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Growth Performance of the Freshwater Mussel, *Unio terminalis delicates* (Lea, 1863) (Mollusca: Bivalvia: Unionidae) in the Gölbaşı Lake, Turkey

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Authors' Contribution
MAG conceived and designed the study and wrote the article. HS cultured mussels and executed all the experiment work.

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***Unio terminalis delicates*, cage culture, stocking density, growth performance, water quality parameters**

A B S T R A C T

In this study, the effects of four different stocking densities (20, 40, 60, 80 individuals/m^2) were investigated on growth performance of the *Unio terminalis delicates* in a natural lake (Lake Gölbaşı, Kırıkhan, Hatay, Turkey). Growth in live weight, shell length, width and height were measured monthly for the four different stock groups during 6 months. The highest growth rate was obtained from 40 ind./m^{2}group, while the best condition factor was acquired from the lowest density group (20 ind./m^2).The specific growth rate for length and weight were highest in June and July in all groups. On the other hand, plankton biodiversity, chlorophyll a, Mg, NO_2, NO_3, amount of organic matters, NH_3, PO_4, Si, Ca and chemical oxygen demand (COD) were determined as biological and chemical characteristics. At the end of the study, the greatest live weight (5.06±0.34 g) was obtained from 40 ind./m^2, with 3.34±0.05 cm, 1.36±0.03 cm and 1.91±0.04 cm as length, width and height values, respectively. Therefore, it could be advised that juveniles should be stocked in early spring for *U. terminalis delicates* at a level of 40 ind./m^2. This results suggest that stocking density is the key factor in mussels culture and important for captive breeding in mussels production.

INTRODUCTION

Freshwater mussels (Unionidae) are a diverse and conspicuous members of the benthic fauna in fresh waters (Haag and Staton, 2003; Haag, 2013). They play important role in freshwater ecosystem and are economically valuable for their shells (Strayer *et al*., 2004). The life cycle of unionids is quite different and remarkable (Barnhart, 2006; Şereflişan *et al*., 2013). In part because of this complex life cycle, mussels are now one of the most imperiled groups of organisms on Earth (Haag, 2013). The bivalve culture has a huge potential in aquaculture sector (McMahon, 1991; Parsons and Dadswell, 1992; Monteforte *et al*., 1994; Mueller and Patzner, 1996; Morris and Corkum, 1999). Bivalve culture systems are classified into spawning, larval breeding and intensive raising stages. Over the past decade, efforts to propagate and culture unionids have expanded. However, few studies have tested the effects of factors such as temperature, water quality, food type, or food availability on juvenile growth and survival (Barnhart, 2006).

Culture studies carried out on other unionids have shown differences in growth performances at different locations (Mueller and Patzner, 1996; Paterson and Nell, 1997). These differences were relatively related with environmental factors such as chlorophyll a, organic matter, pH and temperature (Morris and Corkum, 1999). Growth performance varies according to spat stage, planktonic population and density (Chatterji *et al*., 1984), and water flow rate (Doroudi ve Soutgate, 2000) in the culture area. Spat stage has major affect on the growth performance in culture (Chatterji *et al*., 1984), because juveniles show an exponential growth when compared to elder individuals (Stanczykowska and Levandowski, 1995). Furthermore, it is claimed that the substrate or depth structure doesn't have as much as effect on the growth and survival rates compared to other factors (Beaty and Neves, 1996; Monteforte and Garcia-Gasca, 1994; Monteforte *et al*., 1994; Monteforte and Morales-Muliay-Mulia, 2000; Taylor *et al*., 1998).

In contrast to marine species, freshwater mussels juvenile specimens of many species have bysal thread which is mostly lost in adults (Bogan, 2008). So, cage culture is globally accepted as an efficient method for freshwater mussels. Previous studies on *Crassostrea virginica* (Simmons *et al*., 1995), *Pinctada margaritifera* (Parsons and Dadswell, 1992), *Placopecten magellanicus* (Parsons and Dadswell, 1992; Southgate and Beer, 1997), *Mytilus edulis* (Karayücel and Karayücel, 2000a), *Pinctada mazatlanica* (Monteforte *et al*., 1994) and the golden freshwater mussel (*Limnoperna fortunei*)

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(Boltovskoy and Cataldo, 1999) and revealed that stocking density has a significant effect on the growth and survival rate.

The study was conducted in a natural lake which is located in Hatay province, Turkey. The dominant freshwater species of this lake, *Unio terminalis delicates,* has an economical value in southeastern Turkey (Şereflişan, 2014). However, there have been no studies on the environmental requirements, growth and survival rates in cages for *Unio terminalis delicates.* Moreover, there has been no effort to culture this species . Thus, in this study, the effect of different stocking densities in cage culture system on growth performance of *Unio terminalis delicates,* was investigated, to assess the potential to culture *U. terminalis delicates* as an alternative food source.

MATERIALS AND METHODS

Study site

The study was organized between June - November 2001 in Lake Gölbaşı, Kırıkhan, Hatay (36º 30′16″N; 36º 29′42″ E). The experiment was carried out in Lake Gölbaşı, Hatay, southern Turkey, between May 2001 and April 2002. Lake Gölbaşı is in the eastern Mediterranean region of Turkey, 50 km north of the city of Antakya. The lake is a natural lake with a surface area of 12 km^2 at altitude of 80 m (Fig. 1).

Biological materials

Juveniles mussel (1200 Nm) were collected with a scoop net and a hand dredge at a depth of 1–3 m in Lake Gölbaşı. The shell lenght was measuremened with digital caliper. The initial main shell measurements were 6.2±0.08 mm in length, 4.0±0.01 mm in height and 2.5±0.02 mm in width. The average initial weight of the juvenile mussels was 0.64±0.08 g. Juveniles were stocked in cylindrical cages of one cubic m volume (115 cm diameter and 25 cm height). Cages were covered with a metal net (2 cm mesh size), and a polyamide net with 6 mm mesh size covered the inside of the metal net. The experimental design was composed of four stocking density treatments with three replicates each. Four each treatement the stocking density was: A - 20 ind./m2, B - 40 ind./m^2, C - 60 ind./m^2, and D - 80 ind./m^2. The juvenile mussels were placed in 12 metal cages at approximately 2 m depth. Sampling and biometry Systematic sampling were conducted according to Hoggarth (1999). Shell length, width, height and live weight measurements were taken monthly for 12 months, while wet meat weight measurements were determined at the end of the study. Measurements were performed on of 20 mussels randomly sampled from each cage. The mantle cavity water of the sampled mussels was drained before weighing. The growth parameters were estimated from the changes in shell length (L), live weight (LW) and wet meat weight (WMW). Mortality was determined by counting the number of empty shells in each cage monthly.

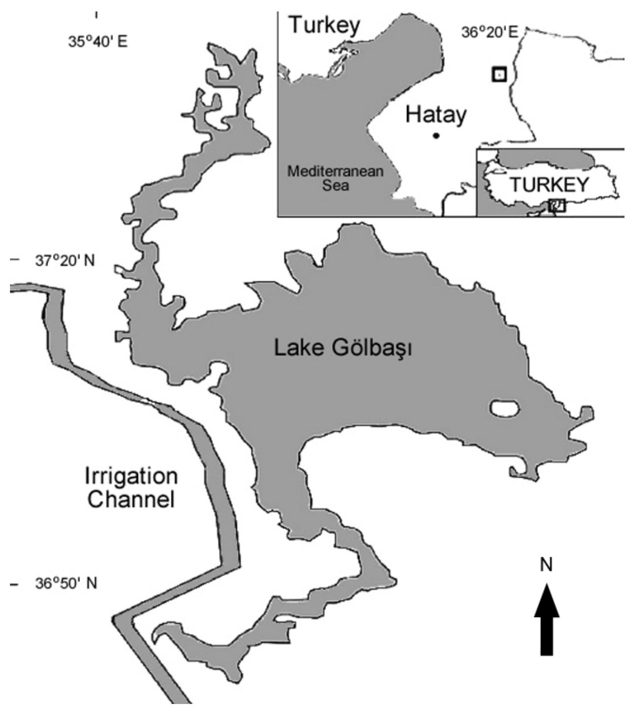

Fig. 1. Map of the Hatay city showing the study site, Gölbaşı Lake, Turkey.

Growth parameters

Growth parameters were determined from the changes in shell length (L), live weight (LW) and wet meat weight (WMW). Mortality was assessed monthly, by counting the number of empty shells in each cage.

Condition factor (Monteforte and Morales-Mulia, 2000) and the specific growth rate (Chatterji *et al*., 1984) were calculated by using the following equations.

$$\text{Condition factor} = (TWW/SV) \times 100$$

TWW, total wet weight; SV, shell volume

$$\text{Specific growth rate (\%)} = [(\ln L_2 - \ln L_1) / (T_2 - T_1)] \times 100$$

LnL2, ending shell length; LnL1, beginning shell length; T2-T1, the time interval.

Water quality parameters

Oxygen, temperature and pH were measured directly in the field with digital instruments. Oxygen and temperature were measured by a YSI model 52 oxygen meter and pH by an Orion model 420A pH meter. Nansen-type bottles were used for lake water sampling. Water samples (1 L) were taken to laboratories of Mustafa Kemal University for the analysis chlorophyll a (Ch a), particulate organic matter (POM), ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), calcium (Ca), magnesium (Mg), phosphate (PO_4) and silica (Si). For Ch a and POM analysis, water samples were passed through a 150 µm nylon mesh to remove large particles. The number of particles was determined with a Fluorometrik method (APHA, 1980). The EDTA (Gehrke *et al*., 1954) method was used to analyze Ca and Mg, whereas a spectrophotometer was employed to analyze NH_3, NO_2, NO_3, PO_4 and Si (APHA, 1971).

Statistical analysis

Analysis of variance (ANOVA) was employed to detect growth differences between the stocking groups with a significance level of 0.05. The results of variance analysis, the lowest standard error and regression coefficients were also evaluated to find the best regression model. Statistics contained in Zar (1999) was used to compare the regression equations of the models. The Excel tool Pack program (Microsoft Office Excel 2013) was used to determine the mean and standard errors for water quality parameters. All statistical analyses were carried out with the SPSS (Statistical Package for the Social Sciences) software.

RESULTS

Shell and tissue growth

The mean weight (W), length (L) and height (H) values of each mussel group are summarized in Figures 2, 3, and 4. All groups showed growth from June to August. The growth in length was highest in groups B (40 ind./m^2) and C (60 ind./m^2) (Fig. 2). On the other hand, there was no statistical difference on final growth performance between groups B and C, and between groups A and D (p>0.05). Wet meat weight was highest in the stocking group B of 40 ind./m^2, and wet meat yields of 20 ind./m^2 and 40 ind./m^2 were found to be higher than those of the stocking groups of 60 and 80 ind./m^2 (Fig. 4). A sharp decrease in growth rate was observed from the beginning of the study until August, followed by a more stable period until November (Figs. 2, 3). A negative growth was observed in winter months, followed by quick recovery in spring. The highest condition factor value was obtained from Group A with 13.84±0.69 and the lowest from Group C with 11.21±0.50. There were no statistical differences observed for all groups except Group A (P<0.05).

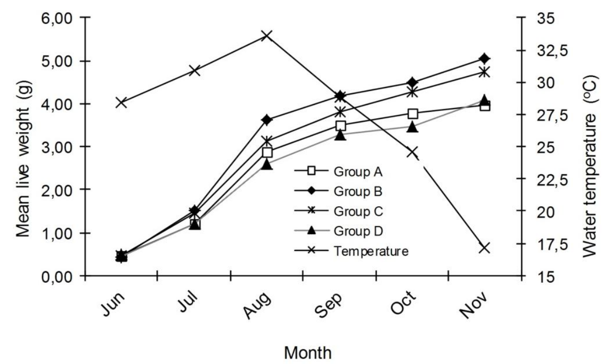

Fig. 2. Monthly comparison of average increase in mean live weight among groups from June to the and of November and relation of growth with temperature. [Stock groups Group A (20 ind./m^2), Group B (40 ind./m^2), Group C (60 ind./m^2), Group D (80 ind./m^2)].

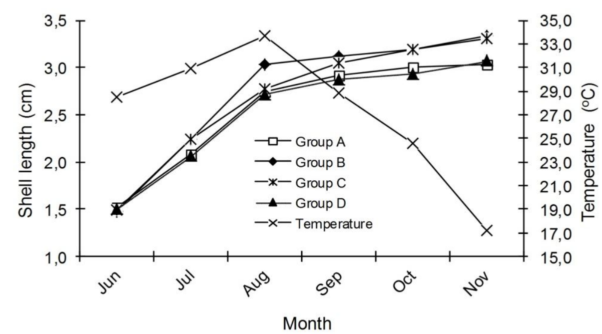

Fig. 3. Comparison of growth in shell length of mussels in relation to temperature on monthly basis (June-November). Stock groups [Group A (20 ind./m^2), Group B (40 ind./m^2), Group C (60 ind./m^2), Group D (80 ind./m^2)].

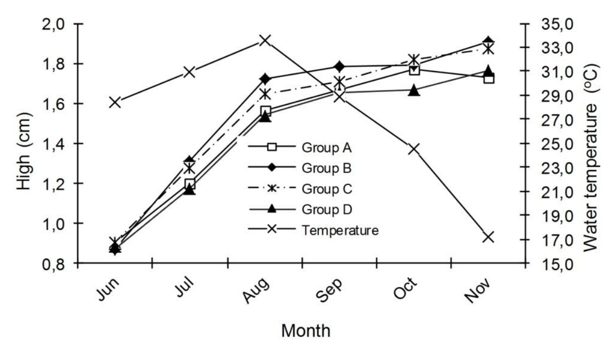

Fig. 4. Comparison of growth in shell high of mussels in relation to temperature on monthly basis (June-November). Stock groups [Group A (20 ind./m^2), Group B (40 ind./m^2), Group C (60 ind./m^2), Group D (80 ind./m^2)].

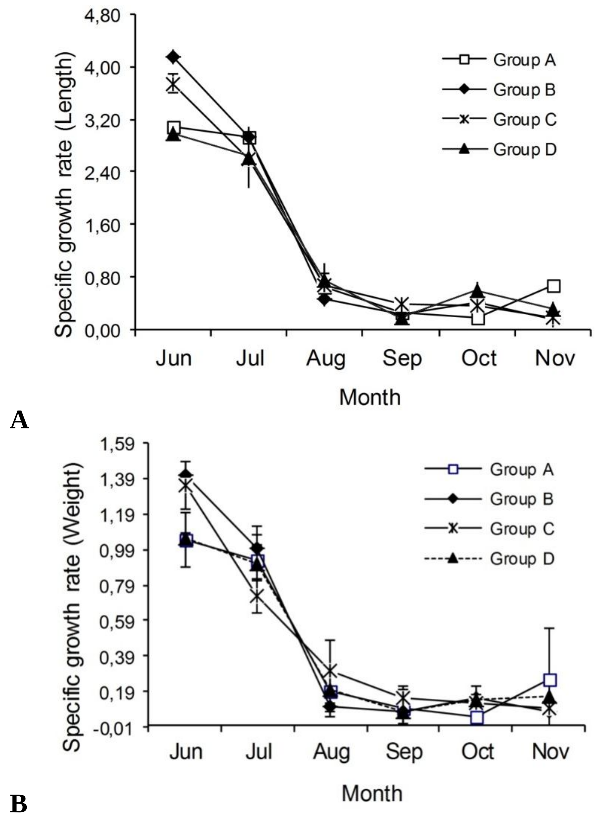

Fig.5. Comparison of SGR in length (a) and weight (b) on monthly basis.

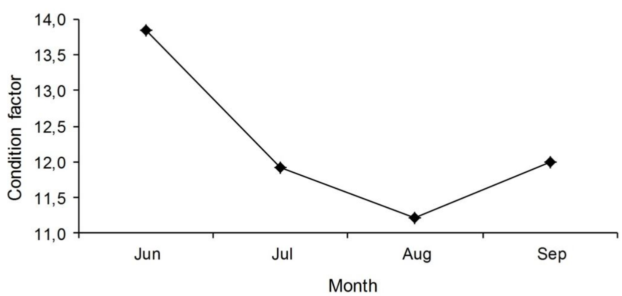

Fig. 6. Variation condition factor according to stock groups at the end of the experiment (November, 2002).

Environmental factors

The lake water temperature ranged from 10.59°C in January to 33.63°C in August. Annual range of oxygen concentration was 4.51 ppm (January) to 9.60 ppm (November). The changes in pH were nearly insignificant during the course of the study. Monthly contents of Ch a, POM, NH_3, NO_2, NO_3, Ca, Mg, PO_4 and Si are shown in Table I. Monthly contents of Ch a, Ca, and Mg varied

Table I.- Water quality parameters measured for a duration of 6 months in the Lake Gölbaşı of Turkey (mg l^{-1}) (Mean ±SE); Ch, Chlorophyll a; Mg, magnesium; NO_2, nitrite; POM, particulate organic matters; NH_3, ammonia; NO_3, nitrate; PO_4, phosphate; Si, silica; Ca, calcium; COD, chemical oxygen demand.

Months	Ch a	Mg	NO_2	POM	NH_3	NO_3	PO_4	Si	Ca	COD
June	0,53± 0,01^{a}	2,85±0,04^{a}	0,020±0,00^{c}	3,83±0,06^{b}	0,43±0,01^{a}	1,20±0,00^{c}	0,03±0,01^{b}	4,45±0,00^{cd}	4,42±0,01^{b}	10,01±0,01
July	0,25± 0,02^{cd}	2,81±0,02^{a}	0,070±0,00^{a}	0,63±0,06^{d}	0,18±0,00^{b}	1,32±0,01^{b}	0,00±0,00^{cd}	3,83±0,00^{e}	4,58±0,01^{a}	10,00±0,00
August	0,22±0,01^{e}	2,54±0,02^{a}	0,003±0,00^{d}	1,04±0,01^{c}	0,11±0,01^{c}	1,14±0,00^{d}	0,07±0,01^{a}	11,09±0,02^{a}	4,17±0,02^{d}	9,43±0,17
September	0,24±0,01d	2,54±0,03^{b}	0,046± 0,00^{b}	4,56±0,03^{a}	0,11±0,01^{c}	1,40±0,00^{a}	0,01±0,00^{c}	2,95±0,01^{f}	4,34±0,03^{c}	8,42±0,16
October	0,27±0,01^{cb}	2,54±0,03^{b}	0,020±0,00^{c}	4,56±0,04^{a}	0,17±0,01^{b}	1,32±0,01^{b}	0,01±0,00^{c}	4,60±0,00^{bc}	4,06±0,04^{e}	6,07±0,06
November	0,29±0,01^{b}	2,54±0,05^{b}	0,026±0,00^{b}	4,56±0,01^{a}	0,19±0,00^{d}	1,31±0,03^{b}	0,05±0,01^{ba}	4,76±0,01^{b}	4,32± 0,04^{c}	5,03±0,04

Letters a, b, c, d, e, f and g show statistical differences in vertically ($P<0.05$).

significantly different (P<0.05). The highest Ch a (0.53±0.01 mg/L) and NO_3 (1.40±0.00 mg/L) levels were in May, and the highest NH_3 (0.43±0.00 mg/L) level was in June. POM (4.56±0.03 mg/L) and NO_2 (0.070±0.00 mg/L) were highest in September, and the highest PO_4 (0.07±0.00) and S (9.47±0.01) levels were in August. Mg content was highest in June with the value 2.85±0.04, and Ca was highest in July with 4.58±0.01.

DISCUSSION

Stocking density is one of the most important factors affecting growth, yield and survival of cultured species. In general, by increasing stocking density, it will also increase competition for food and space. On the other hand, the effects of stock density on survival are not contentious. While Parsons and Dadswell (1992) reported no direct correlation between the two factors, Karayücel and Karayücel (2000a) claimed the opposite, detecting different survival rates from different stock densities. In the present study, growth characteristics of mussels were expected to be higher for the lower stocking densities compared to the higher densities due to less competition as in Mackie (1984). Our results, however, indicated that there was not an inverse relation between growth and stocking density. This mode of growth pattern may be related to such behavioral characteristics such as proper site selection, food search, and protection against predators. In this study, survival was not affected by stocking density.

It was determined that stocking densities had a significant effect on the live weight and shell length growth of *U. terminalis delicates* for the duration of 6 months (*P*<0.05). The best growth was achieved in group B (40 ind./m^2). Theoretically, individual growth rate of a given species declines with increasing intraspecific density (Beal and Kraus, 2002). However, in the present study, the highest growth did not occurred in the lowest stocking density (Group A).

In this study, the shell length increased from June to the end of August in all groups, however growth performance started to decrease slightly as the temperature drops in the beginning of September. On the other hand, it shell length growth of *U. terminalis delicates* was lower in the colder in the warmer months for all stocking groups. According to Boltovskoy and Cataldo (1999), the golden freshwater mussel (*Limnoperna fortunei*) also grew slower in colder than in warmer months (Boltovskoy and Cataldo, 1999). Also, it was reported that mussel shell growth of *Mytilus edulis* was low in winter (Richardson *et al*., 1980; Crosby and Dale, 1990). Condition factor is strongly related to temperature and stocking density (Shafee *et al*., 1998; Karayücel and Karayücel, 2000a). In this study, the highest condition factor was obtained during November in group A (20 ind./m^2).

Food availability and water quality are considered to be effective on growth during these months. In shallow lakes, the better growth performance has been reported throughout spring and mild winters, under high phytoplankton levels (Chatterji *et al*., 1984; Spencer and Ellis, 1990; MacIsaac, 1996).On the other hand, specific growth rate began to diminish with temperature increases during July and August. This suggests that growth of *U. terminalis delicates*, depends mainly on food availability hence, an increase in temperature is not a necessity for a higher growth rate.

Oxygen and pH values also have a biological effect on all living organisms (Morris and Corkum, 1999; Karayücel and Karayücel, 2000b). In our study, pH and oxygen values changed with temperature. Some Unionid species are able to live at a pH of 4.7 (the minimum level) and to reproduce and grow at pH values between 5.6–8.3 (McMahon, 1991). pH levels of our study are within the range of 7.78±0.04 to 8.02±0.01, which is in accordance with the intermediate levels for this taxa. Nitrate-nitrogen (NO_3-N) level (1.01–1.43 mg/L) was within the optimum range for living biomass in our study.The low nitrite-nitrogen (NO_2-N) value in our study indicated that the lake water has enough oxygen for nitrification. Organic matter concentration in lake water varied between 1.23–3.22 mg/L. This variation might be due to precipitation and runoff. The highest silica value in the lake was 9.47±0.01 in August. The silica level can be low during spring when algae population is the highest, and this level may also show differences depending on season, water flow and precipitation.

Despite the fact that mussel growth is strongly related to annual primary productivity, it is not as related to chlorophyll a concentration (Small and Van Stralen, 1990). In shallow lakes, increased phytoplankton and zooplankton levels do not mean that the season has a direct effect on the chlorophyll a level (Adrian *et al*., 1999). Our results, confirming to the earlier findings, showed that the mussel growth levels were highest in August, and chlorophyll a levels were highest in April and May. It doesn't necessarily mean that spring has direct effect on chlorophyll a just because phytoplankton and zooplankton rich to maximum concentrations in shallow lakes during spring time (McQuenn *et al*., 1986; Adrian *et al*., 1999). However, phosphate (PO_4) content is known to be a limiting factor on Chlorophyll a (Lauritsen, 1986; Spencer and Ellis, 1990; Shapiro, 1995).

In conclusion; the present study was the first attempt investigating optimum stock density for the culture of *U. terminalis delicates*. Since the highest live weight and shell height were obtained from the stocking groups of 40 ind./m^2, it could be advised to stock the juveniles of *U. terminalis delicates* at a level of 40 ind./m^2. Also, other unionids should be investigated as a cultivable alternative species.

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Statement of conflict of interest

Authors have declared no conflict of interest.

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