Influence of estuarine zonation on exploited shrimp populations in a Mexican biosphere reserve: a feature for management and conservation

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The influence of estuarine zonation in a coastal lagoon on the population variability of exploited penaeid shrimps *Farfantepenaeus aztecus*, *F. brasiliensis*, *F. duorarum* and *F. notialis* (Crustacea: Decapoda) at the 'Ría Celestún' Biosphere Reserve, Mexico, was evaluated. Monthly samples of shrimp and environmental factors were taken throughout 1997 and 1998 in three zones (seaward, middle, inner) of Celestún lagoon. Salinity and aquatic vegetation biomass exhibited a clear spatial heterogeneity of habitat. A total of 20,757 shrimps were collected mainly at the seaward zone, which registered the highest salinity and aquatic vegetation biomass. This revealed the critical contribution of the seaward zone as the most suitable habitat for shrimp populations, mainly for recruits. Results support the implementation of spatially-explicit management strategies, such as the closure of the seaward zone for fishing activities. The significant relationship between the recruits and the subsequent abundance of shrimp in the lagoon also support this operational measure.

INTRODUCTION

The use of 'no take' zones in marine protected areas has been gaining popularity around the world as an alternative tool for fishery management and enhancement (Murray et al., 1999). The establishment of 'no take' zones directed to protect and conserve exploited marine resources (e.g. 'fishing refugia') relies on the knowledge of life history traits (Allison et al., 1998). However, this situation is particularly complicated when the resource is sequentially exploited by two fleets during different phases of its life cycle. This is the case of the penaeid shrimp populations of the Gulf of Mexico: the mechanized or industrial fleet targets the adult phase at sea whereas the artisanal one targets the estuarine shrimp phase (Garcia & Le Reste, 1981). Thus, the identification and protection of nursery habitats within estuaries is a key factor to achieve shrimp management goals.

In Mexico, the establishment of 'no take' zones are explicitly considered only for Biosphere Reserves, which have been designed exclusively to protect the landscape and some charismatic species (e.g. coral reefs, marine turtles, manatees, flamingos and other migratory birds: INEGI, 2000). Consequently, the spatial scales considered when delineating Mexican Biosphere Reserves (MBRs) are incongruent with those inherent to the scales of dispersion of exploited marine resources (Fernández & Castilla, 2000), and thus have failed to achieve the proposed goals of sustainable management and conservation (Castilla, 2000; Castilla & Defeo, 2001). Celestún lagoon (Mexico), situated within the limits of the 'Ría Celestún' Biosphere Reserve (RCBR), is an example. Biodiversity conservation is the primary goal of this reserve, and thus a small proportion of the lagoon

(5%) is considered a 'no take' zone because of its importance as a main food zone of the American flamingo (*Phoenicopterus ruber ruber* Linnaeus, 1758), one of the target species to be protected in this reserve (Defeo et al., 1998). The largest proportion of the lagoon is circumscribed to an area called the 'buffer zone', within which fishing activities are allowed (Diario Oficial, 2000).

However, the prevailing open access regime to fisheries generates a mutually exclusive view between biodiversity conservation and resource management. As a result, most marine resources on the RCBR are fully exploited or overexploited (Defeo et al., 1998), thus severely compromising the effectiveness of this biodiversity reserve. This urgently calls for the implementation of scientifically sound tools for managing the artisanally exploited marine resources in the RCBR, notably the multispecific penaeid shrimp fishery (Defeo et al., 1998), which includes *Farfantepenaeus aztecus* Ives, 1891, *F. brasiliensis* Latreille, 1817, *F. duorarum* Burkenroad, 1939 and *F. notialis* Pérez-Farfante, 1967. The main objective of this paper was to identify the main nursery habitat for shrimp populations in RCBR in order to provide guidelines for fishery management.

MATERIALS AND METHODS

Celestún lagoon is located in the north-west Yucatan Peninsula, Gulf of Mexico. It is about 22.5 km long, a total area of 28.14 km^2, with a permanent connection to the sea by a 0.46-km wide mouth (see figure 1 in Pérez-Castañeda & Defeo, 2002). There are no rivers, so the spatial salinity gradient is conditioned by groundwater discharges (via freshwater springs at the north part of the lagoon), tides
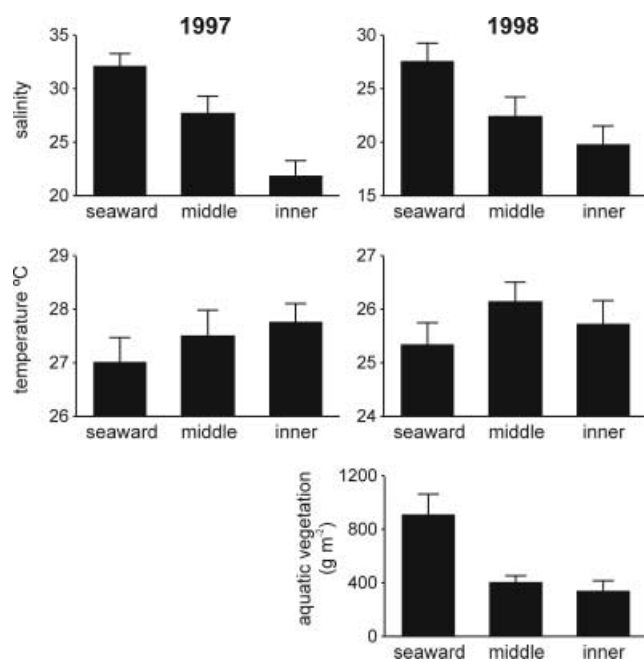
Figure 1. Spatial variations in salinity, temperature and aquatic vegetation biomass at the three estuarine zones (seaward, middle and inner).

Figure 2. Mean ($+SE$) relative abundance of shrimp populations, (A) recruits; and (B) discriminated by species at the seaward (solid bars), middle (crosshatched bars), and inner (open bars) zones. Note the different scales in the Y-axis.

and climatic seasons: 'dry'=March to May; 'rainy'=June to October; and 'nortes'=November to February. The 'nortes' season is characterized by strong winds from the north, little rainfall, and cool air temperatures. According to these characteristics, three hydrological zones (seaward, middle and inner) had been defined by Herrera-Silveira (1994) in relation to physical-chemical variables. Relative extension of each zone is as follows: seaward (26.7%), middle (23.3%), and inner (50.0%).

Shrimps were collected monthly during January 1997 to December 1998 by taking two replicate samples (trawls) at each of the three hydrological zones defined above during the same day. Sampling was always early in the morning (0700–1000 h), coinciding with the maximum catchability period for *Farfantepenaeus* species in estuaries (see review in Dall et al., 1990). To collect a sample, an artisanal fishing gear called a 'triangle' was dragged by one person along the bottom (1–1.5 m depth) for 5 min (covering a distance of 80 m). This gear is a conical-shaped net (mesh size=1.3 cm) attached to a triangular mouth (2.45-m wide and 1.25-m high) made with three mangrove poles. Shrimps collected were preserved in 70% ethyl alcohol and returned to the laboratory where they were counted and identified to species according to Pérez-Farfante (1970a,b). Specimens smaller than 8.0 mm carapace length (CL) were identified only to genus (i.e. *Farfantepenaeus* spp.) because of the very close taxonomic relationships of the species and the lack of distinct species characteristics at these sizes (Pérez-Farfante, 1970a,b). Because this is a shallow coastal lagoon without thermal stratification (mean depth=1.2 m), water temperature and salinity were measured at the first 10 cm of the water column for each replicate sample in each zone during both years. Aquatic vegetation biomass (wet weight) was collected monthly during 1998, simultaneously with shrimp samples, with 1 m² quadrats randomly allocated along and parallel to each trawl, resulting in three replicates per zone.
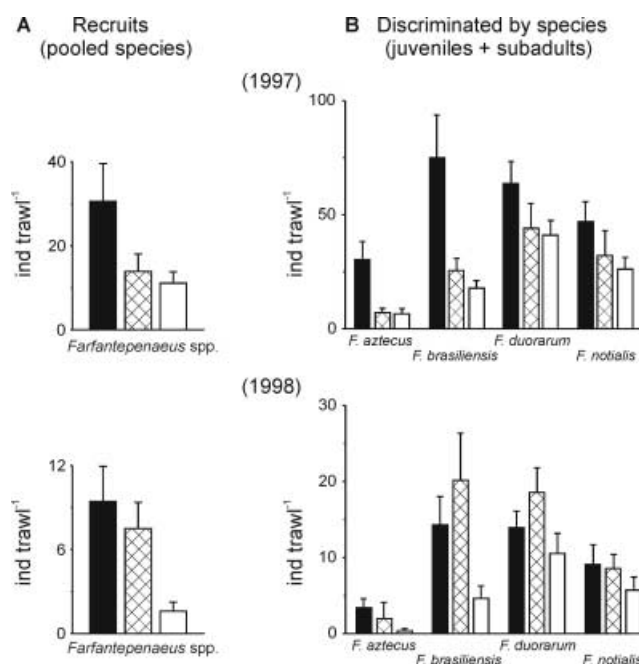
Two-way analyses of variance (ANOVAs) were applied to test for differences between zones and years in (i) abundance of recruits and of the four shrimp species; and (ii) salinity and temperature. A posteriori Tukey honestly significant difference test was used when significant differences were found. When necessary, data were transformed with $\log(x+1)$ to fulfil homoscedasticity. Differences in aquatic vegetation were tested by Kruskal–Wallis test because the normality assumption was not fulfilled (Zar, 1996).

RESULTS

Estuarine zonation

Salinity and aquatic vegetation biomass significantly differed ($P<0.001$) among the three hydrological zones. Spatial salinity pattern was consistent in both years: highest at the seaward zone and lowest at the inner one (Figure 1). The zonation of aquatic vegetation biomass followed the same pattern as salinity, being two times higher at the seaward zone (907 ± 155 g m^{-2}) and lower in the inner one (337 ± 79 g m^{-2}) (Figure 1). Though temperature did not vary significantly among zones, it was lower at the seaward zone than at the inner one (Figure 1).

Shrimp populations

A total of 20,757 shrimps belonging to four *Farfantepenaeus* species were collected in our 2-y study. *Farfantepenaeus duorarum* was most abundant (32.17%), followed by *F. brasiliensis* (27.24%), *F. notialis* (20.34%) and *F. aztecus* (7.47%). The remaining shrimps (12.78% of total) were recruits (CL<8.0 mm).

A highest relative abundance (ind trawl^{-1}) at the seaward zone and lowest at the inner one was a recurrent pattern for

Table 1. *Results of the statistical tests directed to evaluate differences in environmental factors and shrimp populations among estuarine zones and years.* F, *results of two-way ANOVAs;* H, *Kruskal–Wallis test.*

| Variables	Year	Zone	Year×Zone
		Effects	
Environment			
Salinity	$F_{1,162}=8.11$**	$F_{2,162}=15.55$***	$F_{2,162}=0.25$
Temperature	$F_{1,162}=8.49$**	$F_{2,162}=2.44$	$F_{2,162}=0.16$
Aquatic vegetation	–	$H_{2,108}=19.03$***	–
Shrimp populations			
Farfantepenaeus aztecus	$F_{1,174}=38.42$***	$F_{2,174}=8.42$***	$F_{2,174}=0.32$
F. brasiliensis	$F_{1,174}=45.19$***	$F_{2,174}=14.43$***	$F_{2,174}=2.98$
F. duorarum	$F_{1,174}=64.61$***	$F_{2,174}=2.86$	$F_{2,174}=3.49$*
F. notialis	$F_{1,174}=63.68$***	$F_{2,174}=2.01$	$F_{2,174}=2.98$
Recruits	$F_{1,174}=26.25$***	$F_{2,174}=7.30$***	$F_{2,174}=1.23$

*, $P<0.05$; **, $P<0.01$; ***, $P<0.001$.
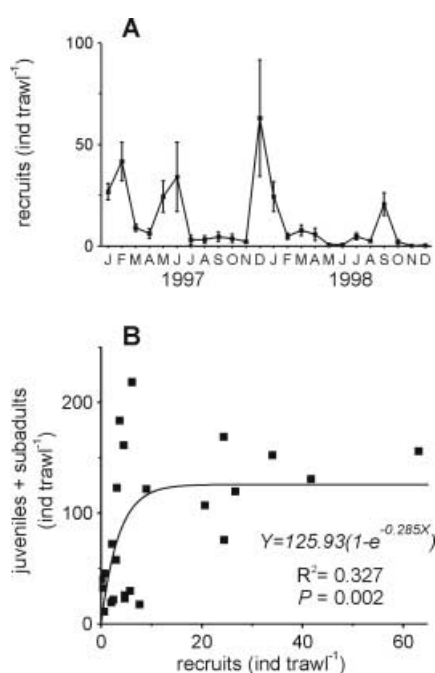
Figure 3. *Farfantepenaeus* spp. (A) Monthly variations in relative abundance (mean ±SE) of recruits; (B) asymptotic relationship between recruits and juveniles+subadults.

all shrimp species in both years, except for *F. brasiliensis* and *F. duorarum* during 1998, which showed highest relative abundance at the middle zone (Figure 2). Significant differences among zones were consistently detected only in *F. aztecus* and *F. brasiliensis* (Table 1). Relative abundance of recruits decreased consistently from the seaward zone to the inner one in both years ($P<0.001$; Table 1).

Recruits occurred throughout the sampling period, suggesting continuous recruitment, but registered four density peaks mainly during 'nortes' and 'rainy' seasons (Figure 3A). An asymptotic model successfully explained the relationship between recruits and juveniles+ subadults, indicating the importance of recruits for predicting the subsequent abundance of older shrimps (Figure 3B). Compensatory losses between recruits and older shrimps are indicated by this model.

DISCUSSION

The spatial distribution of shrimp populations exhibited a strong affinity for spatial salinity and aquatic vegetation patterns. A similar preference by penaeids for polyhaline environments and sea grass beds (i.e. seaward and middle zones) has been reported for other estuarine systems from the Gulf of Mexico (Minello et al., 1990; Wenner & Beatty, 1993; Howe et al., 1999). The mean salinity values at the seaward zone, which had consistently the highest abundance of recruits in our 2-y study, agreed with the optimum salinity for growth and survival of juvenile penaeids (Brito et al., 2000). Salinity was the most important factor controlling the spatial distribution of aquatic vegetation along the estuarine gradient. Subsequent surveys (R. Pérez-Castañeda, unpublished data) have demonstrated the recurrent spatial heterogeneity of vegetated beds, where the seaward zone is characterized by the sea grass *Halodule wrightii*, the middle zone by the sea grass *Ruppia maritima* and the inner zone by the sea grass *R. maritima* and the green alga *Chara fibrosa*. Vegetated habitats are important in determining the distribution of penaeids in estuaries, because they provide food and refugia from predators (Minello & Zimmerman, 1991). In this sense, sea grasses from the seaward and middle zones appeared to be preferred by shrimp populations. The spatial pattern observed for the penaeid shrimps could also be explained by Bell & Westoby's (1986) settlement model: they suggest that crustacean meroplanktonic larvae settle on the first sea grass patch they encounter. The settlement of postlarvae at the middle and inner zones may be less advantageous because they could imply higher energetic costs and exposure time to predation than at the seaward zone, with higher availability of refugia (Minello & Zimmerman, 1991).

Main nursery habitat as fishing refugium

Our results could support the implementation of spatially-explicit management strategies. Thus, the closure of the seaward zone for fishing could be useful to: (i) reduce the capture of recruits; (ii) increase the weight yield; and (iii) avoid the degradation of this main nursery habitat by fishing activities. Our results underscore the critical

contribution of the seaward zone as the most suitable habitat for shrimp populations, mainly for recruits. The protection of this younger population component may be crucial, as supports the subsequent abundance of shrimps in the lagoon (Figure 3B; see also Pérez-Castañeda & Defeo, 2000). Exclusion of trawling in the seaward zone could also be justified from an economic point of view, because the lower fishing yield (more individuals are needed to obtain 1 kg catch) and lower values in condition were consistently registered at this zone (Pérez-Castañeda & Defeo, 2002). Garcia & Demetropoulos (1986) reported an increase in yield when preventing fishers from trawling too close to the littoral nursery grounds for red mullet, resulting in diminished juvenile mortality. Protecting specific habitats for younger shrimps has been a successful strategy for pink shrimps in Florida, Gulf of Mexico (Nichols, 1986; Roberts, 1986). It has been widely documented that trawling disturbs bottom habitats and can modify the structure of estuarine benthic communities (Blaber et al., 2000), resulting in cascading effects throughout the ecosystem (Hixon & Carr, 1997). Thus, the closure of this zone should avoid indirect impacts of bottom trawling (e.g. habitat degradation) and protect non-target species incidentally captured mainly on vegetated habitats at the seaward zone (Meyer et al., 1999).

Considering that the two highest peaks of recruits were registered during the 'nortes' season (November–February) (Figure 3A), fishing effort should be restricted mainly during these months. The marked decrease in abundance of subadults and shrimp condition during this season (Pérez-Castañeda, 1999; Pérez-Castañeda & Defeo, 2002), also support this seasonal closure.

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