

Distribution of *Farfantepenaeus aztecus* and *F. duorarum* on submerged aquatic vegetation habitats along a subtropical coastal lagoon (Laguna Madre, Mexico)

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*The spatial distribution of Farfantepenaeus shrimp was analysed in the Laguna Madre of Tamaulipas, Mexico. Sampling was carried out on submerged aquatic vegetation (SAV) habitats at five sites located along the coastal lagoon. Two nocturnal surveys were conducted during winter in 2005 (January–February), collecting a total of 3268 shrimp individuals. SAV beds were composed of a mixture of drift algae (mainly *Digenia simplex*), attached algae (mainly *Penicillus capitatus* and *Udotea occidentalis*) and seagrass (mainly *Halodule wrightii*). *Farfantepenaeus aztecus* was more abundant (39.5%) than *F. duorarum* (36.8%), and the remaining 23.7% corresponding to small unidentified *Farfantepenaeus* spp. were classified as recruits. Abundance of *F. aztecus* was significantly higher at sites 2 and 4, whereas *F. duorarum* did not show significant distribution differences along the Laguna Madre. Recruits, juveniles and total shrimp tended to decrease significantly at the northern part of the lagoon (site 1), where substrate was dominated by drifting algae and seagrasses were scarce or absent. The abundance of shrimp was positively related to seagrass biomass and/or water temperature, whereas there was a negligible or negative relationship with algal biomass. With the exception of subadults, a significant positive linear relationship between seagrass and shrimp abundance was fitted, indicating an increase in number of individuals of both species with increasing seagrass biomass. This suggests that seagrass is the most important component of SAV beds influencing the abundance of *F. aztecus* and *F. duorarum* along this hypersaline coastal lagoon.*

Keywords: penaeid shrimp, seagrass, drift algae, attached algae, subtropical coastal lagoon, Laguna Madre, Mexico

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INTRODUCTION

Estuaries and coastal lagoons represent highly important environments for marine biodiversity and productivity, due to their potential value as nurseries for several marine species including commercially important fish and invertebrates (Boesch & Turner, 1984; Beck *et al.*, 2001). Among these, shrimp species of the family Penaeidae represent one of the most important fishery resources inhabiting tropical and subtropical estuarine ecosystems during part of their life cycle (García & Le Reste, 1981). Spawning and larval development of penaeid shrimps take place in the sea, then they settle as postlarvae in estuaries and coastal lagoons where they spend their juvenile stage, and later as subadults migrate offshore and join the adult population (Dall *et al.*, 1990).

Submerged aquatic vegetation (SAV) in estuarine ecosystems is composed of different types of primary producers, including seagrasses and macroalgae, which cover the substrate in shallow areas forming extensive subtidal vegetated habitats

(Little, 2006). Seagrass and algal meadows have a positive influence on the abundance of juvenile fish and macrofaunal invertebrates (Jackson *et al.*, 2001; Bolam & Fernandes, 2002; Salovius & Kraufvelin, 2004; Unsworth *et al.*, 2007; Casares & Creed, 2008). In fact, physical and biological aspects of SAV (presence/absence, cover, density, biomass and species composition) can affect the distribution and abundance of juvenile shrimp in tropical estuaries and coastal lagoons (Haywood *et al.*, 1995; Loneragan *et al.*, 1998; Pérez-Castañeda & Defeo, 2004). Furthermore, it has been recognized that the density and biomass of seagrass enhance growth and survival of juvenile penaeids (Loneragan *et al.*, 2001; Pérez-Castañeda & Defeo, 2005), demonstrating the importance of SAV habitats as nursery areas for penaeids in the tropical region.

Although intertidal salt marsh vegetation is surmised to be the main estuarine habitat used by juvenile penaeids in subtropical latitudes (Boesch & Turner, 1984; Zimmerman *et al.*, 2000; Web & Kneib, 2002), some studies have also pointed out the value of SAV beds for the abundance of shrimp species in the subtropical regions of the western Atlantic (Sheridan, 1992; Murphey & Fonseca, 1995; Rozas & Minello, 1998; Clark *et al.*, 2004). However, the distribution of penaeid shrimps in relation to SAV habitats and abiotic environmental factors has not been examined in a microtidal

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hypersaline system where intertidal saltmarsh habitats are absent. This is of particular relevance because biotic, abiotic or landscape factors may affect the relative value of SAV beds as nurseries for penaeids (Beck *et al.*, 2001).

Abiotic environmental factors (e.g. salinity and temperature) also influence the distribution of juvenile shrimp within estuarine ecosystems (Lüchmann *et al.*, 2008). Juvenile *Farfantepenaeus aztecus* Ives, 1891 and *F. duorarum* Burkenroad, 1939 have been found in salinity regimes ranging from oligohaline to mixoeuhaline (2 to 37), and temperatures from 5 to 30°C; however, the preference for a particular range of salinity and temperature differs among estuaries (Murphey & Fonseca, 1995; Howe *et al.*, 1999; Pérez-Castañeda & Defeo, 2004) indicating that, irrespective of the abiotic conditions, other factors are also important in determining the distribution and abundance of penaeids.

The Laguna Madre of Tamaulipas is the biggest subtropical coastal lagoon in Mexico, extending 200 km along the Gulf of Mexico. It is a microtidal hypersaline ecosystem with extensive subtidal SAV beds, where three penaeid shrimp species, *Farfantepenaeus aztecus*, *F. duorarum* and *Litopenaeus setiferus* Linnaeus, 1767, co-occur (Britton & Morton, 1989; Barba, 1999). Unfortunately, information about the distribution of penaeids on SAV beds along this important coastal lagoon is not available elsewhere. In this study, we examine the abundance and distribution of *Farfantepenaeus* species on SAV habitats in the Laguna Madre of Tamaulipas in order to assess the utilization of SAV beds by penaeids along a subtropical hypersaline ecosystem, and to evaluate the relative influence of biotic and abiotic factors on shrimp abundance.

MATERIALS AND METHODS

Study area

The Laguna Madre of Tamaulipas (north-eastern Mexico) is a 200 km-long subtropical coastal lagoon with a diurnal microtidal regime located on the Gulf of Mexico (latitude 23°50' – 25°30'N and longitude 97°15' – 97°45'W). It has an area of about 2000 km² and a maximum depth of a little more than 3 m. The northern part of the lagoon has a width of ~20 km, decreasing southward to <3 km (Britton & Morton, 1989). The lagoon is for the most part cut off from the sea by long and narrow sandy barrier islands. However, four small (200–400 m width) permanent tidal inlets (Boca Mezquitil, Boca Ciega, Boca de Catán and Boca Caballo) breach the barrier islands (Figure 1), providing a little water exchange between the lagoon and the Gulf of Mexico. This situation combined with the lack of significant river discharges and the semi-arid climate, has made the Laguna Madre of Tamaulipas a hypersaline lagoon, where salinities are often over 33 (Barba, 1999) and sometimes in excess of 130 (Britton & Morton, 1989). In fact, the Laguna Madre of Tamaulipas is the largest hypersaline coastal lagoon in Mexico, and together with the Laguna Madre of Texas (USA) they comprise the greatest hypersaline lagoon system on the North American continent (Tunnel & Judd, 2002).

Peak recruitment of *F. aztecus* postlarvae into estuaries and coastal lagoons of the northern Gulf of Mexico occurs in spring (March–April) and autumn (August–October) (Matthews, 2008), whereas high densities of immigrating *F. duorarum* postlarvae have been found mainly from July to September (Criales *et al.*, 2006). Although both species occur throughout

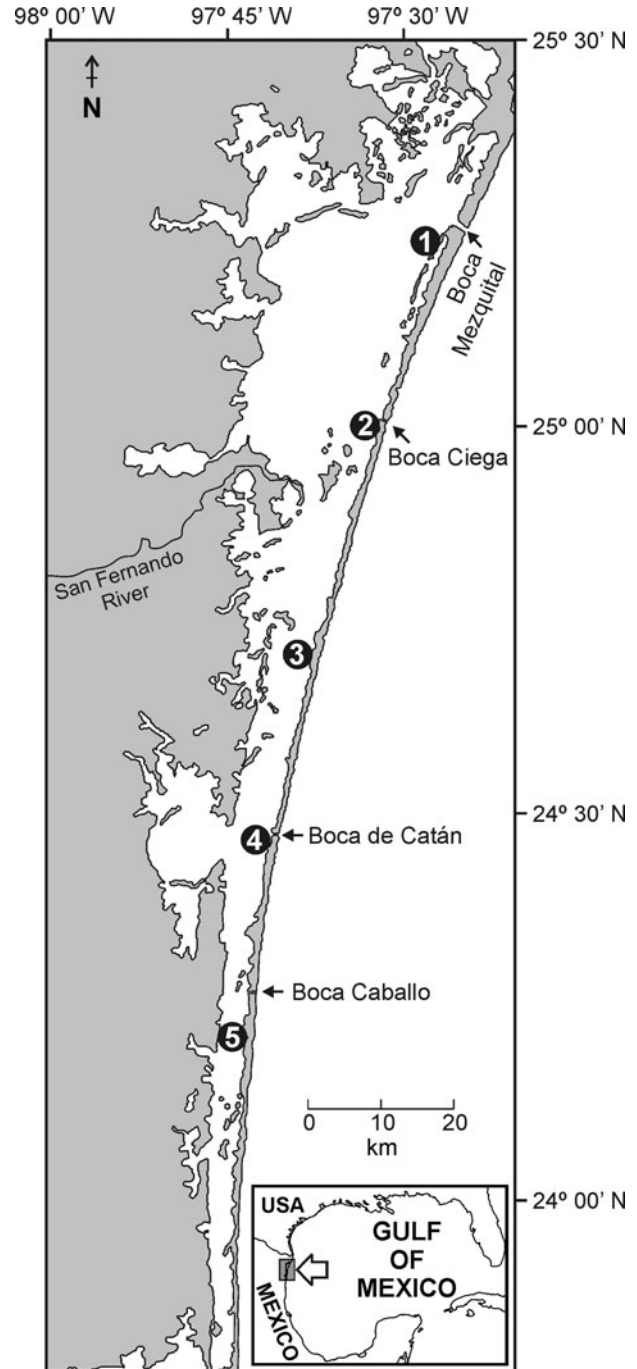


Fig. 1. Location of sampling sites (•) along the Laguna Madre of Tamaulipas (Mexico). Name and location of permanent tidal inlets are indicated by black arrows.

the Gulf of Mexico, *F. aztecus* is concentrated along the coast of Texas, Louisiana and eastern Mexico, whereas *F. duorarum* has centres of abundance in south-western Florida and south-eastern Mexico (Renfro & Brusher, 1982). However, locations of the main spawning areas of *F. aztecus* and *F. duorarum* are unknown for the Mexican coasts in this region.

Sampling and laboratory procedures

Five sites along the Laguna Madre of Tamaulipas were sampled during two winter months (January and February

2005), covering a distance of approximately 120 km along the inner margin of the island barriers (Figure 1). Shrimp were collected at night on flood tide by taking three replicate samples (tows) at each sampling site, using a beam trawl (2.0 × 0.6 m mouth; 2.5 m long; mesh size 1.3 cm). The beam trawl was hand-hauled 50 m along the bottom (1.0 m depth approximately) parallel to the water's edge, resulting in a sampling area of 100 m² per tow. A total of 30 beam-trawl samples were obtained for this study.

For each replicate sample, water temperature (°C) and dissolved oxygen (mg l⁻¹) were measured with a hand-held field instrument (YSI model 550A), and salinity with an optical refractometer. Additionally, submerged aquatic vegetation (SAV) was collected by taking two replicate samples (using a 1 m² quadrat) along a transect parallel to each 50 m trawl. SAV was bagged and transported to the laboratory for biomass determination (wet weight, g m⁻²) discriminating by type of SAV: algae and seagrass (excluding rhizomes). The algal community was composed of unattached forms drifting on the bottom of the lagoon (drift algae) and attached algae, which were analysed separately.

Shrimp were preserved in 70% ethyl alcohol. Each individual shrimp was measured (carapace length (CL)) to the nearest 0.1 mm and separated by species, according to morphological characteristics, under a dissecting microscope (Pérez-Farfante, 1970). All specimens smaller than 8.0 mm CL were only identified to the genus level, because of the lack of distinctive characteristics in *Farfantepenaeus* spp. below this size. Shrimp were categorized into 3 population components: recruits (CL < 8.0 mm), juveniles (CL ≥ 8.0 and < 15.0 mm) and subadults (CL ≥ 15.0 mm).

Data analyses

Data from both sampling dates were pooled to evaluate spatial variations in environmental factors and shrimp abundance. One-way ANOVAs were used to test for differences among sites in salinity, temperature, dissolved oxygen, algal (drift and attached) and seagrass biomass (g m⁻²), as well as to evaluate spatial differences in shrimp abundance (ind 100 m⁻²) discriminated by species, and population component. When necessary, data were transformed using log (x + 0.5) or fourth-root to fulfil ANOVA assumptions. At each site, length–frequency distributions were constructed for each species and compared with Kolmogorov–Smirnov tests (Zar, 1999).

Forward stepwise multiple regression analysis was used to assess the relative effect of salinity, temperature, dissolved oxygen and SAV biomass (discriminated by algae and seagrass) on shrimp abundance. This analysis was undertaken using F values of 1 and 0, chosen *a priori* for variable entry and removal, respectively, until the best regression model was obtained. Partial correlations and redundancy of independent

variables were also analysed. Additionally, linear functions were fitted to evaluate the influence of seagrass biomass on shrimp abundance.

RESULTS

Environmental variables

Salinity ranged from 34 (site 1) to 45 (site 3) and showed significant differences between sites along the coastal lagoon ($P < 0.01$, ANOVA). Salinity (mean ± SE) was significantly higher at site 3 (44.2 ± 0.4), whereas lower salinities were registered near the tidal inlets (Figure 1; Table 1), particularly at sites 1 (35.2 ± 0.4) and 5 (36.3 ± 1.3) which were not significantly different from each other. Water temperature tended to be slightly higher at site 5 (21.6 ± 0.3°C) and lower at site 1 (20.2 ± 0.7°C) (Table 1); however such differences were not significant ($P > 0.05$, ANOVA). Mean dissolved oxygen concentration varied from 5.5 to 7.1 mg l⁻¹ among sites (Table 1); however, no significant differences were found ($P > 0.05$, ANOVA).

The dominant drift alga was *Digenia simplex* (Wulfen) Agardh, 1822, whereas *Penicillus capitatus* Lamark, 1813 and *Udotea occidentalis* Gepp & Gepp, 1911 comprised most of the biomass of attached algae. On the other hand seagrass meadows were dominated by *Halodule wrightii* Ascherson, 1868 (shoal grass) with 90.6% of total seagrass biomass, while the remaining 9.4% corresponded to *Syringodium filiforme* Kützing, 1860 (manatee grass). Biomass of drift and attached algae was significantly different among sites along the lagoon ($P < 0.05$, ANOVA). The highest biomass of drift algae was observed at site 1 (751.4 ± 333.7 g m⁻²), whereas the lowest occurred at site 3 (15.1 ± 7.1 g m⁻²) (Table 1). Attached algae had the lower biomass at site 3 (6.4 ± 3.5 g m⁻²) and higher at site 2 (137.0 ± 40.5 g m⁻²). Significant differences in seagrass biomass were also detected among the different sites ($P < 0.05$, ANOVA), being highest at site 4 (99.8 ± 39.4 g m⁻²) and lowest at site 1 (1.1 ± 1.0 g m⁻²) (Table 1).

Farfantepenaeus shrimp

A total of 3268 shrimp belonging to two *Farfantepenaeus* species were collected in the Laguna Madre. *Farfantepenaeus aztecus* represented 39.5% of the total abundance, followed by *F. duorarum* with 36.8%. The remaining 23.7% corresponded to recruits (CL < 8.0 mm). With the exception of *F. duorarum* and subadults, shrimp abundance exhibited significant differences (ANOVAs, $P < 0.05$) among sites along the lagoon. Abundance of recruits and total shrimp was significantly lower at site 1 (ANOVAs, $P < 0.05$; Figure 2) and higher at sites 2 to 5, which did not reveal significant differences

Table 1. Spatial variation (mean ± SE) in salinity, temperature, dissolved oxygen, algae and seagrass biomass at five sampling sites along the Laguna Madre (Mexico).

Site	Salinity	Temperature (°C)	Dissolved oxygen (mg l ⁻¹)	Drift algae (g m ⁻²)	Attached algae (g m ⁻²)	Seagrass (g m ⁻²)
1	35.2 (0.4)	20.2 (0.7)	6.6 (1.0)	751.4 (333.7)	73.9 (31.1)	1.1 (1.0)
2	38.8 (0.5)	20.4 (1.0)	6.2 (1.0)	45.6 (25.0)	137.0 (40.5)	75.9 (22.8)
3	44.2 (0.4)	21.1 (1.6)	5.5 (0.1)	15.1 (7.1)	6.4 (3.5)	36.0 (12.5)
4	38.6 (0.4)	20.4 (0.2)	6.0 (0.2)	102.7 (68.2)	57.5 (27.1)	99.8 (39.4)
5	36.3 (1.3)	21.6 (0.3)	7.1 (0.5)	40.6 (21.6)	18.1 (5.7)	27.7 (13.1)

among them. On the other hand, *F. aztecus* was significantly more abundant at site 2 (ANOVA, $P < 0.05$), whereas the remaining sites were not significantly different from each other (Figure 2). Although the mean number of *F. duorarum* individuals tended to increase at site 5 (Figure 2) such differences were not significant (ANOVA, $P > 0.05$).

Length–frequency distributions by site showed a clear dominance of juveniles, constituting $\geq 70\%$ of collected individuals (Figure 3). In spite of the fact that the proportion of subadults (bigger individuals) was slightly higher at sites 5 and 1 for *F. aztecus* and *F. duorarum* respectively (Figure 3), there were no significant differences in length–frequency distributions among sites (Kolmogorov–Smirnov, $P > 0.05$).

Multiple regression models accounted for 30 to 56% of the variance of shrimp abundance. The densities of total shrimp and *F. duorarum* (juveniles + subadults and only juveniles)

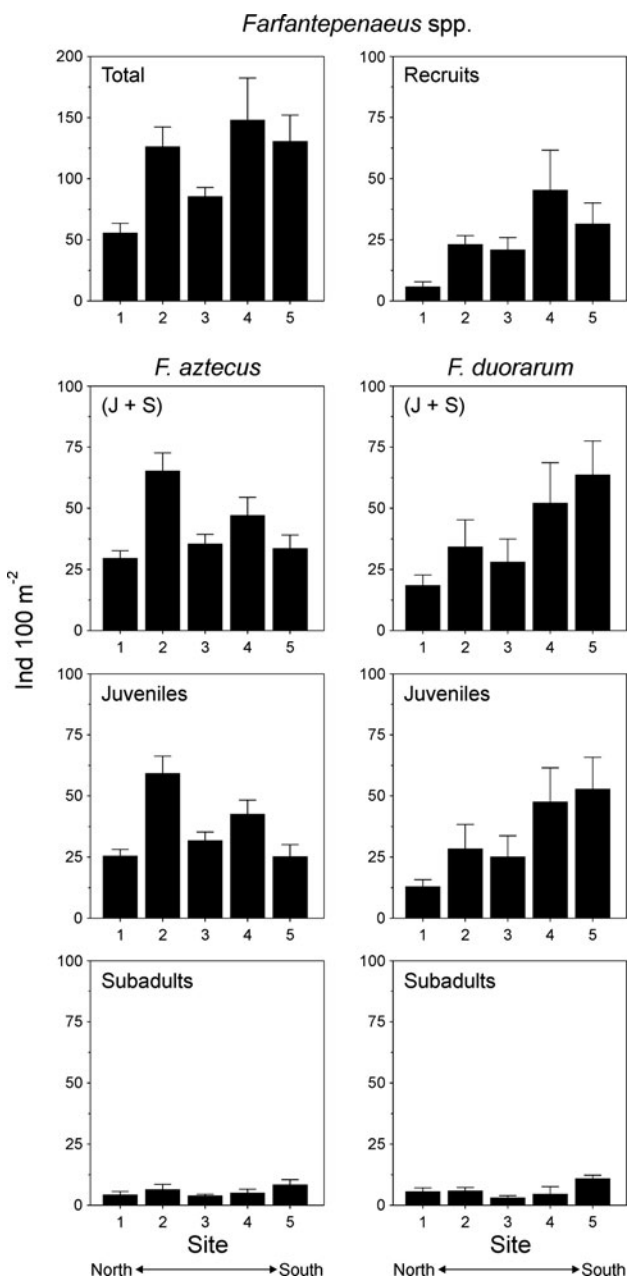


Fig. 2. Spatial variation of *Farfantepenaeus* shrimp abundance (mean + SE) by species and population component. J + S, juveniles + subadults.

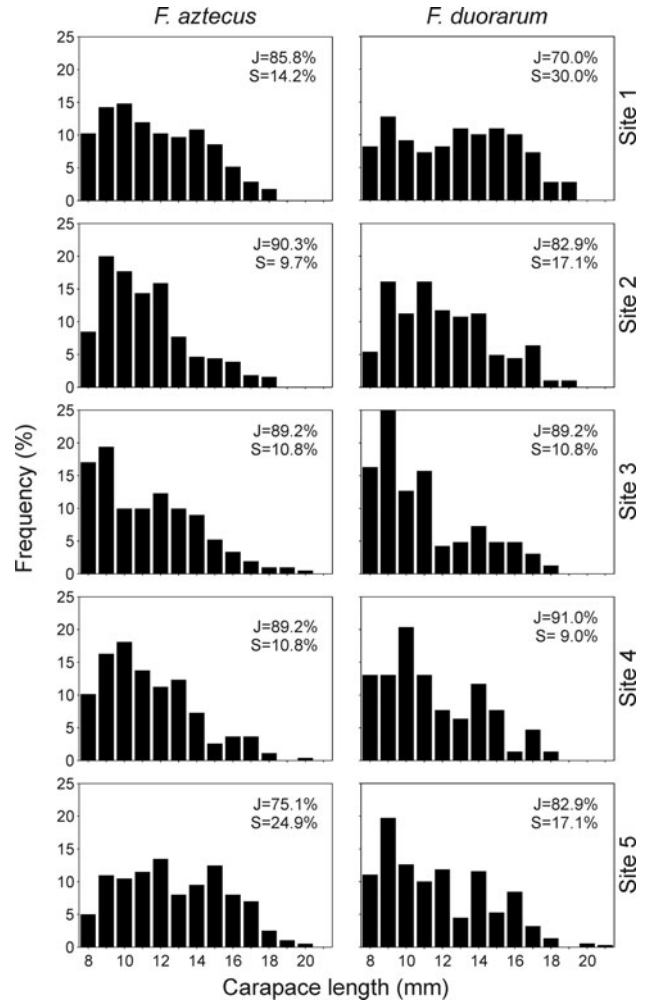


Fig. 3. Spatial variations in length–frequency distributions of shrimp species. Percentages of juveniles (J) and subadults (S) are indicated.

were positively related to seagrass biomass and water temperature, whereas subadults of this species were positively related to temperature. Abundance of *F. aztecus* (juveniles + subadults and only juveniles) was significantly explained by the seagrass biomass, whereas the abundance of recruits was inversely related to drift and attached algae, and positively with seagrass biomass (Table 2). In all of the above cases, with the exception of subadults, a significant positive linear relationship between seagrass and shrimp abundance was fitted, indicating an increase in numbers of individuals with increasing seagrass biomass (Figure 4).

DISCUSSION

Submerged aquatic vegetation

Spatial patterns in biomass were relatively different for each component of SAV. The peak biomass of drift and attached algae occurred at the northern part of the lagoon (sites 1 and 2, respectively). Conversely, seagrass was scarce at site 1, but it reached a peak biomass at site 4 (Table 1). Biomass of drifting algae was clearly higher than seagrass at sites 1 and 5, whereas the biomass of attached algae was markedly higher than seagrass at sites 1 and 2 (Table 1). In some

Table 2. *Farfantepenaeus* spp. Regression coefficients (\pm SE) for predictor variables in forward stepwise multiple-regression analyses of shrimp abundance (species and population components). Only predictors with at least one significant relationship are shown. Results of *F. aztecus* subadults are not shown because environmental variables were not significant predictors. J + S, juveniles + subadults; ns, not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

	Total shrimps	Recruits	<i>F. aztecus</i>		<i>F. duorarum</i>		
			(J + S)	Juveniles	(J + S)	Juveniles	Subadults
Intercept	-89.03 (72.76)	27.13 (4.72)***	31.69 (3.96)***	27.56 (3.87)***	-145.45 (39.21)**	-125.03 (36.79)**	-23.02 (8.95)*
Temperature	8.16 (3.64)*	ns	ns	ns	8.55 (1.96)***	7.29 (1.84)***	1.38 (0.44)**
Drift algae (g m^{-2})	ns	-0.01 (0.005)*	ns	ns	ns	ns	ns
Attached algae (g m^{-2})	ns	-0.11 (0.04)*	ns	ns	ns	ns	ns
Seagrass (g m^{-2})	0.48 (0.10)***	0.09 (0.04)*	0.22 (0.05)***	0.20 (0.048)***	0.14 (0.06)*	0.14 (0.05)*	ns
R ² adjusted	0.56***	0.45**	0.48***	0.45***	0.55***	0.53***	0.30**

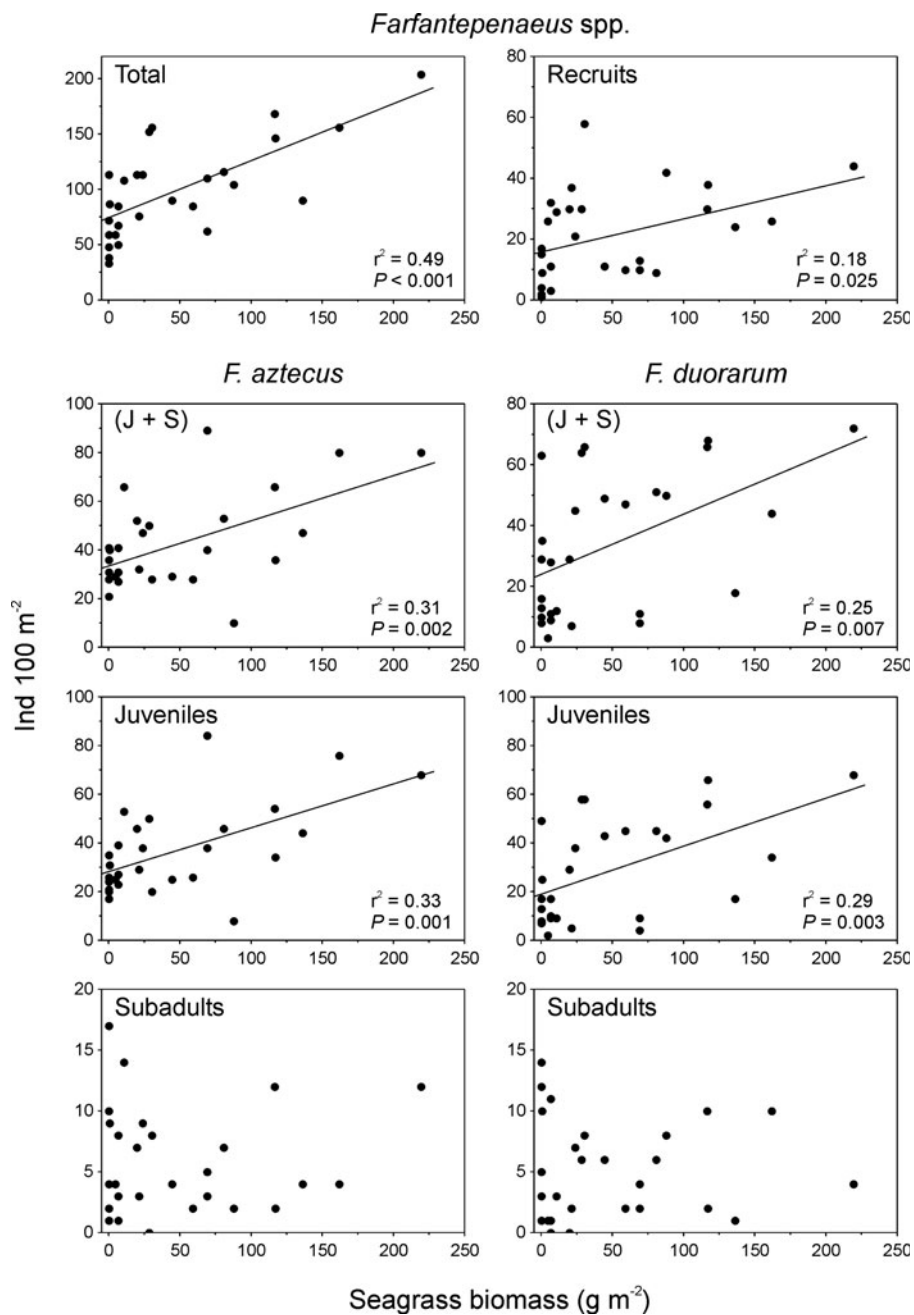


Fig. 4. Relationships between seagrass biomass and *Farfantepenaeus* shrimp abundance. A linear model of the form $Y = a + bX$ was fitted in all cases, excluding subadults. J + S, juveniles + subadults.

temperate estuarine ecosystems, loss of seagrass often coincides with increased macroalgal accumulations, because of light reduction for the newly recruiting seagrass shoots induced by the macroalgal canopy (Hauxwell *et al.*, 2001). This fact could explain the lower seagrass biomass in some areas along the Laguna Madre.

Distribution of shrimp along the lagoon

The presence of *Farfantepenaeus aztecus* and *F. duorarum* in the Laguna Madre is related to their natural distribution range, including the Gulf of Mexico coast (Pérez-Farfante, 1988). *Litopenaeus setiferus* is another penaeid shrimp species inhabiting this ecosystem (Barba, 1999), and it is indeed captured by artisanal fishers in the lagoon; however, this species was not present in any of our samples. The fact that the recruitment of *L. setiferus* postlarvae does not occur until May, as documented in Galveston Bay, Texas (Baxter & Renfro, 1966) may explain the absence of *L. setiferus* during our study.

The abundance proportions of *F. aztecus* and *F. duorarum* were roughly in agreement with the results obtained by Barba (1999) at the central part of the lagoon. On the other hand, this result differs from the abundance reported by commercial landings from the Tamaulipas coast, where *F. aztecus* constitutes >87% of the total shrimp catch (SAGARPA, 2005). Similarly, Howe *et al.* (1999) found an apparent anomaly between shrimp densities in a coastal lagoon of Alabama (USA) and commercial landings. They argued that *F. aztecus* and *F. duorarum* are not consistently distinguished from one another when harvested along the Alabama coastline, which may in part explain these differences.

Both shrimp species were approximately equally abundant in the lagoon; however, their spatial distribution patterns were quite different. *Farfantepenaeus aztecus* exhibited higher abundance at site 2, whereas no significant differences were detected for *F. duorarum*. The spatial patterns of abundance and shrimp size along the lagoon can be related to different biotic and abiotic factors influencing settlement, survival and growth of *F. aztecus* and *F. duorarum*. Indeed, local population densities of marine species are the result of both pre- and post-settlement processes operating together (Caley *et al.*, 1996). It is probable that the tidal inlets in the Laguna Madre have a differential postlarval influx, caused by their relative location to the spawning centre and by spatial variations in coastal currents, as has been reported for the supply of *F. duorarum* postlarvae to nursery grounds in Florida Bay (Criales *et al.*, 2006). However, although the abundance of juvenile shrimp is affected by the supply of postlarvae from offshore (Vance *et al.*, 1998), environmental conditions and SAV communities are key factors in explaining the spatial distribution of penaeids within estuaries and coastal lagoons (Haywood *et al.*, 1995; Loneragan *et al.*, 1998; Pérez-Castañeda & Defeo, 2004).

Laguna Madre exhibited extensive SAV beds composed of a mixture of drift algae (mainly *Digenia simplex*), attached algae (mainly *Penicillus capitatus* and *Udotea occidentalis*) and seagrasses (mainly *Halodule wrightii*). Drifting and attached algae can provide suitable habitats for macrofauna (Salovius & Kraufvelin, 2004), including some penaeid shrimp species in estuaries (Haywood *et al.*, 1995). However, according to our results, algae biomass (drift and attached) did not have a positive influence on shrimp

abundance in Laguna Madre, indicating that penaeids do not show a preference for drift or attached algae.

Spatial distribution of recruits suggests lower recruitment and/or higher mortality of smaller individuals at site 1, where the substratum was dominated by drifting algae. In some estuaries, it has been reported that algal beds can support densities of postlarval and juvenile shrimp (*Penaeus semisulcatus*) equal to those found in seagrass beds (Haywood *et al.*, 1995). However, in the present study algal material appear not to provide an important habitat for the settlement and survival of shrimp postlarvae. The negative influence of algae biomass on the abundance of recruits (Table 2) also gives support to this idea. On the other hand, seagrass biomass was a consistent linear predictor of abundance for *Farfantepenaeus* species and their population components, with the exception of subadults, suggesting a preference for seagrasses (i.e. *Halodule wrightii*). The lack of significant relationships between the abundance of subadults and seagrass biomass could be associated to shifts in habitat use among population components (Loneragan *et al.*, 1998). Previous studies have indicated that some penaeids have differential preferences for vegetated structures according to shrimp size and time of day (Kenyon *et al.*, 1995; Liu & Loneragan, 1997). Thus, the dependence of the population components of *F. aztecus* and *F. duorarum* on seagrass meadows could differ between day and night periods. This issue should be evaluated in the near future.

Even though seagrasses dominated the substrata at site 3, exhibiting higher seagrass biomass than site 5 (Table 1), site 3 was far away from the tidal inlets, and thus from the source of postlarvae, which may partially explain the lower abundance observed at this site in comparison with sites 2, 4 and 5, close to the tidal inlets Boca Ciega, Boca de Catán, and Boca Caballo, respectively (Figure 1). This result agrees with previous studies showing that the value of seagrass habitats for aquatic fauna is influenced by their location within the estuary (Hannan & Williams, 1998; Pérez-Castañeda & Defeo, 2004). Additionally, higher salinity levels at site 3 (44.2; Table 1) might also influence the use of seagrass habitats by penaeids. High salinity in combination with low temperature (i.e. 21.1°C) has negative effects on shrimp growth (Browder *et al.*, 2002), and thus, a lower affinity of penaeids for these areas may be expected. On the other hand, SAV beds at site 1 (neighbouring the tidal inlet Boca Mezquital) were clearly dominated by algae, which did not provide an equivalent habitat to seagrass for penaeids resulting usually in lower abundance of shrimp at this site. Shrimp inhabit seagrass beds because they provide food and protection against predators (Minello, 1993; Corona *et al.*, 2000). Indeed, a significantly higher abundance of shrimp was observed when seagrass biomass increased (Figure 4).

Temperature is directly related to movement, feeding, growth and survival of penaeids (Dall *et al.*, 1990), which could explain the positive influence of water temperature on the total abundance of shrimp and *F. duorarum*. This result is consistent with previous studies of penaeids where temperature influenced the spatial and temporal patterns of *F. brasiliensis* in a subtropical coastal lagoon from South America (Lüchmann *et al.*, 2008). In contrast, the lack of effect of salinity on shrimp density was the opposite of that observed in other tropical (Celestun) and subtropical (Conceição) lagoons, where shrimp density was positively related to salinity (Pérez-Castañeda & Defeo, 2001; Lüchmann *et al.*,

2008). However, Laguna Madre has higher salinity levels (34 to 45) than Celestun (22 to 32) and Conceição (23 to 27) which could account for these differences.

In summary, our results indicate that shrimp abundance was positively related to seagrass biomass and/or to water temperature, whereas there was a negligible or negative relationship with algal biomass, suggesting that seagrass is the most important component of SAV beds influencing the abundance of *F. aztecus* and *F. duorarum*. In this sense, the protection of seagrass beds from human impact may be critical for the conservation and management of these shrimp species of commercial value in the Gulf of Mexico.

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REFERENCES

- Barba E. (1999) Variación de la densidad y la biomasa de peces juveniles y decápodos epibénticos de la región central de la Laguna Madre, Tamaulipas. *Hidrobiológica* 9, 103–116.
- Baxter K.N. and Renfro W.C. (1966) Seasonal occurrence and size distribution of postlarval brown and white shrimp near Galveston, Texas, with notes on species identification. *Fishery Bulletin* 66, 148–158.
- Beck M.W., Heck K.L. Jr, Able K.W., Childers D.L., Eggleston D.B., Gillanders B.M., Halpern B., Hays C.G., Hoshino K., Minello T.J., Orth R.J., Sheridan P.F. and Weinstein M.P. (2001) The identification, conservation, and management of estuaries and marine nurseries for fish and invertebrates. *BioScience* 51, 633–641.
- Boesch D.F. and Turner R.E. (1984) Dependence of fishery species on salt marshes: the role of food and refuge. *Estuaries* 7, 460–468.
- Bolam S.G. and Fernandes T.F. (2002) The effects of macroalgal cover on the spatial distribution of macrobenthic invertebrates: the effect of macroalgal morphology. *Hydrobiologia* 475/476, 437–448.
- Britton J.C. and Morton B. (1989) *Shore ecology of the Gulf of Mexico*. Austin: University of Texas Press.
- Browder J.A., Zein-Eldin Z., Criales M.M., Robblee M.B., Wong S., Jackson T.L. and Johnson D. (2002) Dynamics of pink shrimp (*Farfantepenaeus duorarum*) recruitment potential in relation to salinity and temperature in Florida Bay. *Estuaries* 25, 1355–1371.
- Caley M.J., Carr M.H., Hixon M.A., Hughes T.P., Jones G.P. and Menge B.A. (1996) Recruitment and the local dynamics of open marine populations. *Annual Review of Ecology and Systematics* 27, 477–500.
- Casares F.A. and Creed J.C. (2008) Do small seagrasses enhance density, richness, and diversity of macrofauna? *Journal of Coastal Research* 24, 790–797.
- Clark R.D., Christensen J.D., Monaco M.E., Caldwell P.A., Matthews G.A. and Minello T.J. (2004) A habitat-use model to determine essential fish habitat for juvenile brown shrimp (*Farfantepenaeus aztecus*) in Galveston Bay, Texas. *Fishery Bulletin* 102, 264–277.
- Corona A., Soto L.A. and Sánchez A.J. (2000) Epibenthic amphipod abundance and predation efficiency of the pink shrimp *Farfantepenaeus duorarum* (Burkenroad, 1939) in habitats with different physical complexity in a tropical estuarine system. *Journal of Experimental Marine Biology and Ecology* 253, 33–48.
- Criales M.M., Wang J.D., Browder J.A., Robblee M.B., Jackson T.L. and Hittle C. (2006) Variability in supply and cross-shelf transport of pink shrimp (*Farfantepenaeus duorarum*) postlarvae into western Florida Bay. *Fishery Bulletin* 104, 60–74.
- Dall W., Hill B.J., Rothlisberg P.C. and Sharples D.J. (1990) The biology of the Penaeidae. In Blaxter J.H.S. and Southward A.J. (eds) *Advances in marine biology*. Volume 27. London: Academic Press, pp. 1–489.
- Garcia S. and Le Reste L. (1981) *Life cycles, dynamics, exploitation and management of coastal penaeid shrimp stocks*. FAO Fisheries Technical Paper 203. Rome: FAO.
- Hannan J.C. and Williams R.J. (1998) Recruitment of juvenile marine fishes to seagrass habitat in a temperate Australian estuary. *Estuaries* 21, 29–51.
- Hauxwell J., Cebrian J., Furlong C. and Valiela I. (2001) Macroalgal canopies contribute to eelgrass (*Zostera marina*) decline in temperate estuarine ecosystems. *Ecology* 82, 1007–1022.
- Haywood M.D.E., Vance D.J. and Loneragan N.R. (1995) Seagrass and algal beds as nursery habitats for tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) in a tropical Australian estuary. *Marine Biology* 122, 213–223.
- Howe J.C., Wallace R.K. and Rikard F.S. (1999) Habitat utilization by postlarval and juvenile penaeid shrimp in Mobile Bay, Alabama. *Estuaries* 22, 971–979.
- Jackson E.L., Rowden A.A., Attrill M.J., Bossey S.J. and Jones M.B. (2001) The importance of seagrass beds as a habitat for fishery species. *Oceanography and Marine Biology: an Annual Review* 39, 269–303.
- Kenyon R.A., Loneragan N.R. and Hughes J.M. (1995) Habitat type and light affect sheltering behaviour of juvenile tiger prawns (*Penaeus esculentus* Haswell) and success rates of their fish predators. *Journal of Experimental Marine Biology and Ecology* 192, 87–105.
- Little C. (2006) *The biology of soft shores and estuaries*. New York: Oxford University Press.
- Liu H. and Loneragan N.R. (1997) Size and time of day affect the response of postlarvae and early grooved tiger prawns *Penaeus semisulcatus* De Haan (Decapoda: Penaeidae) to natural and artificial seagrass in the laboratory. *Journal of Experimental Marine Biology and Ecology* 211, 263–277.
- Loneragan N.R., Kenyon R.A., Staples D.J., Poiner I.R. and Conacher C.A. (1998) The influence of seagrass type on the distribution and abundance of postlarval and juvenile tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) in the western Gulf of Carpentaria, Australia. *Journal of Experimental Marine Biology and Ecology* 228, 175–195.
- Loneragan N.R., Haywood M.D.E., Heales D.S., Kenyon R.A., Pendrey R.P. and Vance D.J. (2001) Estimating the influence of prawn stocking density and seagrass type on the growth of juvenile tiger prawns (*Penaeus semisulcatus*): results from field experiments in small enclosures. *Marine Biology* 139, 343–354.
- Lüchmann K.H., Freire A.S., Ferreira N.C., Daura-Jorge F.G. and Marques M.R.F. (2008) Spatial and temporal variations in abundance and biomass of penaeid shrimps in the subtropical Conceição, southern Brazil. *Journal of the Marine Biological Association of the United Kingdom* 88, 293–299.
- Matthews G.A. (2008) Variability in estimating abundance of postlarval brown shrimp, *Farfantepenaeus aztecus* (Ives), migrating into Galveston Bay, Texas. *Gulf and Caribbean Research* 20, 29–39.
- Minello T.J. (1993) Chronographic tethering: a technique for measuring prey survival time and testing predation pressure in aquatic habitats. *Marine Ecology Progress Series* 101, 99–104.
- Murphey P.L. and Fonseca M.S. (1995) Role of high and low energy seagrass beds as nursery areas for *Penaeus duorarum* in North Carolina. *Marine Ecology Progress Series* 121, 91–98.

- Pérez-Castañeda R. and Defeo O.** (2001) Population variability of four sympatric penaeid shrimps (*Farfantepenaeus* spp.) in a tropical coastal lagoon of Mexico. *Estuarine, Coastal and Shelf Science* 52, 631–641.
- Pérez-Castañeda R. and Defeo O.** (2004) Spatial distribution and structure along ecological gradients: penaeid shrimps in a tropical estuarine habitat of Mexico. *Marine Ecology Progress Series* 273, 173–185.
- Pérez-Castañeda R. and Defeo O.** (2005) Growth and mortality of transient shrimp populations (*Farfantepenaeus* spp.) in a coastal lagoon of Mexico: role of the environment and density-dependence. *ICES Journal of Marine Science* 62, 14–24.
- Pérez-Farfante I.** (1970) *Diagnostic characters of juveniles of the shrimps* *Penaeus aztecus aztecus*, *P. duorarum duorarum*, and *P. brasiliensis* (Crustacea, Decapoda, Penaeidae). US Fish and Wildlife Service, Special Scientific Report, Fisheries No. 599, 26 pp.
- Pérez-Farfante I.** (1988) *Illustrated key to Penaeoid shrimps of commerce in the Americas*. NOAA Technical Report NMFS 64, 32 pp.
- Renfro W.C. and Brusher H.A.** (1982) *Seasonal abundance, size distribution, and spawning of three shrimps* (*Penaeus aztecus*, *P. setiferus*, and *P. duorarum*) in the northwestern Gulf of Mexico, 1961–1962. NOAA Technical Memorandum NMFS–SEFC-94, 49 pp.
- Rozas L.P. and Minello T.J.** (1998) Nekton use of salt marsh, seagrass, and nonvegetated habitats in a south Texas (USA) estuary. *Bulletin of Marine Science* 63, 481–501.
- SAGARPA** (2005) *Carta nacional pesquera*. Diario Oficial de la Federación, 25 de agosto de 2006 (Primera sección), 21 pp.
- Salovius S. and Kraufvelin P.** (2004) The filamentous alga *Cladophora glomerata* as a habitat for littoral macro-fauna in the northern Baltic Sea. *Ophelia*, 58, 65–78.
- Sheridan P.F.** (1992) Comparative habitat utilization by estuarine macrofauna within the mangrove ecosystem of Rookery Bay, Florida. *Bulletin of Marine Science* 50, 21–39.
- Tunnel J.W. Jr and Judd F.W.** (2002) *The Laguna Madre of Texas and Tamaulipas*. College Station: Texas A&M University Press.
- Unsworth R.K.F., De Grave S., Jompa J., Smith D.J. and Bell J.J.** (2007) Faunal relationships with seagrass habitat structure: a case study using shrimp from the Indo-Pacific. *Marine and Freshwater Research* 58, 1008–1018.
- Vance D.J., Haywood M.D.E., Heales D.S., Kenyon R.A. and Loneragan N.R.** (1998) Seasonal and annual variation in abundance of postlarval and juvenile banana prawns *Penaeus merguensis* and environmental variation in two estuaries in tropical northeastern Australia: a six year study. *Marine Ecology Progress Series* 163, 21–36.
- Web S.R. and Kneib R.T.** (2002) Abundance and distribution of juvenile white shrimp *Litopenaeus setiferus* within a tidal marsh landscape. *Marine Ecology Progress Series* 232, 213–223.
- Zar J.H.** (1999) *Biostatistical analysis*, 4th edition. New Jersey: Prentice-Hall.
- and
- Zimmerman R.J., Minello T.J. and Rozas L.P.** (2000) Salt marsh linkages to productivity of penaeid shrimps and blue crabs in the northern Gulf of Mexico. In Weinstein M.P. and Kreeger D.A. (eds) *Concepts and controversies in tidal marsh ecology*. Dordrecht: Kluwer Academic Publishers, pp. 293–314.

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