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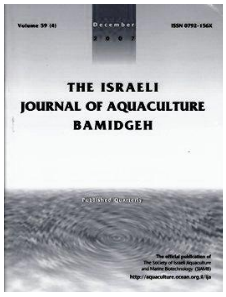

Growth and Survival of *Anadara inaequivalvis* (Bruguiere, 1789) in Sufa Lagoon, Izmir, Turkey

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Abstract

The growth and survival of 5, 7, 9, and 11-mm juvenile blood cockle (*Anadara inaequivalvis*) cultured in suspended nets in Sufa Lagoon, Izmir, Turkey, were investigated. Shell length, width, and thickness and total weight were measured monthly during May 2007-May 2008. Temperature was measured every 6 h. Salinity, chlorophyll *a*, particulate organic matter, particulate inorganic matter, and total particulate matter were followed every two weeks. Mean increases were 16.68 and 13.46 mm and 3.62 and 5.74 g for small and large spat, respectively. Length increased significantly faster in small cockle than in large cockle ($p<0.05$). Survival was 65% and 100% in small and large cockles, respectively ($p<0.05$). Von Bertalanffy growth parameters L_∞ (27 mm) and k (0.28/month) showed that growth performance ($\Phi' = 3.22$) was greater than for other species in the natural population. Slope b from the length-weight relationship was 3.098±0.115, indicating significantly better allometric growth ($p\leq0.05$). Results indicate that *A. inaequivalvis* is a good candidate for suspended aquaculture in the Sufa Lagoon, Turkey.

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Introduction

Anadara inaequivalvis, also known as the blood cockle or ark shell, is a bivalve belonging to the family Arcidae. Species in this family have a blood red color due to a high consistent level of hemoglobin in their bodies, allowing them to colonize in habitats with low oxygen concentrations (Kawamoto, 1928). *Anadara inaequivalvis* can attain a maximum length of 9.5.cm with a common length of 8 cm, typical to tropical regions (Fischer et al., 1987). It generally prefers places where plankton are abundant, near river mouths, and also a soft substratum where it can easily burrow. Its preferred substratum is generally clay and sand (Sahin et al., 2009). The spawning season for *A. inaequivalvis* on the southern Black Sea coast is from June to September. The minimum size for spawning is 20 mm (Sahin et al., 2006).

Anadara species have very high economic value in the Indo-Pacific Region (Malaysia, West India) and culture of blood cockles, primarily *Scapharca broughtonii* and *A. gronosa*, is an important commercial and export activity in China, Malaysia, Thailand, and Korea (FAO, 2004).

The growth and survival of bivalves are affected by environmental factors, especially water temperature and food quality. Because of tidal effects and the availability of food, lagoons are suitable for shellfish culture. Sufa Lagoon has large areas of salt wetlands where local fish (*Mugil cephalus, Liza ramada, L. saliens, L. aurata, Chleon labrosus, Dicentrarchus labrax, Sparus aurata, Solea vulgaris, Anguilla anguilla*) and shellfish (*Ostrea edulis, Ruditapes decussatus, Cerastoderma glaucum*) are natural populations. Blood cockle culture in Turkey is a potentially renewable resource and alternative source of employment. The study of their growth rates in Sufa Lagoon will help to develop *Anadara* culture techniques.

Material and Methods

Study area. The experiment was conducted in Sufa Lagoon in Izmir Bay, Turkey, from May 2007 to May 2008. The costal lagoon (38º31′30″ N, 026º50′50″ E) is 7.4 × 3 km. Long-line culture systems for blood cockle were set up on the surface of a canal (1.5 m maximum depth) between the lagoon and the sea (Karayücel et al., 2002, 2003). Water temperature was monitored with a temperature recorder (Star-Oddi) at 6-h intervals. Salinity was measured with a light refractometer (±1‰). Chlorophyll *a*, particulate organic matter, particulate inorganic matter, and total particulate matter were determined according to the methods of Strickland and Parson (1972). Except for temperature, measurements for determining environmental factors were taken from the surface water every two weeks.

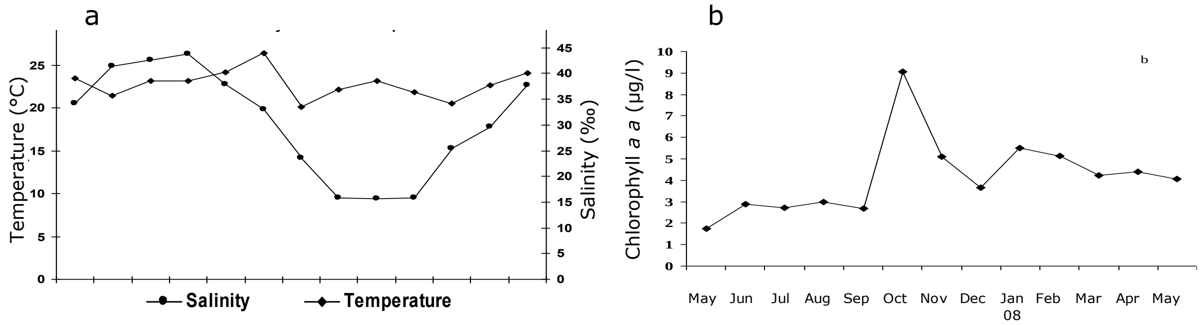
Growth and survival. Blood cockle spat were gathered from pearl oyster collectors at Karantina Island in the middle of Izmir Bay, Aegean Sea (38º22′44″ N, 26º47′12″E). The cockles were separated from the collectors by hand and transported to the laboratory to form four length groups of 150 individuals, divided into triplicates of 50 cockles, each. Initial anterior-posterior lengths were 5.6±1.8, 7.79±0.45, 9.76±1.23 mm, and 11.43±0.65 mm. Groups were put into cylinder-conic plastic mesh bags and the bags were placed in Sufa Lagoon two days after collection. The bags were renewed at each sampling, and fouling organisms were removed from the blood cockles with a knife. The length, width, thickness, and total weight of each cockle were measured. Shell length (anterior-posterior) and width (dorsal-ventral) were measured with a composing stick and total weight with an electronic balance after being dried on blotting paper.

The cockles were sampled monthly to estimate growth. Specific growth rates (SGR) for length and weight were calculated as per Grecian et al. (2000): SGR = 100(ln final length - ln length at a specific time)/specific time. Growth parameters were fitted to age-length data in the von Bertalanffy (1938) equation as follows: $L_t = L_\infty (1- e^{(-k(t - to)})$, where L_∞ is the asymptotic length (mm), *k* is the growth constant, t is the age, and t_0 is the age at zero length. Each monthly sampling was evaluated as 1/12 years. In the first year of growth, the estimated coefficient *k* value was annual while L_∞ should be regarded as the length reached in the first year. The index used to measure growth performance, phi prime (Φ′), was defined as log(*k*) + 2log(L_∞) as in Munro and Pauly (1983) and Pauly and Munro (1984). Living and dead individuals were counted to determine mortality (%) as 100(No - Nt)/No, where No is the number of blood cockles at the beginning of the experiment and Nt is the number of live blood cockles at time t (Lok et al., 2006).

Data analysis. Differences between size groups in shell length and weight increments were analyzed for each sampling time by one-way ANOVA. Mortality at the end of the study was tested by chi square. The relationship between shell length (L) and total live weight (W) was tested using regression analysis and Student's *t* test (Zar, 1984). Parameters a (intercept) and b (slope) of the L/W relationships were estimated by the nonlinear: $W = aL^b$. Depending on the value of the exponent, the relationships were classified as allometric ($b \neq 3$) or isometric ($b = 3$). The b value was tested by *t* test at the 0.05 significance level to verify that it significantly differed from isometric growth. Single regression analysis was used to investigate the relationship between growth rate and temperature, chlorophyll *a*, and total particulate matter. Statistic analyses were performed with Excel (2003) and SPSS version 13.0 for Windows.

Results

Temperature generally increased from May to August 2007, reached a maximum of 31°C, then decreased until February (Fig. 1). Salinity ranged 43.8‰ (October) to 33.4‰ (November). Chlorophyll *a* was low in May 2007 (1.7 µg/l) and reached a maximum in October 2008 (9.0 µg/l). Particulate organic matter corresponded with the seasonal variation in particulate inorganic matter, while total particulate matter was highest in September 2007 (50 mg/l) and lowest in March 2008 (7.49 mg/l).



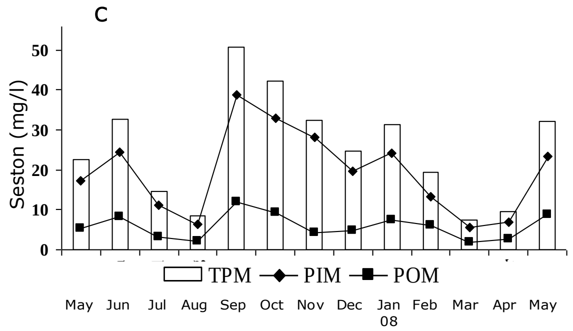


Fig. 1. Fluctuation in (a) temperature and salinity, (b) chlorophyll *a*, and (c) particulate organic matter (POM), particulate inorganic matter value (PIM), and total particulate matter (TPM) between May 2007 and May 2008 in Sufa Lagoon, Turkey.

The cockles grew continuously throughout the experiment although seasonal growth varied (Fig. 2). At the end of twelve months of rearing, mean shell width in the smallest size group (5 mm) reached 15.4 mm, in the next group (7 mm) 17.78 mm, the next group (9 mm) 19.2 mm, and the largest group (11 mm) 18.24 mm. Initial shell thicknesses were 2.3, 3.37, 4.45, and 5.24 mm for the four groups while final shell thicknesses were 11.03, 13.08, 16.05, and 14.5 mm, respectively, and final weights were 3.62, 4.75, 6.87, and 5.74 g. Length and weight growths significantly differed between groups.

The highest specific growth rates (57%-153%) in all size groups occurred during May-June 2007 (Fig. 3). The growth rates correlated with temperature and chlorophyll *a*, but not with total particulate matter. The allometric growth relationship between total

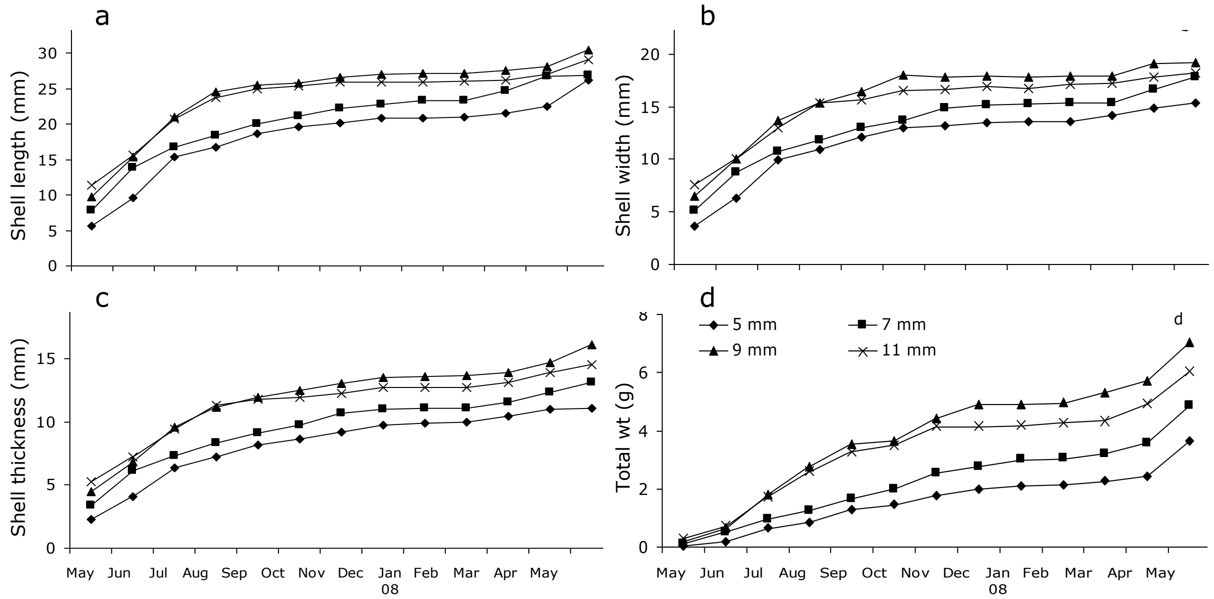


Fig. 2. Growth of *Anadara inaequivalvis* in terms of length (a), width (b), thickness (c) and total weight (d) during the study period.

weight (W) and length (L) was W = $0.1972L^{3.0948}$ (R^2 = 0.96) while the slope b and condition factor were 3.098 and 0.115, respectively (Fig. 4). Positive allometric growth according to linear regression significantly differed. The von Bertalanffy model generated the following results (L in mm; *t* in years): L = 29.65(1 - $e^{-1.19(t\ +\ 0.30)}$), and provided estimates of asymptotic length (L_∞ = 29.65 mm), while k = 1.19/year (Fig. 5). The growth index, pi prime (Φ′), was 2.34. The highest mortalities were 5% in May 2008 for 5 mm, 3% in January 2007 for 7 mm, and 8% in April 2008 for 9 mm (Fig. 6). Final mean survival was 65%, 71%, 84%, and 100% for the 5 mm, 7 mm, 9 mm, and 11 mm size groups, respectively.

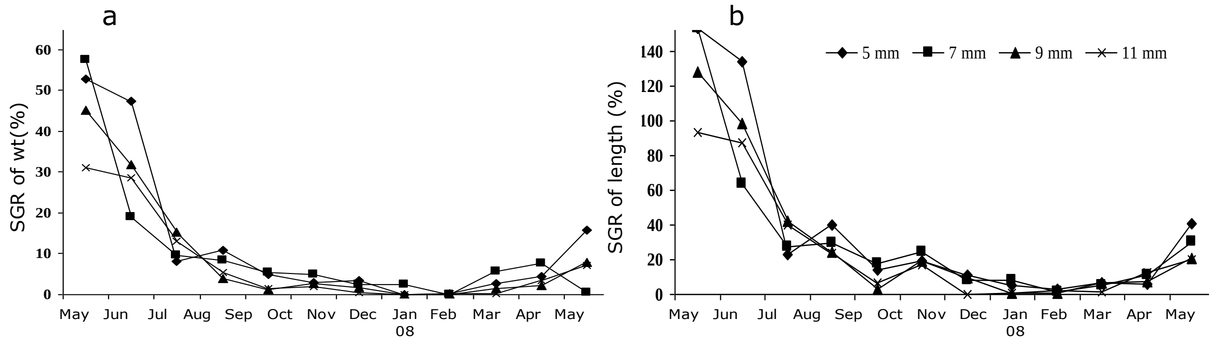


Fig. 3. Monthly specific growth rates (SGR) of shell (a) weight and (b) length.

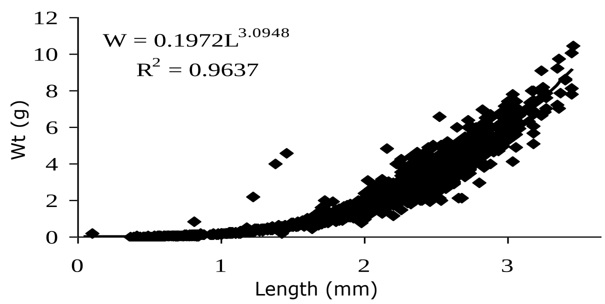


Fig. 4. Relationship between shell length (L) and total weight (W) in blood cockle raised in Sufa Lagoon, Turkey.

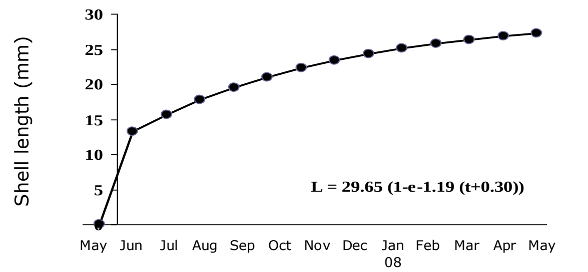


Fig. 5. Von Bertalanffy growth curve of *Anadara inaequivalvis*.

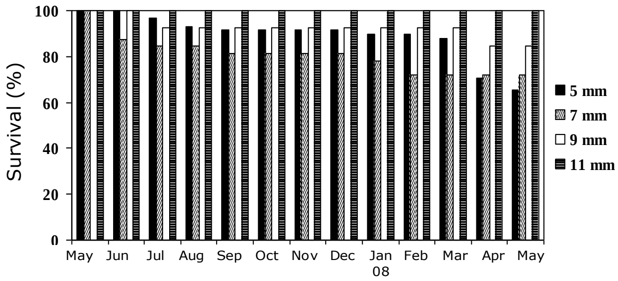


Fig. 6. Monthly survival rates of *Anadara inaequivalvis* of different size groups.

Discussion

Growth in bivalves is influenced by many factors, including temperature, food intake, current action, salinity, food availability, water flow, and reproductive state. Temperature has an important influence on the physiological and biochemical attributes of bivalves (Newell and Branch, 1980). This influence, in relation to food availability (Toro et al., 1999) influences tolerance to high (Ansell et al., 1991; Wilson and Elkaim, 1991) and low (Beukema, 1979; Dekker and Beukema, 1993) temperatures. Sufa Lagoon water has considerably high chlorophyll *a* and total particulate matter in comparison to other bivalve culture areas in Turkey where bivalve food resources have been examined. Chlorophyll *a* and total particulate matter were 3.88 µg/l and 13.12 mg/l, respectively, in Mersin Bay, Aegean Sea (Lok et al., 2006). In our study, the growth rate of shell length correlated positively with temperature and chlorophyll *a* ($p<0.05$). Similarly, growth of blood ark (*A. ovalis*) is minimal in winter and rapid in spring and summer (Walker, 1998).

Blood cockle reached 26.28-30.48 mm in this study, i.e., 1.21 mm/month during one year. This rate is slow when compared to small *A. ovalis* cultured in suspended subtidal pearl nets that grew from 7.5 mm to 38.46 mm in 12 months at a rate of 2.58 mm/month (Walker, 1998) or those that grew from 31.87 mm to 44.99 mm with a monthly average of 1.85 mm when cultured in mesh bags on soft bottom sediments (Power and Walker, 2001). Our growth rates significantly differed between groups, especially that of small spat (5 mm) that quickly adapted to study conditions. Growth is usually rapid during the first months and decreases with age, size, and environmental factors (King, 1977; Brown and Hardwick, 1988). Because of this, growth declined in later months and even stopped during winter.

Growth curves and von Bertalanffy parameters were used to compare growth between our cultured cockles and natural populations (Table 1). The k and Φ' values show that growth was faster in our study than in natural populations, indicating that our culture conditions are suitable for *A. inaequivalvis*. There are major differences in growth between populations both on a wide geographical scale and in relatively close locations (Ansell et al., 1991). Bags, suspended boxes, and bottom boxes are effective for growth and survival of cultured pearl oysters (Urban, 2000). In this study, positive allometric growth was obtained for the W/L relationship, in agreement with results for *Scapharca broughtonii* (Park and Oh, 2002) and *A. transversa* (*demiri*; Morello et al., 2004), but in contrast to isometric growth in *A. angulata* (Mzighani, 2005).

Table 1. Growth parameters and growth performance index (Φ') of *Anadara* species.

Species	*Location*	*k (year)*	*L_∞ (mm)*	*Φ'*	*Source*
A. inaequivalvis	Sufa Lagoon, Aegean Sea	1.9	29.65	3.22	This study
A. inaequivalvis	Black Sea	0.23	89.3	3.26	Sahin et al. (2009)
A. tuberculosa	Costa Rica	0.14	63.15	2.75	Stern-Pirlot and Wolff (2006)
A. ovalis	USA	0.45	57.5	3.17	McGraw et al. (2001)
A. gronosa	Philippines	1.84	36.9	3.39	Vakily (1992)

In the present study, the smallest size group (5 mm) had significantly lower survival (65%) than the other groups. Handling samples for monthly measurement affects the survival rate of mussels and oysters in small size classes (Cáceres-Martínez et al., 1995; Lök et al., 2007). *Anadara ovalis* kept in mesh bags on soft bottom sediments in Georgian coastal waters grew well with little mortality (35%) in a year of culture (Power and Walker, 2001), but survival of *A. ovalis* in pearl nets suspended from a floating dock was 57-62.3% (Walker, 1998), lower than the survival rate of *A. inaequivalvis* in Sufa Lagoon (65-100%).

In conclusion, this study shows that the survival rate of *A. inaequivalvis* cultured in suspended nets in Sufa Lagoon is relatively high, although growth is rather slow.

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