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Effects of Salinity on Growth and Molting of Sympatric Callinectes spp. from Camaronera Lagoon, Veracruz, Mexico

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EFFECTS OF SALINITY ON GROWTH AND MOLTING OF SYMPATRIC *CALLINECTES* SPP. FROM CAMARONERA LAGOON, VERACRUZ, MEXICO

Sergio Cházaro-Olvera and Mark S. Peterson

ABSTRACT

Megalopae of *Callinectes rathbunae* Contrareras, 1930 and *C. sapidus* Rathbun, 1896 were exposed to salinities of 5, 15, and 25 at 25.0ºC (through crab stage 16) to determine if there were species-specific differences in survival, growth, and intermolt duration. Survival of *C. rathbunae* decreased significantly at higher salinities, but there was no salinity effect for *C. sapidus*. *Callinectes rathbunae* had significantly higher survival than *C. sapidus* in salinities of 5 and 15, but survival was not different in a salinity of 25. There was no difference in survival of *C. rathbunae* by gender; survival of both genders was generally lowest at a salinity of 25. There was no difference in survival for females of *C. sapidus* among salinities, but males had lowest survival at the lowest salinity. Additionally, males had significantly greater survival than females in salinities of 15 and 25. Females of *C. rathbunae* grew faster than males at all salinities and both genders grew fastest in a salinity of 15. In contrast, males and females of *C. sapidus* grew at the same rate, with the lowest growth rate for both genders at the lowest salinities. Relative to *C. rathbunae*, *C. sapidus* had a significantly higher growth rate and shorter intermolt duration at the highest salinity. There was no significant difference in intermolt duration between genders for *C. rathbunae* or *C. sapidus.* However, intermolt duration among salinity treatments for *C. rathbunae* differed significantly in crabs ≥ stage 7, with the longest duration in the highest salinity. In contrast, intermolt duration of *C. sapidus* was shortest in a salinity of 25. Results of this study suggest that *C. rathbunae* is more tolerant of low salinity habitats than *C. sapidus.*

Crabs of the genus *Callinectes* are among the dominant benthic macroinvertebrates along the Atlantic coast of North and South America (Chávez and Fernández, 1976; Ettinger and Blye, 1981; Rosas, 1989; Rosas et al., 1994; Cházaro-Olvera et al., 2000). In the southern Gulf of Mexico (GOM), the sharptoothed swimming crab, *Callinectes rathbunae* Contreras, 1930 and the blue crab, *Callinectes sapidus* Rathbun, 1896, support important commercial fisheries (Alvarez and Calderón, 1996).

The geographic range of *C. sapidus* extends from Nova Scotia south throughout the Caribbean islands to Argentina. Additional records of *C. sapidus* from the Mediterranean and western European coasts are likely due to larval introductions via ship ballast water (Williams, 1974, 1984; Powers, 1977; Rocha et al., 1992; Ruíz, 1993; Guerin and Stickle, 1997a). *Callinectes sapidus* and *C. rathbunae* coexist sympatrically in shallow, coastal waters from Texas to the Términos Lagoon, Campeche, Mexico (Williams, 1974; Powers, 1977; Raz-Guzmán et al., 1992; Rocha et al., 1992; Cházaro-Olvera et al., 2000) in salinities ranging up to 15, although *C. sapidus* also occupies higher salinity habitats. Both species have been grouped in the 'bocourti' group and are considered tolerant of low salinity (Norse and Fox-Norse, 1979).

Salinity is one of the most important factors influencing distribution of many organisms (Peterson et al., 1999; and references therein) within estuaries, including portunid crabs. Because portunids comprise one of the most dominant groups of crabs supporting

important fisheries worldwide, there have been intensive efforts to rear a number of species like *Portunus pelagicus* (Linnaeus, 1766), *Charybdis japonica* (A. Milne Edwards, 1861) and *Thalamita sima* H. Milne Edwards, 1834 in the laboratory (Bookhout and Costlow, 1977). The portunid genera *Arenaeus* Dana, *Callinectes* Stimpson, *Cancer* Linnaeus, *Cronius* Stimpson, *Ovalipes* Rathbun, and *Portunus* Weber are known to occur in the GOM (Powers, 1977; Williams, 1974, 1984), but complete laboratory-based larval development for GOM portunid species is known for only *C. sapidus* (Costlow and Bookhout, 1959), *C. similis* Williams, 1966 (Bookhout and Costlow, 1974), and *Portunus spinicarpus* Stimpson, 1871 (Bookhout and Costlow, 1977). Similar laboratory salinity-development relationships are not available for other portunid crabs in the GOM, and in particular, for portunids in the southern GOM.

This comparative study describes the differential influence of salinity on development of two commercially important portunid crabs collected from the southern GOM and relates these differences to the ecology and distribution of these species in Camaronera Lagoon, Veracruz, Mexico. Megalopae of *C. rathbunae* and *C. sapidus* were exposed to salinities of 5, 15, and 25 at 25.0 ± 1.0ºC and survival, growth, and molting duration were determined over the course of development from megalopa to crab stage 16.

MATERIALS AND METHODS

Megalopae of *C. sapidus* and *C. rathbunae* were obtained from the mouth of the Camaronera Lagoon, Veracruz, Mexico (18º52′15″N, 95º42′20″W) in April 1997, June 1998, and September 1999 in nighttime plankton collections with a 243 mm mesh conical net. Salinity and water temperature at the time of collection were 35.0 ± 0.0 and 29.0 ± 1.0º C, respectively, for April 1997, 22.0 ± 0.0 and 20.0 ± 1.0º C, respectively, for June 1998, and 22.0 ± 12.0 and 27.0 ± 2.0º C, respectively, for September 1999. Megalopae were transported to the laboratory at Universidad Nacional Autónoma de México, Campus Iztacala, and allocated (within eight hrs of collection) to the experimental units. Water for each experimental salinity was prepared from aerated, bottled water and Instant Ocean® sea salts.

All experiments were conducted in a vertical re-circulating system consisting of a highly aerated biological filter made of crushed oyster shell and sand, and a submersible heater to maintain water temperature. A submersible pump, PVC pipe and valves provided water of the correct salinity and temperature to plastic reservoirs (n = 9) that housed the experimental units (see below). Natural photoperiod was used over the course of the experiments and water temperature was maintained in all experiments at 25.0 ± 1.0ºC because of the small natural variability in the lagoon. Nitrate and ammonia were monitored daily and water in the entire system was changed when nitrate ≥ 0.35 mg L^{-1} or ammonia ≥ 0.30 mg L^{-1}; this occurred about every two weeks. Flow rate into each reservoir was 11 ml s^{-1} resulting in a complete water exchange every 6.8 hrs. Dissolved oxygen in the system was always > 6 mg L^{-1} (YSI oxygen meter).

For each salinity treatment, megalopae were slowly acclimated up or down (over a 12 hr period) from the ambient collection salinity (22–35) to the desired salinity. Each megalopa was initially housed in individual circular experimental units (1 mm Nitex® mesh) maintained in each of the plastic reservoirs to prevent cannibalism and allow for easy measurement of individuals over the course of the study. The plastic reservoirs and individual experimental units varied in size depending on the developmental stage and size of the crab. The plastic reservoirs used for megalopae were 9 L each and held up to 25 individual experimental units (30 × 35 mm), each unit contained one megalopa. Once the crab began metamorphosing through crab stage 16, larger plastic reservoirs (20 L) and experimental units (50 × 70 mm) were used. When the crab metamorphosed into crab stage 7 and larger, the experimental units were enlarged again (105 × 135 × 100 mm tall) for the

remaining developmental stages. Because of space and equipment limitations, equal replicates (n = 100) of both species were interspersed among the nine reservoirs and processed for each salinity treatment (5, 15, 25) sequentially. As the initial number of megalopae used in these experiments decreased due to mortality, the number of experimental units in each reservoir also decreased. All experiments continued until each species reached crab stage 16, which is about 110 mm carapace width (CW) and a commercial size.

For each salinity treatment, 100 megalopae of each species were placed into an experimental unit, distributed equally to the plastic reservoirs on the vertical recirculating system, and monitored daily. Megalopae were fed nauplii of *Artemia*, but the diet was gradually changed to adult *Artemia* after metamorphosis to crab stage 1. Individuals larger than crab stage 3 were fed small pieces of poecillid fishes (*Poecillopsis gracilis, Poecillopsis balsa, Poecillopsis lucida,* and *Poecillopsis formosa*). In all developmental stages, crabs were fed ad libitum to maximize survival and growth. Carapace width (mm) of all crab stages was determined with calipers two days after each molt, which allows sufficient time for water uptake and recalcification (Cadman and Weinstein, 1988).

Gender was determined only after each species metamorphosed to crab stage 7, necessitating two separate analyses. First, as an overall test, we used a 2×3 factorial analysis of variance (ANOVA) on percent survival, intermolt duration (d), and growth rate (mm d^{-1}; dependent variables) with gender pooled within species (n = 2) and salinity treatment (n = 3) as the main effects. Second, we conducted two separate ANOVAs on the same metrics by species (using abundance of each species at crab stage 7 as our starting values) with gender (n = 2) and salinity (n = 3) as the main effects. If no significant interactions were documented for either analyses, mean responses were separated with a Bonferroni pairwise comparison test (Sokal and Rohlf, 1995). If significant interaction terms were documented, we used one-way ANOVA and subsequent Bonferroni tests to separate the main effects and aid in interpretation of the results. Homogeneity of variance and normality assumptions of ANOVA were tested and unless noted, were met prior to each test. If the assumptions were violated, the data were $\log_{10}$ transformed prior to analysis, but if that did not correct the problem we followed Underwood (1997), who argued that ANOVA models are robust to violation of the assumptions when sample sizes are large and balanced. All percent data were arcsine transformed prior to analysis (Sokal and Rohlf, 1995). All crab measurements (mm) are presented as the mean ± 1 standard error (SE), and all statistics were calculated with SigmaStat for Windows (Ver. 2.0, Jandel Corp.). All comparisons were considered significant when P ≤ 0.05.

RESULTS

OVERALL ANALYSES.—There was a significant interaction between species and salinity for percent survival to crab stage 16 ($F_{2,95}$ = 3.975, P = 0.022). There was a significant difference in percent survival for *C. rathbunae* (one-way ANOVA: $F_{2,47}$ =12.765, P ≤ 0.001), with percent survival in salinity 25 less than either of the lower salinities (Fig. 1; Table 1). For *C. sapidus*, there was no overall difference in percent survival (one-way ANOVA: $F_{2,47}$ = 0.159, P = 0.853). Comparisons between species within salinity treatments indicated that *C. rathbunae* had higher percent survival than *C. sapidus* in the salinity 5 and 15 treatments (Bonferroni t = 2.271 and 2.763, respectively, all P < 0.05) compared to those in salinity 25. There was no significant difference in percent survival in the salinity 25 treatment between species (Bonferroni t = 0.910, P > 0.05).

There was a significant interaction between species and salinity for growth rate to crab stage 16 (ANOVA: $F_{2,89}$ = 22.816, P < 0.001). Growth rate differed among salinities for *C. rathbunae* (one-way ANOVA: $F_{2,44}$ = 13.151, P < 0.001) and *C. sapidus*, (one-way ANOVA: $F_{2,44}$ = 15.568, P < 0.001; Table 2). Bonferroni pairwise comparisons indicated that growth of *C. rathbunae* in salinity 5 was similar to growth at 25, but growth at salinity 5 was less
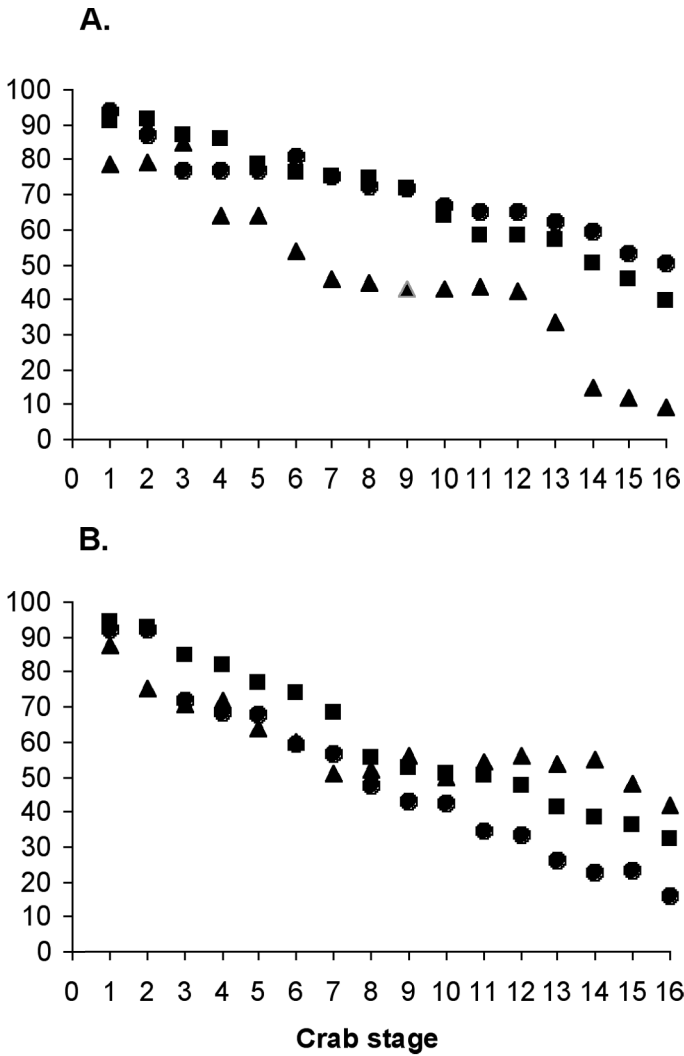
A.

B.

Crab stage

Figure 1. Percent survival by crab stage of (A) *Callinectes rathbunae* and (B) *Callinectes sapidus* in 5 (●), 15 (■), and 25 (▲) salinity treatments.

Table 1. Percent survival (mean ± SE) of *Callinectes rathbunae* and *Callinectes sapidus* by salinity (5, 15, 25) for total crabs (gender pooled) and gender based on crab stages 7−16.

Species	Gender	5	N	15	N	25	N
Callinectes rathbunae	Total	67.1 ± 4.9	148	72.0 ± 4.9	151	42.8 ± 4.9	130
	Female	59.9 ± 2.6	77	64.1 ± 3.4	77	28.9 ± 3.9	41
	Male	67.5 ± 2.6	71	54.9 ± 4.3	72	37.4 ± 5.8	49
Callinectes sapidus	Total	51.4 ± 4.9	142	52.9 ± 4.9	157	49.1 ± 4.9	122
	Female	35.9 ± 4.5	65	38.8 ± 3.4	62	42.4 ± 2.1	44
	Male	35.5 ± 3.9	66	59.2 ± 4.1	78	60.2 ± 0.9	61

Table 2. Growth rates (mm d^{-1}, mean ± SE) of *Callinectes rathbunae* and *Callinectes sapidus* by salinity (5, 15, 25) for total crabs (gender pooled) and gender based on crab stages 7−16.

Species	Gender	5	N	15	N	25	N
Callinectes rathbunae	Total	0.29 ± 0.02	148	0.38 ± 0.02	151	0.22 ± 0.02	130
	Female	0.28 ± 0.02	77	0.44 ± 0.04	77	0.27 ± 0.01	41
	Male	0.27 ± 0.02	71	0.35 ± 0.04	72	0.22 ± 0.01	49
Callinectes sapidus	Total	0.24 ± 0.02	142	0.33 ± 0.02	157	0.40 ± 0.02	122
	Female	0.28 ± 0.02	65	0.36 ± 0.04	62	0.49 ± 0.02	44
	Male	0.28 ± 0.02	66	0.39 ± 0.05	78	0.40 ± 0.03	61

than growth at 15, and growth was greater at 15 than growth at 25. Growth rate for *C. sapidus* varied linearly by salinity treatment with growth at 5 < 15 < 25 (Fig. 2). Comparisons between species within salinity treatments indicated that there was no difference in growth rate between *C. rathbunae* and *C. sapidus* in the salinity 5 and 15 treatments (Bonferroni t = 1.932 and 1.895, respectively, all P > 0.05). However, *C. rathbunae* had a significantly lower growth rate in salinity 25 than *C. sapidus* (Bonferroni t = 6.339, P < 0.05).

There was a significant interaction between species and salinity for intermolt duration to crab stage 16 (ANOVA: $F_{2,95}$ = 5.564, P = 0.005). There was no overall difference in intermolt duration among salinities for *C. rathbunae* (one-way ANOVA: $F_{2,47}$ = 2.396, P = 0.103; Table 3). For *C. sapidus,* however, there was a significant difference in intermolt duration (one-way ANOVA: $F_{2,47}$ = 3.695, P = 0.033), with duration at salinity 5 > salinity 25, but not the intermediate salinity (Fig. 3; Table 3). Comparisons between species within salinity treatments indicated that there was no difference in intermolt duration between *C. rathbunae* and *C. sapidus* in the salinity 5 and 15 treatments (Bonferroni t = 1.711 and 1.099, respectively, all P > 0.05). However, *C. rathbunae* had a significantly longer intermolt duration in salinity 25 than *C. sapidus* (Bonferroni t = 2.646, P < 0.05). The time required for megalopae collected in Camaronera Lagoon to reach commercial size differed by species and was influenced by salinity. For *C. rathbunae*, 110 mm CW was reached in 11–12 mo at salinity 5, in 8–10 mo at salinity 15, and 15–18 mo at salinity 25. In contrast, for *C. sapidus*, 110 mm CW was reached at salinity 5 in 15 mo, at salinity 15 in 10 mo and at salinity 25 in 8–9 mo.

ANALYSES BY GENDER.—There was a significant interaction between gender and salinity for percent survival of *C. rathbunae* (ANOVA: $F_{2,59}$ = 3.651, P = 0.033). Percent survival among salinities for female (one-way ANOVA: $F_{2,29}$ = 31.483, P < 0.001) and male (one-way ANOVA: $F_{2,29}$ = 13.709, P < 0.001) *C. rathbunae* was different, with survival in salinity 25 being significantly less than survival at the lower salinities (Table 1). There was no difference between genders for any salinity treatment (all P > 0.05). There was no significant difference in percent survival of females of *C. sapidus* among salinities (one-way ANOVA: $F_{2,29}$ = 0.739, P = 0.487), but percent survival of males differed significantly (one-way ANOVA: $F_{2,29}$ = 17.427, P ≤ 0.001), with survival in salinity 5 being less than higher salinities (Table 1). There was no difference between genders for the salinity 5 treatment (P > 0.05); however, in the salinity 15 and 25 treatments, males had significantly greater survival than females (all P < 0.05).

There was no significant interaction between gender and salinity in the growth rates of *C. rathbunae* (ANOVA: $F_{2,53}$ = 1.499, P = 0.234). There was a significant difference in growth rate between genders (ANOVA: $F_{1,53}$ = 5.211, P = 0.027), with females growing
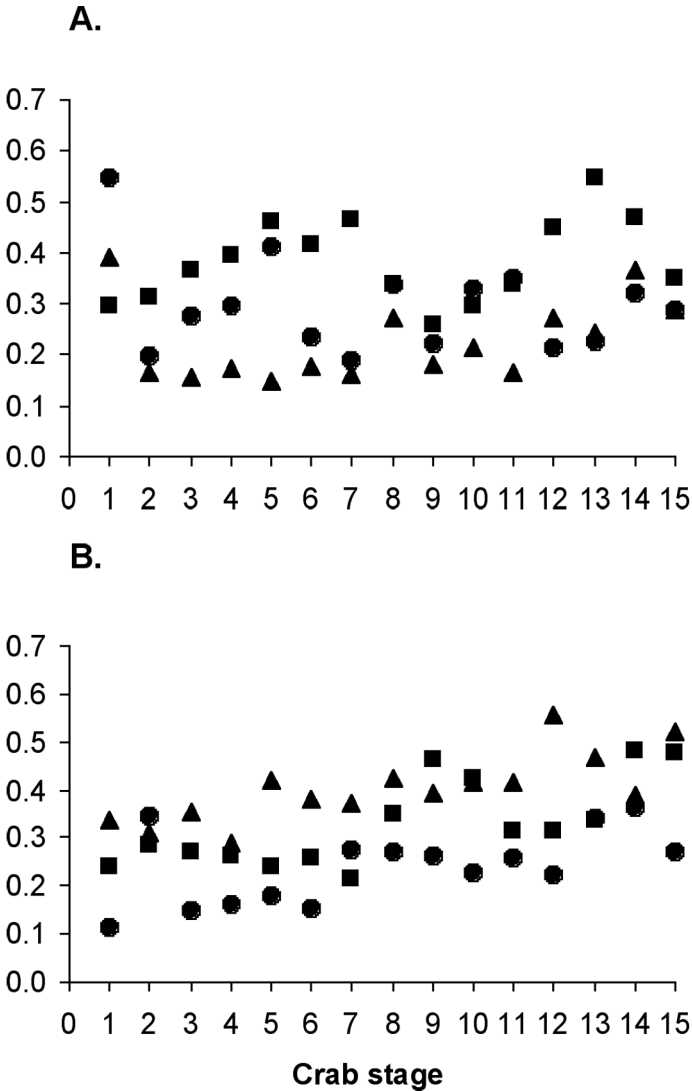
A.

B.

Crab stage

Figure 2. Growth rate (mm d^{-1}) by crab stage of (A) *Callinectes rathbunae* and (B) *Callinectes sapidus* in 5 (●), 15 (■) and 25 (▲) salinity treatments. Each point represents growth between successive crab stages (1 = growth between stages 1–2, 2 = growth between stages 2–3, etc.)

faster than males. Growth rate among salinity treatments also differed significantly (ANOVA: $F_{2,53}$ = 17.544, P < 0.001), with growth in salinity 15 being greater than either 5 or 25 (Table 2). There was also no significant interaction between gender and salinity for *C. sapidus* (ANOVA: $F_{2,53}$ = 1.579, P = 0.217). There was no significant difference in growth rate between genders (ANOVA: $F_{1,53}$ = 0.702, P = 0.406). Growth rate among salinity treatments was significantly different (ANOVA: $F_{2,53}$ =13.296, P < 0.001), with growth in salinity 5 being lower than growth at 15 or 25 (Table 2).
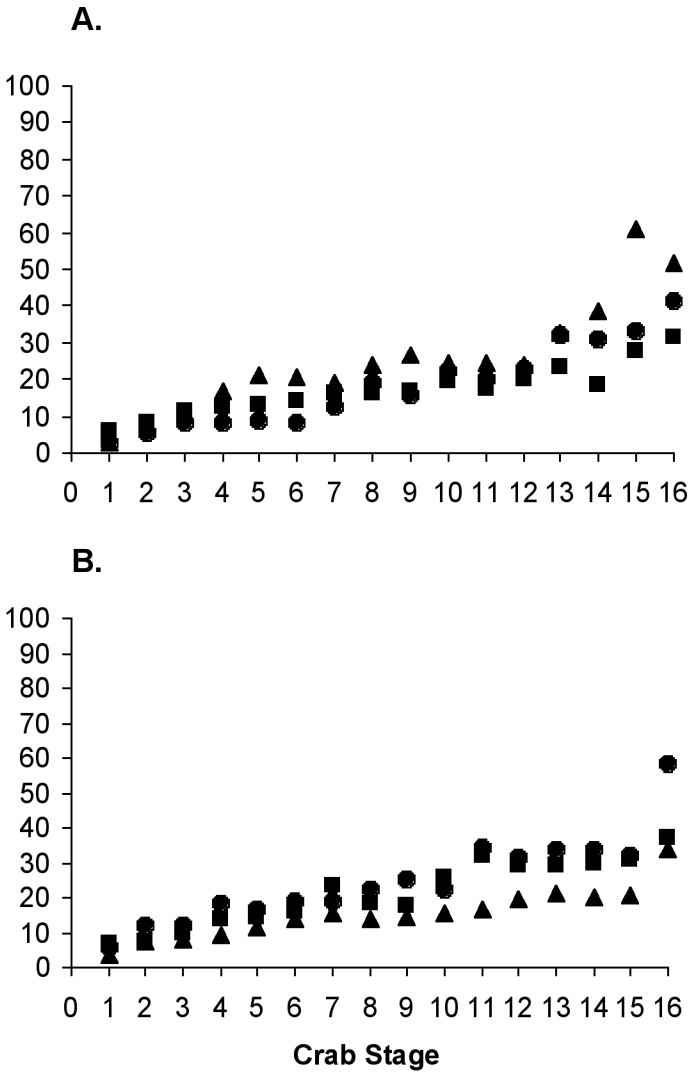
A.

B.

Crab Stage

Figure 3. Intermolt duration (d) by crab stage of (A) *Callinectes rathbunae* and (B) *Callinectes sapidus* in 5 (●), 15 (■) and 25 (▲) salinity treatments.

Table 3. Intermolt duration (d, mean ± SE) of *Callinectes rathbunae* and *Callinectes sapidus* by salinity (5, 15, 25) for total crabs (gender pooled) and gender based on crab stages 7–16.

Species	Gender	5	N	15	N	25	N
Callinectes rathbunae	Total	18.2 ± 2.7	148	17.1 ± 2.7	151	25.3 ± 2.7	130
	Female	24.5 ± 2.7	77	21.9 ± 1.4	77	30.4 ± 4.9	41
	Male	25.4 ± 3.0	71	19.5 ± 2.6	72	34.7 ± 3.9	49
Callinectes rathbunae	Total	24.7 ± 2.7	142	21.3 ± 2.7	157	15.2 ± 2.7	122
	Female	30.3 ± 3.4	65	27.6 ± 1.9	62	18.4 ± 1.3	44
	Male	32.2 ± 3.7	66	26.9 ± 2.5	78	19.7 ± 2.9	61

For all two-way ANOVA and one-way ANOVA tests on intermolt duration by gender (between crab stage 7 and 16), the homogeneity of variance assumption was met (all P > 0.05). However, the normality tests failed (P < 0.01) and transformation did not stabilize the distribution. There was no significant interaction between gender and salinity for *C. rathbunae* (ANOVA: $F_{2,59} = 0.539$, P = 0.586). There was also no significant difference in intermolt duration between genders (ANOVA: $F_{1,59} = 0.122$, P = 0.728). Intermolt duration among salinity treatments differed significantly (ANOVA: $F_{2,59} = 6.668$, P < 0.01), with duration in salinity 15 being less than the duration in 25 (Table 3). There was no significant interaction between gender and salinity in intermolt duration for *C. sapidus* (ANOVA: $F_{2,59} = 0.119$, P = 0.888). There was no significant difference in intermolt duration between genders (ANOVA: $F_{1,59} = 0.141$, P = 0.709), but intermolt duration differed significantly among salinity treatments (ANOVA: $F_{2,59} = 10.261$, P < 0.001), with duration in salinity 25 being less than in either of the other salinities (Table 3).

DISCUSSION

Understanding the functional value of estuaries in relation to successful nekton recruitment requires knowledge of suitable physiochemical conditions, prey abundance, available habitat, and interactions with other organisms. Estuarine-dependent nekton like *C. rathbunae* and *C. sapidus* spawn near entrances of estuaries and sounds and early stages develop for 30–50 d at sea and are transported back into estuaries prior to settling and metamorphosing into young crabs. The early juvenile stages are distributed in numerous shallow habitats along the estuarine salinity gradient, and preferentially settle in structured habitats like seagrass (Perkins-Vissar et al., 1996; Pardieck et al., 1999; Jackson et al., 2001) and salt marsh (e.g., *Spartina* or *Juncus*; Mense and Wenner 1989; Peterson and Turner, 1994; Minello, 1999; Zimmerman et al., 2000), or other habitats such as ephemeral bryozoan mats (Pederson and Peterson, 2002).

In Camaronera Lagoon, Mexico, these two portunids are equally abundant, but vary in their spatial distribution within the lagoon (Cházaro-Olvera, 2002). Assuming habitat availability and prey abundance are not limiting factors to *C. rathbunae* and *C. sapidus*, quantification of the influence of salinity on development of these important commercial species is vital to better understand their biology and ecology as well as to provide data for culture of these species in the southern GOM.

Most estuarine-dependent nekton distribute differentially within estuaries and are able to utilize these areas of different salinity because they are good osmoregulators. Peterson and Ross (1991) indicated that juveniles of *C. sapidus* segregated along a salinity gradient in a Mississippi tidal river-estuarine ecosystem, with highest abundance in mesohaline to polyhaline habitats. In spite of the fact that megalopae have a high capacity to osmoregulate, the drastic change from marine to low salinity conditions during estuarine invasion can cause high mortality, which lessens as development proceeds (Hartnoll, 1982). For instance, Sulkin and Van Heukeleum (1986) noted that megalopal duration of *C. sapidus* is highly variable, being effected by salinity and water temperature. Results of our experiments indicate that the highest mortality in both species of *Callinectes* occurred early in the experiments during transformation from megalopa to crab stage 1, and ranged from 5–21%. Mortalities like this are not unexpected: Paul et al. (1983) determined a 30–35% mortality, and Dittel and Epifanio (1984) noted a mean mortality of

Table 4. Comparison of growth rates of *Callinectes* spp. Values presented are absolute rates except for the current study where mean rates are presented. *Values based on field conditions and modal size frequencies peaks.

Species (Gender)	Growth rate (mm d^{-1})	Salinity	Reference
C. sapidus (pooled)	0.61	5.7	Darnell, 1959*
C. sapidus (pooled)	0.33	18.8	Tagatz, 1968*
C. sapidus (pooled)	0.56	6	Jaworski, 1972*
C. sapidus (pooled)	0.82	15	Perry, 1975*
C. sapidus (pooled)	0.43	27	Leffler, 1972
C. sapidus (male)	0.24	5	This study
C. sapidus (female)	0.24	5	This study
C. sapidus (male)	0.35	15	This study
C. sapidus (female)	0.33	15	This study
C. sapidus (male)	0.38	25	This study
C. sapidus (female)	0.44	25	This study
C. arcuatus (male)	0.60	34–35	Paul et al., 1983
C. arcuatus (female)	0.51	34–35	Paul et al., 1983
C. arcuatus (male)	0.33	0–35	Quijano-Fernández, 1985*
C. arcuatus (female)	0.26	0–35	Quijano-Fernández, 1985*
C. arcuatus (pooled)	0.29	38	Dittel and Epifanio, 1984
C. rathbunae (male)	0.30	5	This study
C. rathbunae (female)	0.30	5	This study
C. rathbunae (male)	0.34	15	This study
C. rathbunae (female)	0.44	15	This study
C. rathbunae (male)	0.20	25	This study
C. rathbunae (female)	0.23	25	This study

20% for *C. arcuatus* during metamorphosis from megalopa to crab stage 1. Important physiological changes, which occur rapidly after the transformation from megalopa to crab stage 1, have been suggested as a reason for this mortality (Hartnoll, 1982). In field populations, these effects could be very important and quite evident because of the tendency of zoeal and megalopal stages to form patches when entering the estuarine system.

Juveniles and adults of *C. sapidus* are known to be able to tolerate extreme salinities (Williams, 1984), so it is not surprising that we found no difference in survival of *C. sapidus* in salinities ranging from a salinity of 5–25. Another congeneric species, *C. similis,* can also live in a wide range of salinities, as Guerin and Stickle (1997b) found no mortality in juveniles exposed to salinities of 5 and 45 for 21 d. However, *C. rathbunae* does not appear to be as tolerant, as we found survival significantly decreased with increasing salinity. There is some indication that survival in varying salinities may be related to individual acclimation and population adaptation to a particular salinity regime. Juveniles of *C. sapidus* from brackish water areas in Louisiana survived 2 mo at salinity 0, where all crabs from higher salinity areas in Texas died within 9 d at this salinity (Guerin and Stickle, 1992).

Growth rate varied considerably by species, salinity, and gender. Females of *C. rathbunae* always grew faster than males, and both genders grew fastest at the intermediate salinity. In contrast, males and females of *C. sapidus* grew at the same rate, similar to that reported by Haefner and Shuster (1964), Tagatz (1968), and Leffler (1972). We found growth of *C. sapidus* decreased with lower salinities, similar to results for *C. sapidus* and *C. similis*

Table 5. Comparison of the time required to achieve commercial size for *Callinectes* spp.

Species	Salinity	Commercial size (mm)	Time (mo)	Author
C. sapidus	5	110	15	This study
C. sapidus	9.6	127	12–20	Lippson, 1973
C. sapidus	15	110	10	This study
C. sapidus	15	112	10	Perry, 1975
C. sapidus	18.8	120	10–12	Tagatz, 1968
C. sapidus	25	110	8–9	This study
C. rathbunae	5	110	11–12	This study
C. rathbunae	15	110	8–10	This study
C. rathbunae	25	110	15–18	This study

from other studies (Tagatz, 1968; Guerin and Stickle, 1997a,b). Growth rates for *Callinectes* spp. are typically not distinguished by gender or across a range of salinity (Table 4). These data are often presented as absolute values and tend to obscure differences by size as well. Since salinity has also affected the scope for growth in brackish-water population of juvenile *C. sapidus* and *C. similis* (Guerin and Stickle, 1992; Guerin and Stickle, 1997a,b), it is important to make estimates by gender and salinity to more accurately model bioenergetics of growth.

As with growth rates, we found that intermolt duration was also influenced by salinity for one species, but in contrast, did not differ between genders for either species. There was no difference in intermolt duration among salinities for *C. rathbunae*; however, for *C. sapidus,* intermolt duration was significantly longer over the course of this study at the lowest salinity. Costlow and Bookout (1959) noted that *C. sapidus* required a longer time to metamorphose from a megalopa to a crab 1 stage when salinity was 31.1 compared to salinities of 20.1–26.7. This difference is probably due to differences in the stage of crabs considered and the salinity treatments. In other studies, however, salinity was reported to have no influence on intermolt duration in *C. sapidus* (Tagatz 1968; Cadman and Weinstein 1988). *Callinectes rathbunae* had a significantly longer intermolt duration in salinity 25 than *C. sapidus*, suggesting that *C. rathbunae,* like *C. similis* (Guerin and Stickle 1997a), molts most rapidly at intermediate salinities.

The time required to reach commercial size (110 mm CW) in Camaronera Lagoon, Mexico differed by species and was influenced by salinity. For *C. rathbunae*, this size was reached in 11–12 mo at low salinity, in 8–10 mo at intermediate salinity, and 15–18 mo at high salinity. In contrast, *C. sapidus* required 15 mo at the lowest salinity, 10 mo at intermediate salinity, and 8–9 mo at high salinity. These values are similar to those of *C. sapidus* from other locations, although some geographic variation is apparent (Table 5). These results indicate that potential culture of *Callinectes* spp. will require adjustment of salinity for each species to achieve optimal harvest in the shortest period of time.

Results of this study on the effects of salinity on survival, growth rate, and intermolt duration suggest that *C. rathbunae* is relatively more tolerant of low salinity habitats, whereas *C. sapidus* is more tolerant in mid- to high salinity habitats, although both species were tentatively grouped together into a low salinity clade (Norse and Fox-Norse, 1979). Recent molecular work supports *C. sapidus* being a member of this low salinity clade (Schubart et al., 2001). Other factors, like water temperature, can influence these species but in Camaronera Lagoon, it only varies 7–9°C over the course of the year (Cházaro-Olvera, pers. obs.).

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