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The Effects of Salinity on Postlarval Growth and Survival of *Penaeus semisulcatus* (Decapoda: Penaeidae)

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Abstract: *P. semisulcatus* post-larvae (PLs) had higher survival and better growth at high rather than low salinities between PL20 and PL60. Final survivals at high salinities (30-40 ppt) (19-23%) were significantly higher than those (3-12%) below 25 ppt ($P<0.05$). Final total length (TL) at 10 ppt (17.12 mm) and 15 ppt (17.12 mm) was significantly lower than at 35 ppt (20.46 mm) or 40 ppt (19.62 mm) ($P < 0.05$). PLs grown at 10 and 15 ppt displayed growth rates between 0.053 and 0.068 mm day^{-1} as compared to 0.115 – 0.137 mm day^{-1} at higher salinities (35-40 ppt). Daily growth rates at salinities above 30 ppt (0.114-0.137 mm day^{-1}) were about 2-2.5-fold higher than those obtained at 10 ppt (0.053 mm day^{-1}). PLs grown at 10 and 15 ppt attained the lowest individual wet weight (0.020 – 0.037 g) while those at 35 and 40 ppt had the highest mean weight (0.050-0.051 g) at the end of the 40-day culture period ($P < 0.05$). The results showed that the mean weight obtained at 40 ppt was twice that at 10 ppt. PLs grown at 15, 20 and 25 ppt exhibited intermediate growth in weight ($P > 0.05$). A rise in salinity resulted in an increase in the biomass from 0.020 g at 10 ppt to 0.317 g at 40 ppt ($P < 0.05$). Optimum salinity for the nursery culture of *P. semisulcatus* PLs appeared to be about 40 ppt at 28 °C. Hence, the results of this study demonstrate that *P. semisulcatus* inhabiting the Mediterranean Sea is not a good candidate for culture in waters of low salinity.

Key Words: *Penaeus semisulcatus*, salinity, post-larvae, growth, survival

Tuzluluğun *Penaeus semisulcatus* (Decapoda: Penaeidae)'ta Postlarval Büyüme ve Yaşama Oranı Üzerine Etkileri

Özet: Yaşama ve büyüme oranları açısından, düşük tuzluluklarla kıyaslandığında, *P. semisulcatus* post-larvaları (PL), PL20 ve PL60 dönemleri arasında, yüksek tuzluluklarda daha iyi bir performans göstermişlerdir. Yüksek tuzluluklarda (‰30-40) deneme sonuna kadar yaşayanların yüzdeleri (%19-23) düşük tuzluluklardakinden (<‰25) daha yüksek çıkmıştır (%3-12) ($P<0.05$). Deneme sonuna kadar total boy (TB) olarak büyüme ‰10 (17.12 mm) ve ‰ 15 (17.12 mm) tuzluluklarda, ‰35 (20.46 mm) veya ‰40 (19.62 mm) tuzluluklardakinden önemli derecede daha düşük gerçekleşmiştir ($P<0.05$). ‰10-15 tuzluluklarda büyütülen post-larvalar günlük 0.053 ile 0.068 mm arasında, ‰35-40 gibi yüksek tuzluluklarda ise günlük 0.115 ile 0.137 mm arasında büyüme göstermişlerdir. ‰30'un üzerindeki tuzluluklarda büyüme oranı (0.114-0.137 mm/gün), ‰10 tuzlulukta elde edilendekinden (0.053 mm/gün) yaklaşık 2-2,5 kat daha yüksek çıkmıştır. 40 günlük büyütme periyodu sonunda, post-larvalar en düşük canlı ağırlığa ‰10 ve ‰15'te (0.020 – 0.037 g), en yüksek ağırlığa ise ‰35 ve ‰40 tuzluluklarda (0.050-0.051 g) ulaşmışlardır ($P<0.05$). Sonuçlar, ‰40 tuzlulukta canlı ağırlık artışının ‰10'na göre iki kat daha yüksek olduğunu göstermiştir. ‰15, ‰20 ve ‰25 tuzluluklarda post-larvalar orta düzeyde canlı ağırlık artışı göstermişlerdir ($P>0.05$). Tuzluluğun artması biyomasın 0.020 g'dan (‰10'da) 0.317 g'a (‰40'ta) çıkmasına neden olmuştur ($P<0.05$). 28°C su sıcaklığında, *P. semisulcatus* post-larvaları için optimum tuzluluğun ‰40 civarı olduğu görülmektedir. Böylece, bu çalışma, Akdeniz'de yaşayan *P. semisulcatus*'un post-larva döneminde, düşük tuzluluklarda yetiştiriciliğe uygun bir aday olmadığını göstermiştir.

Anahtar Sözcükler: *Penaeus semisulcatus*, tuzluluk, post-larva, büyüme, yaşama oranı

Introduction

Penaeid shrimps are mostly exposed to rapid salinity fluctuations and extreme environmental conditions in estuarine areas during their early life cycle (Raj and Raj, 1982). Hence, the post-larvae (PLs) and juveniles of most species are expected to have a great ability to adapt and to osmoregulate well at fluctuating salinities.

Peneaus semisulcatus is an Indo-Pacific species distributed along the coast of the Eastern Mediterranean and is one of the most important commercial species in this part of the world. Optimal larval culture salinity has been reported to lie between 30 and 35 ppt for this species (Kumlu et al., 1999; Kumlu and Eroldoğan, 2000). However, contradictory results have been reported on optimal nursery culture salinity for *P.*

semisulcatus. Salinities of 30 ppt by Valencia (1977) and 20 ppt by Samocha (1980) were found to be optimal for the same species during the PL stages. In addition, Harpaz et al. (1991) reported that 18 ppt for growth and 36 ppt for survival were the best salinity levels during the nursery culture of this shrimp species.

A considerable number of studies have been conducted to determine the effects of salinity during the nursery culture of various commercially important penaeid species, such as *P. monodon* (Cawthorn et al., 1983; Parado-Estepa, 1998), *P. aztecus* (Venkataramaiah et al., 1972), *P. setiferus* (Zein-Eldin and Griffith, 1969), *P. vannamei*, *P. stylirostris*, *P. californiensis*, *P. brevirostris* (Mair, 1980), *P. merguiensis*, *P. esculentus*, *Metapenaeus bennettae* (Dal, 1981), *P. japonicus* and *P. chinensis* (Charmantier-Daures et al., 1988) and *P. indicus* (Kumlu and Jones, 1995). Studies with PLs of several shrimp species have revealed that optimal culture salinity is species-specific (Parado-Estepa et al., 1987; Diwan and Laximinarayana, 1989). Therefore, it is important to determine the optimum salinity level for each commercial shrimp species in intensive nursery systems in which the salinity can be altered according to the optimum requirements of a particular species.

The primary aim of the present work was to determine the optimal culture salinity that sustains the greatest growth and highest survival during the nursery culture period of *P. semisulcatus.*

Materials and Methods

The larvae of *P. semisulcatus* were obtained from broodstock captured in the Yumurtalık Bight of the north-eastern Mediterranean (at 40 ppt) and were spawned in the Marine Research Station of the University of Çukurova, Adana, Turkey.

The larvae were fed on micro-algae and *Artemia* until the early PL stages. The animals (PL20) previously grown at 40 ppt salinity were stocked in three replicates for each treatment at a density of 30 PLs into each plastic experimental vessel (35 x 20 x 15 cm), supplied with a continuous gentle aeration. The PLs were acclimated to seven different salinities (10, 15, 20, 25, 30, 35 and 40 ppt) over a period of 2 days by adding well water or aquarium salt (Instant Ocean, Aquarium Systems, USA). The animals were gradually acclimated to the desired test salinities by reducing or increasing salinity by 2-3 ppt, seven to eight times a day from 40 ppt down to 10 ppt. Rearing water was filtered to 1 µm with a sand filter and a series of cartridge filters (10, 5 and 1 µm). All the animals were kept in the final test salinities for at least 8 days before the first sampling carried out on the 10^{th} day of the experiment. The PLs were fed a granulated feed (INVE Aquaculture, Belgium) containing 45% protein four times daily to excess. Salinity and temperature measurements were performed with a direct reading digital salinometer (YSI, USA). The pH was measured weekly with a digital pH-meter (WTW, Germany). Ammonia levels were not measured in the present study. However, in a previous penaeid study (Kumlu et al., 2001), in the same system, at highest loading, the maximum level of total ammonia was 0.175 mg l^{-1}, which is below the acceptable level for penaeids (Wickins, 1976).

The experiment, which lasted 40 days, was conducted under a controlled photoperiod (10L:12D) with artificial fluorescent illumination, and the water temperature was maintained at 28 °C. Uneaten food was removed daily when 25-50% of the rearing water was renewed. A complete water exchange was performed every 10 days and simultaneously the PLs were counted and 10-12 of them were measured from the tip of the rostrum to the end of the tail using callipers (± 0.01 mm). The PLs were rolled in tissue paper to remove surface moisture prior to weighing. At the end of the experiment the animals at PL60 were weighed on a scale (± 0.001 g) to determine individual wet-weight and total biomass.

Data were analysed using one-way ANOVA, and any significant difference was determined at 0.05 probability level by Scheffe's test after the normality and homogeneity (Bartlett's test) of the data had been checked (Sokal and Rholf, 1981) on Minitab statistical software.

Results

Following a gradual acclimatisation over a period of 48 h, the percentages of survivors at 40, 35, 30, 25, 20, 15 and 10 ppt were 79, 84, 81, 75, 63 and 23% on the 10^{th} day of the experiment. High PL mortality at low salinity levels (10 and 15 ppt) was already evident during the first 10 days of the culture. Mortality remained high, below 20 ppt throughout the experiment, confirming

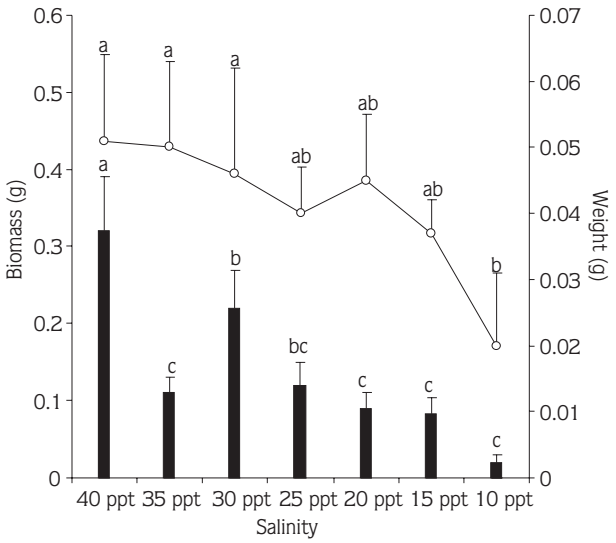

Figure 1. Final weight (line) and biomass (bar) of *Penaeus semisulcatus* reared in various salinities for 40 days. Each bar or symbol is a mean of 3 replicates ± s.d. Means with different superscripts are significantly different from each other ($p < 0.05$).

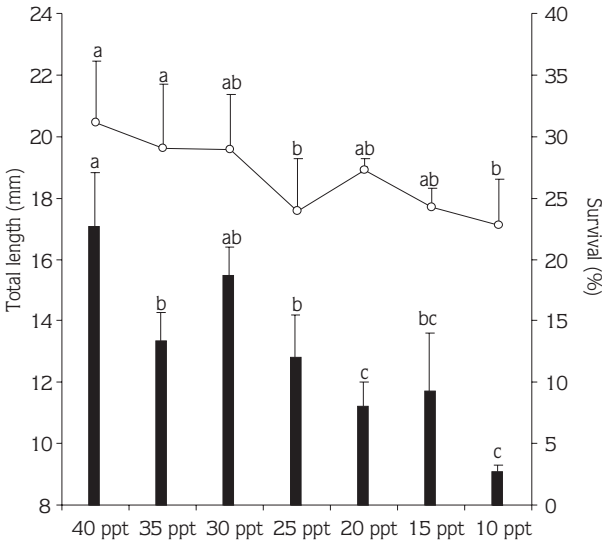

Figure 2. Final total length (line) and survival (bar) of *Penaeus semisulcatus* reared in various salinities for 40 days. Each bar or symbol is a mean of 3 replicates ± s.d. Means with different superscripts are significantly different from each other ($p < 0.05$).

that low salinities were stressful for the PLs (Fig. 1). *P. semisulcatus* PLs enjoyed higher survival rates and better growth at high rather than low salinities between PL20 and PL60 (Figs. 1 and 2). The lowest salinities (10, 15 and 20 ppt) consistently produced high mortalities throughout the experiment, resulting in only 2.67-8% final survivals (Fig. 1, Table). The highest salinity level (40 ppt) tested in this study resulted in 23% survival as compared to 13% at 35 ppt, 19% at 30 ppt and 12% at 25 ppt. Final survivals at high salinities (30-40 ppt) were significantly higher than at lower salinities ($P < 0.05$) (Fig. 1). However, even at high salinities, a high level of cannibalism resulted in high mortalities at all salinities.

Growth as total length (TL) at salinities below 25 ppt was significantly lower than that sustained at higher salinity_levels ($P < 0.05$) (Fig. 1). The PLs grown at 10 and 15 ppt displayed growth rates between 0.053 and 0.068 mm day^{-1} between PL20 and PL60 as compared to 0.115 – 0.137 mm day^{-1} at higher salinities (35-40 ppt) ($P < 0.05$). Final TL at 10 ppt (17.12 mm) and 15 ppt (17.12 mm) was significantly lower than those at 35 ppt (20.46 mm) and 40 ppt (19.62 mm) ($P > 0.05$) (Figs. 1, 3 and Table). Daily growth rates obtained at salinities above 35 ppt were about two fold higher than those obtained at salinities below 15 ppt. These results show that salinities below 20 ppt slow growth and produce high mortality during the nursery culture of *P. semisulcatus*.

The results of individual wet weight and total biomass calculations also confirmed the above findings. PLs grown at 10 and 15 ppt attained the lowest individual wet weight (0.020–0.037 g) while those at 35 and 40 ppt had the highest mean weight (0.050-0.051 g) at the end of the 40-day culture period ($P < 0.05$) (Fig. 2, Table). The results showed that mean weight obtained at 40 ppt was more than twice as high as that at 10 ppt. The PLs grown at 15, 20 and 25 ppt exhibited intermediate growth in weight ($P > 0.05$). The lowest biomass was obtained at 10 ppt (0.020 g). A rise in salinity resulted in an increase in biomass, from 0.020 g at 10 ppt to 0.317 g at 40 ppt ($P < 0.05$) (Fig. 2 and Table).

Throughout the experiment, the temperature and pH of the water in culture vessels were 27.5-28.5 °C and 8.12 - 8.25, respectively.

Discussion

Following a gradual acclimation over a period of 48 h, which has been suggested to be adequate for the PLs of *P. indicus* (Parado-Estepa et al., 1987; Kumlu and Jones, 1995) and *P. monodon* (Cawthorne et al., 1983), *P.*

Table. Survival, total length, mean weight and total biomass of *Penaeus semisulcatus* reared in various salinities for 40 days. Each value is a mean of 3 replicates ± s.d.

	Salinity (‰)						
	10	15	20	25	30	35	40
Survival (%)	2.67 ± 0.58	9.33 ± 4.62	8.00 ± 2.00	12.00 ± 3.46	18.67 ± 2.31	13.33 ± 2.31	23.00 ± 4.36
Total length (mm)	17.12 ± 1.56	17.72 ± 0.60	18.90 ± 0.38	17.58 ± 1.68	19.56 ± 1.79	19.62 ± 2.07	20.46 ± 2.00
Mean weight (g)	0.020 ± 0.011	0.037 ± 0.005	0.045 ± 0.010	0.040 ± 0.007	0.046 ± 0.016	0.050 ± 0.013	0.051 ± 0.017
Total biomass (g)	0.020 ± 0.010	0.083 ± 0.021	0.090 ± 0.020	0.120 ± 0.026	0.223 ± 0.046	0.113 ± 0.015	0.317 ± 0.076

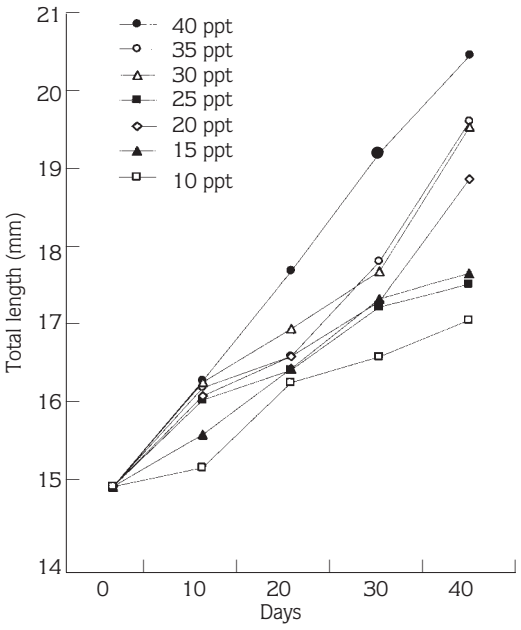

Figure 3. Growth (as total length) of *Penaeus semisulcatus* reared in various salinities for 40 days. Each symbol is a mean of 3 replicates ± s.d.

semisulcatus PLs exhibited poor survival rates, particularly at the lowest salinity levels (10-15 ppt) tested in the current work during the first 10-day culture period. High PL mortality at low salinity levels (10 and 15 ppt) was already evident during the first 10 days of the culture. However, mortality remained high below 20 ppt throughout the experiment, confirming that low salinities were stressful for the PLs. One may argue that the PLs might have needed a slower acclimation rate than that applied in the experiment. However, high mortalities observed at all the experimental test salinities, including normal seawater salinity (40 ppt), indicated that some other reasons might have contributed to the high post-acclimation mortality encountered in this study. It is known that considerable losses may occur in penaeid shrimps during early nursery culture when the PLs are forced to shift from a natural diet to an artificial diet (Fegan, 1992; Ribeiro and Jones, 1996). The heavy cannibalism encountered in this study might also have been triggered by poor adaptation of the PLs to the artificial diet.

Most penaeid shrimps are known to be euryhaline species growing in a wide range of salinities, at least during their nursery stages. In the current work, between PL20 and PL60, the animals had consistently better survival, greater TL and weight gain between 30 and 40 ppt than at low (10-25 ppt) salinities, indicating that their optimal culture salinity lies above 30 ppt. Salinity optima for the larval culture of the same species inhabiting the north-eastern Mediterranean were also reported to be between 30 and 35 ppt (Kumlu et al., 1999; Kumlu and Eroldoğan, 2000). These authors stated that the lowest and highest critical salinity levels were 23 and 55 ppt, respectively, at an acclimation rate of 4-5 ppt h^{-1} and that the preference was towards high rather than low salinities during the larval culture. Animals reared at 10 and 20 ppt exhibited mortalities between 91 and 97%, respectively, during the 40-day-culture period, indicating that the PLs of this species were not able to withstand such extreme salinities. An increase in salinity from 10 ppt to 40 ppt resulted in a consistent rise in survival, TL and biomass. In a study by Harpaz and Karplus (1991), carried out in Israel, 40-day-old PLs of the same species had highest survival rate at 36 ppt and slow growth and low survival at 9 ppt. Hence, it appears that *P. semisulcatus* inhabiting the Mediterranean Sea is not a good candidate for culture in waters of low salinity.

With an Indian strain of *P. semisulcatus*, Raj and Raj (1982) found poor growth at 5 ppt or 45 ppt and that

optimal salinity was between 15 and 25 ppt. Valencia (1977) obtained 100% mortality with the Philippines shrimp population at 55 ppt, whereas Samocha (1980) and Harpaz and Karplus (1991) had 100% survival even at 60 ppt. Based on these results, it appears that Mediterranean PLs of *P. semisulcatus* prefer higher saline media even during their nursery stages whilst populations of the Indo-Pacific regions grow and survive better in lower salinity levels. This might be due to inherent differences in the salinity tolerance between these shrimp populations, as also suggested by Harpaz and Karplus (1991). Kumlu and Jones (1995) have already demonstrated different salinity tolerances of *P. indicus* shrimp populations inhabiting various geographical regions of the world.

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