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Fecundity and Egg Size of Three Shrimp Species, *Crangon crangon*, *Palaemon adspersus*, and *Palaemon elegans* (Crustacea: Decapoda: Caridea), off Sinop Peninsula (Turkey) in the Black Sea

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Abstract: The fecundity and egg size of 3 shrimp species, *Crangon crangon*, *Palaemon adspersus*, and *Palaemon elegans*, were studied off Sinop Peninsula in the Black Sea. Shrimps were sampled by beam trawl with a beam length of 3 m and 10 mm codend mesh size. Mean fecundity of *C. crangon* females was 2297 ± 134 (range: 910-3630). Mean egg size (shortest x longest axis) at early and late embryonic development stages was 0.472 ± 0.005 mm x 0.509 ± 0.008 mm and 0.489 ± 0.003 mm x 0.627 ± 0.004 mm, respectively. Mean fecundity of female *P. adspersus* was 1963 ± 144 (range: 758-3710). Mean egg size (shortest x longest axis) at early and late embryonic development stages was 0.585 ± 0.005 mm x 0.739 ± 0.011 mm and 0.622 ± 0.005 mm x 0.851 ± 0.008 mm, respectively. Mean fecundity of female *P. elegans* was 1057 ± 88 (range: 308-2628). Mean egg size (shortest x longest axis) at early and late embryonic development stages was 0.455 ± 0.005 mm x 0.567 ± 0.007 mm and 0.479 ± 0.008 mm x 0.707 ± 0.007 mm, respectively. Fecundity of all species was positively correlated to the size of the individuals. Egg size for each species increased with increased embryonic development stages. ANOVA results showed that mean egg size was significantly different between early and late embryonic developmental stages of all shrimp species ($P < 0.05$).

Key Words: Shrimp, Caridea, *Crangon crangon*, *Palaemon adspersus*, *Palaemon elegans*, fecundity, egg size

Karadeniz'de Sinop Yarım Adası Civarında Üç Karides Türünün *Crangon crangon*, *Palaemon adspersus* and *Palaemon elegans* (Crustacea: Decapoda: Caridea) Yumurta Verimi ve Yumurta Büyüklüğü

Özet: Bu çalışmada, Karadeniz'de Sinop yarım adası civarında, üç karides türünün, *Crangon crangon*, *Palaemon adspersus* ve *Palaemon elegans*, yumurta verimi ve yumurta büyüklüğü çalışılmıştır. Karides örneklemeleri kiriş uzunluğu 3 m ve torba ağ göz açıklığı 10 mm olan kirişli trol ile yapılmıştır. Dişi *C. crangon* türünün yumurta sayısı ortalama 2297 ± 134 (910-3630 arasında) olarak belirlenmiştir. Erken ve geç embriyo gelişme safhasında ortalama yumurta çapı (kısa eksen x uzun eksen) sırasıyla, 0,472 ± 0,005 mm x 0,509 ± 0,008 mm ve 0,489 ± 0,003 mm x 0,627 ± 0,004 mm olarak saptanmıştır. Dişi *P. adspersus* türünün yumurta sayısı ortalama 1963 ± 144 (758-3710 arasında) olarak belirlenmiştir. *P. adspersus* türünün erken ve geç embriyo gelişme safhasında ortalama yumurta çapı (kısa eksen x uzun eksen) sırasıyla, 0,585 ± 0,005 mm x 0,739 ± 0,011 mm ve 0,622 ± 0,005 mm x 0,851 ± 0,008 mm olarak tespit edilmiştir. *P. elegans* türünün yumurta sayısının ortalama 1057±88 (308-2628 arasında) olduğu belirlenmiştir. Erken ve geç embriyo gelişme safhasında ortalama yumurta çapı ise (kısa eksen x uzun eksen) sırasıyla, 0,455 ± 0,005 mm x 0,567 ± 0,007 mm ve 0,479 ± 0,008 mm x 0,707 ± 0,007 mm olarak tespit edilmiştir. Ayrıca, karides türlerinde yumurta verimi ile boy arasında pozitif bir ilişkinin olduğu ve embriyo gelişim süresince yumurta çapının arttığı belirlenmiştir. Varyans analizi sonuçlarına göre erken ve geç embriyo safhasında ortalama yumurta çapları arasındaki farkın önemli ($P < 0,05$) olduğu belirlenmiştir.

Anahtar Sözcükler: Karides, Caridea, *Crangon crangon*, *Palaemon adspersus*, *Palaemon elegans*, yumurta verimi, yumurtası büyüklüğü

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Introduction

To date, of the 75 species reported from Turkish Seas, 9 shrimp species have been reported from the Black Sea coast of Turkey (Kocataş and Katağan, 2003): *Athanas dentipes*, *A. nitescens*, *Crangon crangon*, *Philocheras trispinosus*, *Hippolyte leptocerus*, *Lysmata seticaudata*, *Palaemon adspersus*, *P. elegans*, and *P. serratus*.

Two species of *Palaemon* shrimps, Baltic shrimp *P. adspersus* Rathke, 1837, and rockpool shrimp, *P. elegans* Rathke, 1837, occur along the Mediterranean coast of Spain, Portugal, Morocco and in the Black Sea (Guerao and Ribera, 1995). The brown shrimp, *C. crangon* (L.), is abundant in the Eastern Atlantic, in shallow coastal areas with sandy or muddy substrata and strong tidal currents (Tiews, 1970). Its distribution ranges from the White Sea (USSR) to the Atlantic coast of Morocco, and into the Baltic, Mediterranean, and Black Seas. *Crangon* is a popular shellfish species for human consumption; for example, 20,000 tons per year were caught off the coasts of such European countries as the Netherlands, Germany, Belgium, and Denmark. It and *Palaemon* species, such as *P. adspersus* and *P. elegans*, are therefore ecologically and commercially important species.

Fecundity is a phenotypic characteristic that is affected by numerous factors and intensities by specific features of different environments (Hines, 1991), and according to Nazari et al. (2003), its variation among species may enable species coexistence. The evaluation of fecundity becomes necessary because it is considered a measure of the reproductive fitness of Crustacea (Nazari et al., 2003) and is directly influenced by natural selection (Stearns, 1977). Furthermore, fecundity, as well as breeding frequency, are characteristics directly related to a species' life strategy (Oh and Hartnoll, 2004). In general, clutch size is highly correlated with the size of individuals in malacostracan crustaceans (Chockley and Mary, 2003). Fecundity is also strongly affected inter-specifically by egg size.

Data on *C. crangon*, *P. adspersus*, and *P. elegans* from Turkish seas are limited. Some basic research has been conducted in the laboratory by Demirhindi (1990, 1991), Bilgin (2000), and Başçınar et al. (2002). Kocataş et al. (1991) presented some general data on the species. Since the distribution and catches of 3 shrimp species in the Black Sea are very limited, studies on the species are also lacking. The aim of this study was to evaluate the fecundity of 3 shrimps belonging to Palaemonidae (*P. adspersus* and *P. elegans*) and Crangonidae (*C. crangon*) around Sinop Peninsula, and to establish its relationship to total length. The size of the eggs and fecundity were evaluated and compared among the species, and incremental changes in egg diameter during the embryonic developmental stages were also evaluated.

Materials and Methods

The specimens were collected from Sinop Peninsula between February 2002 and January 2004. All individuals were captured at depths between 0 and 30 m with a beam trawl 3 m long and 10 mm codend mesh size.

Species identification was based on Kocataş et al. (1991) and Dolgopolskaya (1969). All specimens were clearly recognized as *Crangon crangon* (Linnaeus, 1758), *Palaemon adspersus* Rathke, 1837, and *Palaemon elegans* Rathke, 1837. Total length (TL) (from tip of the rostrum to the tip of the telson along the mid dorsal line) of each specimen was measured to the nearest 0.1 mm using vernier calipers. Specimens were weighed (wet weight) on a balance with a sensitivity of 0.001 g. Eggs were carefully stripped from pleopods using fine forceps, and any setal material or extraneous matter was removed. All of the eggs were counted directly (Mossolin and Bueno, 2002).

Fecundity was derived directly from the number of eggs at stage I from ovigerous females of different sizes. For fecundity only, females (35 *C. crangon*, 45 *P. adspersus* and 50 *P. elegans*) carrying eggs in that developmental stage were used, since loss of eggs during the incubation period was reported for caridean shrimps (Balasundaram and Pandian, 1982). Embryonic development (egg stages) was divided into 3 stages according to Guerao and Ribera (1995) as follows. Stage I: Vitellus occupying > $^{1}/_{2}$ of the egg volume, non-eyed eggs. Stage II: Vitellus occupying < $^{1}/_{4}$ of the egg volume, non-eyed eggs. Stage III: Vitellus occupying ≤ of the egg volume, and decreasing progressively until hatching, eyed eggs.

Egg size was determined for both early (stage I and stage II) and late (stage III) embryonic stages. For this evaluation, 90 ovigerous *C. crangon* (35 from stage I, 25 from stage II, and 30 from stage III), 83 ovigerous *P. adspersus* (45 from stage I, 22 from stage II, and 16 from stage III), and 78 ovigerous *P. elegans* (50 from stage I, 15 from stage II, and 13 from stage III) were selected and 10-13 eggs from each female were gently removed. The longest and shortest axes were measured with an ocular microscope with a micrometric scale (4 x 10 significant) (8, 15). Eggs were treated as ellipsoids and volume quantified by the formula: $4/3\pi r_1(r_2)^2$, where r_1 is half the major axis and r_2 half the minor axis (Oh and Hartnoll, 2004).

Differences in mean length of females, fecundity, and egg size among egg stages were tested using ANOVA and Tukey test, according to Sümbüllüoğlü and Sümbüllüoğlu (2000).

Results

The Brown shrimp *Crangon crangon* (Linnaeus, 1758)

The total length (mean ± standard deviation) of all ovigerous *C. crangon* females was 5.9 ± 0.13 cm (range: 4.5-6.8 cm) (Table 1). The mean fecundity of the 35 ovigerous females was 2297 ± 134 eggs. Individual fecundity ranged from 910, in a female 4.5 cm in total length, to 3630, in a female that was 6.8 cm. Figure 1 shows a positive linear correlation (r = 0.92, P < 0.05) between total length and number of eggs. This correlation was expressed by the equation $F = 0.6369TL^{4.4269}$.

Mean egg size (shortest x longest axis) was 0.472 ± 0.005 mm x 0.509 ± 0.008 mm for stage I eggs, 0.450 ± 0.004 mm x 0.563 ± 0.005 mm for stage II eggs, and 0.489 ± 0.003 mm x 0.627 ± 0.004 mm for stage III eggs (Table 2). Mean egg long axis increased by 23.2% from 0.509 mm in stage I to 0.627 mm in stage III. Mean egg short axis increased by 3.6% from 0.472 mm in stage I to 0.489 mm in stage III; however, mean egg volume increased with incubation stage by 33% from 0.1186 mm^3 in stage I to 0.1575 mm^3 in stage III.

Statistical analyses showed that mean long axis was significantly different between the embryo developmental stages (P < 0.05). The incremental difference in size for short axis during the embryonic phase (between stage I and III, and stage II and III) was statistically significant (P < 0.05), but the difference between stage I and II was not significant (P > 0.05).

Table 1. Fecundity of *Crangon crangon* (n = 35).

	TL (cm)	CL (cm)	AL (cm)	W (g)	Fecundity
Mean	5.9	1.3	3.2	2.817	2297
Std. dev.	0.13	0.03	0.07	0.1746	134
Minimum	4.5	0.9	2.5	1.153	910
Maximum	6.8	1.5	3.6	4.398	3630

TL: Total length; CL: Carapax length; AL: Abdominal length; W: Weight

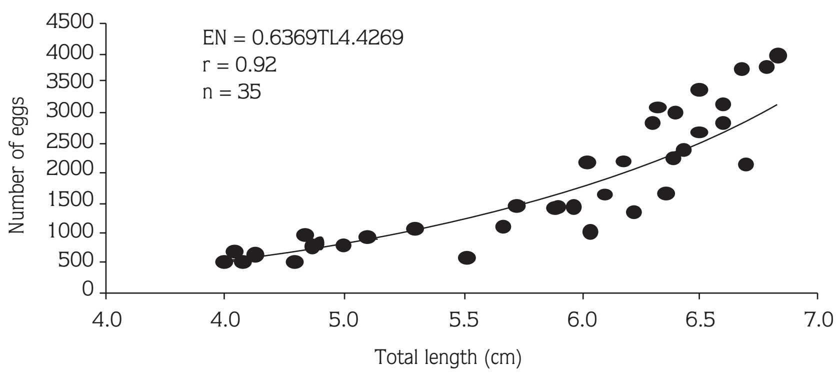

Figure 1. Relationship between total length and number of eggs in *Crangon crangon* females from Sinop Peninsula at the first developmental stage.

Table 2. Egg length (mm) of developing embryos (stages I to III) of *Crangon crangon* from Sinop Peninsula.

	Stage I (n = 350)		Stage II (n = 259)		Stage III (n = 311)	
	Short Axis	Long Axis	Short Axis	Long Axis	Short Axis	Long Axis
Mean	0.472	0.509	0.473	0.563	0.489	0.627
Std. dev.	0.005	0.008	0.004	0.005	0.003	0.004
Minimum	0.425	0.450	0.450	0.500	0.450	0.550
Maximum	0.500	0.600	0.500	0.600	0.550	0.750

Baltic shrimp *Palaemon adspersus* Rathke, 1837

The total length (mean ± standard deviation) of all ovigerous *P. adspersus* females was 6.0 ± 0.10 cm (range: 5.1-7.2 cm) (Table 3). The mean fecundity of the 45 ovigerous females was 1963 ± 144 eggs. The lowest number of eggs was 758, in a female 5.1 cm in total length, while the highest number was 3710, in a female of 7.2 cm. Figure 2 shows a positive linear correlation between total length and number of eggs ($F = 0.6369TL^{4.4269}$, r = 0.96, P < 0.05).

Mean egg size (shortest x longest axis) during embryonic developmental stages I, II, and III was 0.585 ± 0.005 mm x 0.739 ± 0.011 mm, 0.587 ± 0.005 mm x 0.710 ± 0.010 mm, and 0.622 ± 0.005 mm x 0.851 ± 0.008 mm, respectively (Table 4). Mean egg long axis increased by 15.2% from 0.739 mm in stage I to 0.851 mm in stage III. Short axis increased by 6.3% from 0.585 mm in stage I to 0.622 mm in stage III. Egg volume of *P. adspersus* increased 30% during the incubation period; however, egg volume increased with

Table 3. Fecundity of *Palaemon adspersus* (n = 45).

	TL (cm)	CL (cm)	AL (cm)	W (g)	Fecundity
Mean	6.0	1.2	2.6	2.423	1963
Std. dev.	0.10	0.02	0.06	0.135	144
Minimum	5.1	0.9	2.2	1.258	758
Maximum	7.2	1.5	3.5	4.870	3710

TL: Total length; CL: Carapax length; AL: Abdominal length; W: Weight

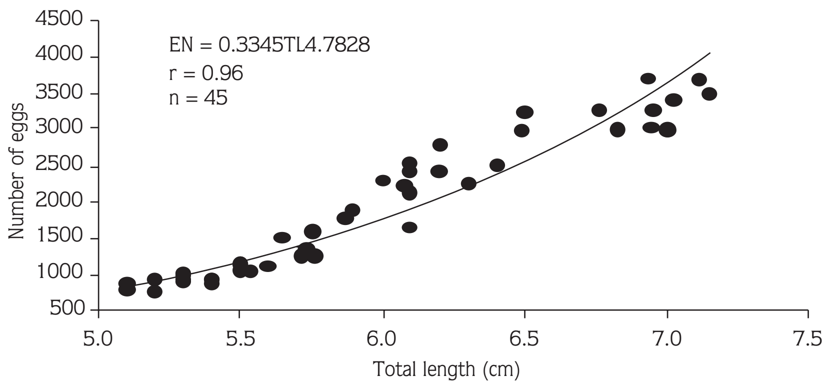

Figure 2. Relationship between total length and number of eggs in *Palaemon adspersus* females from Sinop Peninsula at the first developmental stage.

Table 4. Egg length (mm) of developing embryos (stages I to III) of *Palaemon adspersus* from Sinop Peninsula.

	Stage I (n = 452)		Stage II (n = 235)		Stage III (n = 173)	
	Short Axis	Long Axis	Short Axis	Long Axis	Short Axis	Long Axis
Mean	0.585	0.739	0.587	0.710	0.622	0.851
Std. dev.	0.005	0.011	0.005	0.010	0.005	0.008
Minimum	0.550	0.675	0.550	0.675	0.575	0.750
Maximum	0.675	0.850	0.625	0.775	0.675	0.925

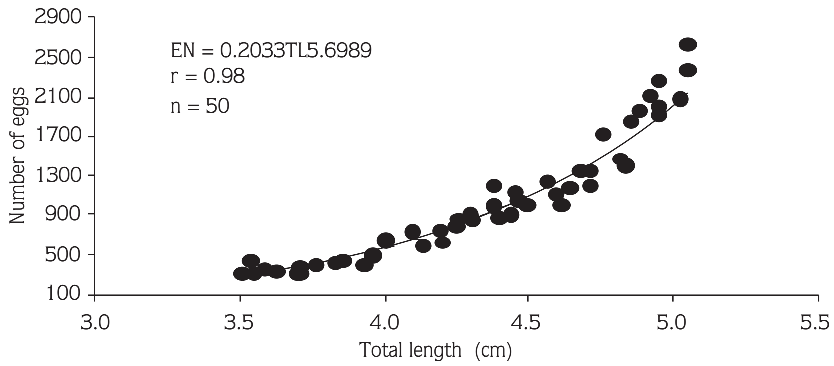

Figure 3. Relationship between total length and number of eggs in *Palaemon elegans* females from Sinop Peninsula at the first developmental stage.

incubation period by 30% from 0.0843 mm^3 in stage I to 0.1097 mm^3 in stage III.

The results of ANOVA showed both mean short and long egg axes of *P. adspersus* were significantly different among the embryo developmental stages ($P < 0.05$), except between stages I and II.

Rockpool shrimp *Palaemon elegans* Rathke, 1837

The total length (mean ± standard deviation) of all ovigerous *P. elegans* females was 4.3 ± 0.07 cm (range: 3.5-5.1 cm) (Table 5). The mean fecundity of the 50 ovigerous *P. elegans* females was 1057 ± 88 eggs. Individual fecundity ranged from 308 to 2628 eggs. Figure 3 shows a positive linear correlation between total length and number of eggs ($F = 0.2033TL^{5.6989}$, $r = 0.98$, $P < 0.05$).

Mean egg size (shortest x longest axis) during embryonic developmental stages I, II, and III was 0.455 ± 0.005 mm x 0.567 ± 0.007 mm, 0.484 ± 0.007 mm x 0.588 ± 0.008 mm, and 0.479 ± 0.008 mm x 0.707 ± 0.007 mm, respectively (Table 6). Mean egg long axis increased by 24.7% from 0.567 mm in stage I to 0.707 mm in stage III. Short axis increased by 5.3% from 0.455 mm in stage I to 0.479 mm in stage III. However, egg volume of *P. elegans* increased 30% over the incubation period, yet egg volume increased with incubation period by 36% from 0.0391 mm^3 in stage I to 0.0532 mm^3 in stage III during the incubation period.

Statistical analyses showed that mean long axis was significantly different between the embryo developmental stages, except for stages I and II ($P < 0.05$). The incremental difference in size for short axis during the embryonic phase (between stages I and II, and stages I and III) was statistically significant ($P < 0.05$), but the difference between stages II and III was not significant ($P > 0.05$).

Table 5. Fecundity of *Palaemon elegans* (n = 50).

	TL (cm)	CL (cm)	AL (cm)	W (g)	Fecundity
Mean	4.3	0.8	2.0	1.028	1057
Std. dev.	0.07	0.01	0.02	0.035	88
Minimum	3.5	0.7	1.7	0.650	308
Maximum	5.1	1.1	2.3	1.910	2628

TL: Total length; CL: Carapax length; AL: Abdominal length; W: Weight

Table 6. Egg length (mm) of developing embryos (stages I to III) of *Palaemon elegans* from Sinop Peninsula.

	Stage I (n = 500)		Stage II (n = 150)		Stage III (n = 130)	
	Short Axis	Long Axis	Short Axis	Long Axis	Short Axis	Long Axis
Mean	0.455	0.567	0.484	0.588	0.479	0.707
Std. dev.	0.005	0.007	0.007	0.008	0.008	0.007
Minimum	0.350	0.475	0.425	0.525	0.450	0.675
Maximum	0.500	0.650	0.550	0.650	0.500	0.725

Discussion

In this study, during incubation, egg size and volume increased for 3 shrimp species, which is a general occurrence in decapods (Pandian, 1994). This was due to increased water content and changes in the biochemical composition during embryonic development (Clarke, 1993).

Havinga (1930) observed that the number of eggs per female in *C. crangon* was a linear function of body length; 8000 to 9000 eggs were produced by an individual during its second year of life and 24,000 to 26,000 in the third year. According to Ehrenbaum (1890), *C. crangon* eggs vary in size up to a maximum long axis dimension of 0.61 mm and short axis of 0.46 mm. Dennis (1993) reported mean egg size of *C. crangon* as 0.441 mm for early stage and 0.590 mm for late stage. Dornheim (1969) reported the number of eggs of 71 *C. crangon* females of varying lengths: those 35 mm long averaged 620 eggs; at 40 mm, 1400 eggs; at 45 mm, 1830 eggs; and at 50 mm, 2700 eggs. Başçınar et al. (2002) reported that *P. elegans* females produce around 306-1704 eggs/individual and that during incubation egg size reached 0.4-0.6 mm in the short axis and ranged from 0.5 to 0.6 mm in the long axis for early stage and from 1.1 to 2.7 mm (axis variation lost) for the latest stage.

Egg loss during incubation in caridean shrimps commonly occurs in nature, which is obviously one of the factors that affect reproductive output. Egg loss could be caused by mechanical stress, parasites, and occasionally an increase in embryo volume during incubation (Blasundaram and Pandian, 1982). The mean fecundity of the shrimp populations in the present study are within the range reported for other populations (Başçınar et al., 2002; Oh and Hartnoll, 2004); however, Oh and Hartnoll (2004) reported a much wider variation in the number of eggs (1288 to 8708) in the *C. crangon* population from the Port Erin Bay.

Comparison between size of eggs at early and late embryonic stages clearly demonstrated a significant increase in size during incubation. Studies on Crangonidae and Palaemonidae species from other research (Table 7), however, usually provide information on egg size either at the early or late embryonic stage, or do not mention the embryonic stage at all. At the end of the incubation period, the growth of egg volume is an important feature of the embryos and the hatching of the larvae (Müller et al., 2003; Nazari et al., 2003).

Eggs in the early stage were significantly larger than those in the late stage, as noted in other studies (Table 7). This phenomenon is common in species' consecutive broods, e.g., *Palaemon adspersus*, *P. elegans* (Berglund, 1984), *P. xiphias*, and *P. serratus* (Guerao et al., 1994; Guerao and Ribera, 2000). A number of studies confirmed that large eggs have more yolk (Guerao and Ribera, 2000; Oh and Hartnoll, 2004). Clarke (1993) found a positive correlation between several measures of egg nutrient content and egg volume in 3 carideans, which is a clear indication that the difference between egg size in broods reflects a difference in reproductive investment per embryo. This variation may result from differences in the amount of resources available, or from environmental factors such as temperature (Clarke, 1993).

The difference in the maximum reproductive output among crustacean species seems to be primarily the result of differences in female body size; however, other biotic or abiotic factors, such as egg size, latitudinal and seasonal variation (Boddeke, 1982), and habitat adaptation (Mantelatto and Fransozo, 1997), may also influence reproductive output. Large egg size at higher latitudes is usually associated with a more advanced larval stage at hatching and an increased development time (Hines, 1982). Selection acts on egg size over evolutionary time scales through feeding conditions for the newly hatched young, whereas overall investment is dictated by feeding conditions for the adults as their ovaries matures (Clarke et al., 1985). Egg size is an important diverse life history characteristic of species. In particular, reproductive patterns and life history traits can be determined by the mode of energy allocation to either single embryos or brood output (Clarke, 1993). In the present study, *P. adspersus* (0.084-0.109 mm^3) and

Table 7. Fecundity and egg size of Palaemonidae and Crangonidae species.

Species	Egg Size (mm)						
	Early Stage		Late Stage		General	Fecundity	References
	Shortest Axis	Longest Axis	Shortest Axis	Longest Axis			
Crangon crangon	0.42-0.50	0.50-0.60	0.45-0.55	0.55-0.75	-	910-3630	Present study
Palaemon adspersus	0.55-0.67	0.67-0.85	0.57-0.67	0.75-0.92	-	758-3710	Present study
Palaemon elegans	0.35-0.50	0.47-0.65	0.45-0.50	0.67-0.72	-	308-2628	Present study
Palaemon elegans	0.40-0.60	0.50-0.60	0.40-0.60	0.50-0.80	-	306-1704	Başçınar et al., 2002
Palaemon elegans	-	-	-	-	-	914	Demirhindi, 1990
Palaemon elegans	-	-	-	-	0.475-0.575	1343-2563	Bilgin, 2000
Palaemon elegans	-	-	-	-	0.650-0.800	-	Holthuis and Hassan, 1975
Palaemon adspersus	-	0.62-0.72	-	0.85-0.95	-	-	Guerao and Ribera, 1995
Palaemon serratus	-	-	-	-	-	1000-2000	Lee and Wickins, 1992
Palaemon xiphias	-	-	-	-	-	318-2750	Guerao et al., 1994
Palaemonetes pugio	-	0.59	-	0.98	-	-	Glas et al., 1997
Crangon crangon	-	0.44	-	0.59	-	-	Dennis, 1993
Crangon crangon	-	-	-	-	-	620-2700	Dornheim, 1969
Crangon crangon	-	-	-	-	-	8000-26000	Havinga, 1930
Crangon crangon	-	-	-	-	-	1288-8708	Oh and Hartnoll, 2004
Macrobrachium olfersi	0.38	0.47	0.43	0.58	-	1029-6320	Nazari et al., 2003
Macrobrachium olfersi	0.449	0.579	0.489	0.648	-	1227	Mossolin and Bueno, 2002
Macrobrachium potiuna	1.37	1.79	1.41	2.17	-	19-65	Nazari et al., 2003

P. elegas (0.039-0.053 mm^3) seemed to retain a relatively small embryo volume compared to other palaemonids species, such as *P. northropi* (0.200 mm^3), *Palaemonetes intermedius* (0.294 mm^3), and *Leander tenuicornis* (0.163 mm^3) (Corey and Reid, 1991). *C. crangon* (0.118-0.157 mm^3) had larger embryo volume compared to *P. adspersus* and *P. elegans*. Moreover, according to results of other studies on palaemon species, maximum fecundity of P. *adspersus* was less than that of *P. elegans, P. xiphias*, and *P. serratus*.

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