Ø') compares the growth performance of different populations of bivalve species. In this study, the growth performance index (Ø') of *D. trunculus* was 3.17, leading to the conclusion that growth is higher compared to the different areas in other studies (Table 5). In addition, between the growth performance obtained from other studies with the growth performance calculated was found to be no significant differences (P>0.05).

The estimated maximum age (t_{max}) for *D. trunculus* is 3.95 years, indicating that it is short-lived and also fast growth of species K values given in Table 4. The maximum age observed in other studies for this species was 5 years on the French coast (Guillou and Le Moal, 1980; Ansell and Lagardére, 1980), 3 years on the Spanish coast (Mazé and Laborda, 1988; Ramón *et al*., 1995; Voliani *et al*., 1997), 3 years on coast of Morocco (Bayed and Guillou, 1985), 4 years on the Italian coast (Zeichen *et al*., 2002) and 3 years on the coast of Israel (Neuberger-Cywiak *et al*., 1990). In Turkey, it was estimated at 4.35 years on the west coast (Çolakoğlu and Tokaç, 2011) and 6 years on the northern coast of the Marmara Sea (Deval, 2009). Regular growth of *D. trunculus* individuals depends mainly on various factors such as temperature, environmental conditions and population density (Neuberger-Cywiak *et al*., 1990; Zeichen *et al*., 2002).

The natural mortality rates (M) were estimated from two different methods. The two mortality rates were averaged for further computations to a mortality value of 1.082 year^{-1}. The average mortality in other studies was estimated to be 0.998 year^{-1} on the west coast (Çolakoğlu and Tokaç, 2011) and 0.98 year^{-1} on the northern coast of the Marmara Sea (Deval, 2009). Cardoso and Veloso (2003) reported that related with temperature of the life span increases and mortality decreases for *Donax* species.

Annual production P, biomass $\overline{B}$ and $P/\overline{B}$ ratio amounted to 16.05 g AFDM m^2 year^1, 15.43 g AFDM m^{-2} and 1.04 year^1, respectively. These values were similar (P = 18.98, $\overline{B}$ = 15.42) and lower (P = 39.99, $\overline{B}$ = 39.35) than those observed for this species on the coast Atlantic (Ansell and Lagardère, 1980). The $P/\overline{B}$ ratio values of *Donax* species indicates variety corresponding to *D. sordidus* (1.30–1.78) (McLachlan, 1979); *D. trunculus* (1.37–2.26) (Mazé, 1990) and (1.02–1.23) (Ansell and Lagardère, 1980); *D. variabilis* (7.64) (Wilson, 1999); *D. serra* (1.167-1.589) (Laudien *et al*., 2003); *D. hanleyanus* (1.45–1.59) (Cardoso and Veloso, 2003) and (0.75–2.18) (Herrmann *et al*., 2009).

Due to economic value and high export potential, *D. trunculus* is a valuable species for commercial exploitation. Therefore, with the opening of *D. trunculus* fishing for the Marmara Sea stock management will become important. This study carried out a baseline study of population dynamics with estimation of potential production and biomass in the area and it will facilitate adequate stock management during future fishing. This study will be the basis for future research.

Table 4. Morphometric relations of *Donax trunculus*

N	*Y*	*X*	*a*	*b*	r^2	Relationship (*t*-test)
2425	log (*H*)	log (*L*)	0.6586	0.9658	0.919*	- allometry
2376	log (*TM*)	log (*L*)	0.0003	2.6855	0.914*	- allometry
1973	log (*SM*)	log (*L*)	0.0002	2.7189	0.936	-
1241	log (*SFWM*)	log (*L*)	0.0004	2.8296	0.795	-

($Y= a+ b X$) (*) = P<0.05

Table 5. Parameters of VBGF of *D. trunculus* from different areas in the world

L_∞	*K*	t_0	Ø'	Location	Source
48.9	0.38	0.29	2.96	Atlantic	Guillou and Le Moal, 1980
43.48	0.77	-	3.08	Atlantic	Ansell and Lagardère, 1980
35.9	0.96	0.67	3.09	Mediterranean Sea	Bodoy, 1982
42.5	-	-	-	Atlantic	Bayed and Guillou, 1985
52.84	0.55	0.52	3.19	Atlantic	Mazè and Laborda, 1988
36.0	0.96	-	3.10	Atlantic	Vakily, 1992
41.8	0.71	0.35	3.09	Mediterranean Sea	Ramón *et al*., 1995
47.3	0.58	0.52	3.11	Atlantic	Gaspar *et al*. 1999
47.56	0.30	-	2.83	Mediterranean Sea	Zeichen *et al*., 2002
44.15	0.62	-0.52	3.08	Marmara Sea	Deval, 2009
42.44	0.75	-0.40	3.13	Marmara Sea	Deval, 2009
40.05	0.69	-0.80	3.04	Marmara Sea	Çolakoğlu and Tokaç, 2011
44.10	0.76	-	3.17	Marmara Sea	This study

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