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# Composition and abundance of decapod crustaceans in mixed seagrass meadows in the Paraguaná Peninsula, Venezuela

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**ABSTRACT.** *Thalassia testudinum* and *Halodule wrigthii* are the dominant seagrasses in the Caribbean, being common across shallow shorelines, either as monospecific or as intermixed meadows. Among the macrofauna associated with these beds, crustaceans are considered essential for the whole ecosystem functioning. However, knowledge about the associated community of decapod crustaceans in assemblages of *T. testudinum* and *H. wrigthii* is still scarce, particularly outside of protected areas. Here we report eight new decapod species for the Paraguaná Peninsula (Falcón State, Venezuela) in association with intermixed seagrass beds: *Achelous tumidulus* Stimpson, 1871, *Alpheus* **aff.** *floridanus* Kingsley, 1878, *Chorinus heros* (Herbst, 1790), *Clibanarius antillensis* (Stimpson, 1859), *Clibanarius sclopetarius* (Herbst, 1796), *Latreutes parvulus* (Stimpson, 1866), *Panopeus occidentalis* Saussure, 1857, and *Processa fimbriata* Manning & Chace, 1971. These records represent habitat extensions and fill gaps in the geographical distribution of the species along the northern coast of South America. Furthermore, we found that statistical differences in decapod species abundance and composition are likely to be caused by the joint action of coverage and heterogeneity of the beds. Our results indicate that typical Caribbean species were the most influential in the community; nevertheless, the abundance of juvenile *Penaeus schmitti* Burkenroad, 1936 was notable, since they have rarely been found in these habitats. This finding highlights the role of non-protected areas as nursery habitats for economically important species. Our results show that seagrass meadows in the Paraguaná Peninsula reflect overall good health when compared to other Caribbean zones, representing an important habitat for the maintenance of crustacean populations.

**KEYWORDS.** Caridean and penaeid shrimps, new records, Falcón state, *Halodule*, *Thalassia*.

**RESUMEN. Composición y abundancia de crustáceos decápodos en praderas mixtas de hierbas marinas en la península de Paraguaná, Venezuela.** *Thalassia testudinum* y *Halodule wrigthii* son las hierbas marinas dominantes en el Caribe, siendo comunes en costas someras, tanto en monocultivos como en cultivos mixtos. Entre la macrofauna asociada a estas comunidades, los crustáceos son considerados esenciales para el funcionamiento del ecosistema. Sin embargo, el conocimiento sobre la comunidad de crustáceos decápodos asociada a praderas mixtas de *T. testudinum* y *H. wrigthii* es escaso, en particular fuera de zonas protegidas. En este trabajo presentamos ocho nuevas especies de decápodos para la Península de Paraguaná (estado Falcón, Venezuela) asociados a praderas mixtas de hierbas marinas: *Achelous tumidulus* Stimpson, 1871, *Alpheus floridanus* Kingsley, 1878, *Chorinus heros* (Herbst, 1790), *Clibanarius antillensis* (Stimpson, 1859), *Clibanarius sclopetarius* (Herbst, 1796), *Latreutes parvulus* (Stimpson, 1866), *Panopeus occidentalis* Saussure, 1857, y *Processa fimbriata* Manning & Chace, 1971. Estos registros representan extensiones de hábitat y completan brechas en la distribución geográfica de las especies a lo largo de la costa septentrional de Sudamérica. Diferencias estadísticas en la abundancia y composición de las especies de decápodos fueron posiblemente causadas por la acción conjunta de cobertura y heterogeneidad de las praderas. Las especies más influyentes en la comunidad son típicas para el Caribe; no obstante, la abundancia de juveniles de *Penaeus schmitti* Burkenroad, 1936 fue notable, puesto que raramente han sido encontrados en estos hábitats. Este hallazgo resalta el rol de áreas no protegidas como hábitats de cría para especies de importancia comercial. Nuestros resultados muestran que las praderas de hierbas marinas en la Península de Paraguaná reflejan un buen estado en comparación con otras zonas del Caribe, y representan un hábitat importante para el mantenimiento de las poblaciones de crustáceos.

**PALABRAS-CLAVE.** Camarones carídeos y peneidos, nuevos registros, estado Falcón, *Halodule*, *Thalassia*.

Seagrass meadows are a conspicuous and widely spread marine ecosystem in temperate and tropical zones (Ávila *et al.*, 2015); they have been ranked among the most valuable ecosystems in the biosphere, since they provide important ecological services, such as maintaining the coastline against erosion, and offering habitat for diverse species that are considered endangered or that have economic importance (Short *et al.*, 2007). In spite of this, seagrasses are experiencing a global decline in abundance (and therefore there is also a reduction of its associated community), which is mainly attributed to anthropogenic activities, such as sedimentation due to deforestation, an excessive production of nutrients in coastal waters, as well as habitat destruction, invasive species, pollution, and hydrological alterations (Cabaço *et al.*, 2008; Ávila *et al.*, 2015). Because of their sensibility to disturbances, seagrasses are considered good



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bioindicators to monitor the health of marine ecosystems, being important components of restoration and conservation projects (Short & Wyllie-Echeverria, 1996; Short & Neckles, 1999).

In the Caribbean area, in the subtidal zone, *Thalassia testudinum* Banks ex König (Hydrocharitaceae) is the dominant seagrass species, followed by *Halodule wrigthii* Ascherson (Cymodoceaceae); and they both occur either as monocultures or as intermixed cultures (Short *et al*., 2001). The benthic macrofauna associated with *Thalassia* spp. meadows is composed of a diverse and abundant community of crustaceans, mollusks, annelids, and fishes (Thayer *et al*., 1984, Bauer, 1985a,b; Sogard, 1989), with a density and distribution that is determined by biological factors (e.g. related to the seagrass, such as coverage, biomass, and leaf length, which increase the complexity of the habitat and its superficial area; as well as predation, competition, and food availability) and physical factors (e.g. dissolved oxygen, light, sedimentation rate, wind disturbance) (Bitter-Soto, 1999; Bostrom & Bonsdorff, 2000; Jiménez *et al*., 2005; Yamada *et al*., 2007). Comparatively, the information regarding *Halodule* spp. and its associated community is scarce, and there is even less information concerning dual assemblages of *T. testudinum* and *H. wrigthii*.

The presence of macrophytes is a major factor that influences the presence and abundance of crustaceans, and it has been shown that vegetated microhabitats consistently support greater species richness and abundance when compared with unvegetated areas (Lewis, 1984; Casares & Creed, 2008). The species richness, abundance, and composition of crustaceans in seagrass meadows is affected by the habitat complexity; notwithstanding, the responses vary along with the characteristics of the specific community and taxa (Lewis, 1984; Bitter-Soto, 1999). Decapod crustaceans have an important role in structuring the community associated with beds of *T. testudimun*, as they constitute an important food item in the diet of several juvenile stages of fishes and other crustaceans (Heck & Weinstein, 1989). In this aspect, epibenthic macroinvertebrates and their predators represent the main link of matter and energy to higher trophic levels (Thayer *et al*., 1984). In addition, their capacity as pollinators of *T. testudimun* during their larval stages has recently been confirmed by experimental evidence (Tussenbroek *et al*., 2016). Hence, their presence and abundance is essential to the whole ecosystem functioning (Lewis, 1984; Zupo & Nelson, 1999).

In Venezuela, decapod crustaceans are known mainly from the work of Rodríguez (1980). In Falcón state, which covers almost a third of the nation's shoreline (approximately 708 km, from a total of 3964 km), Sánchez *et al*. (1994) have made inventories of the penaeid and caridean shrimps, while Carmona-Suárez & Conde (1996) have described the community of brachyuran crabs. However, little attention has been given to brachyurans living within *Thalassia testudinum* meadows (Carmona-Suárez, 2000), and the most researched area is Morrocoy National Park (Carmona-Suárez, 2000; Miloslavich *et al*., 2005). Consequently, there are still localities without detailed studies regarding the taxocenoses associated with seagrass meadows; in particular those outside of protected areas. The aim of the present study was to determine the decapod species associated with mixed seagrass meadows in two zones of the eastern Paraguaná Peninsula (Falcón state, Venezuela). We focus on the richness and abundance of species, relating the effect that biological and physical factors of the meadows have on this associated community. We give a broad ecological account of the ecosystem, in context with other localities in the Caribbean. We also consider the geographical distribution of the decapods, showing that eight species are new records for the state, thus filling gaps in their previous distribution.

## MATERIALS AND METHODS

**Study site**. The studied shoreline at Falcón State is located in the western zone of Venezuela (Fig. 1), and it is composed of a variety of marine ecosystems, namely: rocky and sandy shores, mangrove swamps, coastal lagoons, salt marshes, and seagrass meadows (Carmona & Conde, 1989; Sánchez *et al*., 1994). This region is characterized by abnormally arid conditions, with scarce precipitation and nutrient input (Carmona-Suárez, 2007). The rainfall is markedly seasonal and restricted to a few months of the year: the dry season occurs from January to September, with a monthly mean rainfall of 8.6 mm; the rainy season occurs between October and December, with a monthly mean rainfall between 60 to 80 mm (López *et al*., 2011). The annual average air temperature is 27.7°C, and the annual mean wind speed is 10 km/h, varying according to the season (Goddard & Picard, 1976).

Seagrass beds are well developed in five shallow localities at the Paraguaná Peninsula (Carmona & Conde, 1989), two of which were chosen as study areas: El Supí (12°0'51.2"N, 69°49'59.9"W) and Adícora (11°56'37.2"N, 69°48'7.4"W). These sites are approximately 10 km apart, located outside of protected areas and close to tourist attractions. Both localities are sandy beaches with a low profile and muddy waters, delimited on the eastern side (windward side) by fringing coral reefs, which protect the seagrass meadows from the strong waves that predominate in the area (Carmona & Conde, 1989; Carmona-Suárez, 2007). Samplings were conducted in May 2013, during the predominant dry season.

**Specimen collection**. We conducted intensive samplings during the nighttime using a manual push net with an opening of 1 m (width) x 0.5 m (height), and a mesh size of 1 mm (modified from Manning, 1975). We took five replicas, corresponding to a fringe of approximately 1 m x 13 m (i.e. a sampling unit), in random zones within the meadows at each study site. Collected organisms were transferred to labeled plastic bags and fixed *in situ* using ethanol (70%) with glycerin (1%). In the laboratory, we identified individuals to the lowest possible taxonomic level using specialized keys (i.e. Chace, 1972; Rodríguez, 1980; Abele & Kim, 1986; Pérez-Farfante & Kensley, 1997). Specimens were

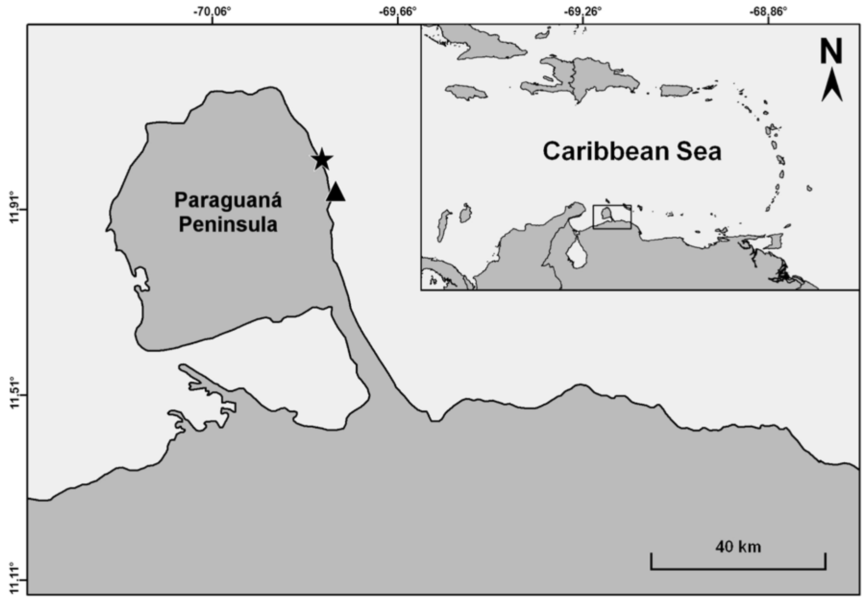


Fig. 1. Location of the sampling sites at the Paraguaná Peninsula, Falcón State, Venezuela (★, El Supí; ▲, Adícora).

deposited in the Colección de Crustáceos Decápodos "Dr. Gilberto Rodríguez" (CCDGR), of the Instituto Venezolano de Investigaciones Científicas (IVIC), Caracas-Venezuela.

**Seagrass meadow characterization**. We measured the total area of the meadows using a Global Positioning System (GPS) receiver. Structural aspects of the seagrass meadows were sampled in four randomly distributed replicas through 1 m² quadrats (with divisions every 10 cm) per each sampling site, which allowed us to measure vegetation coverage and number of short-shoot stems. We measured stem density by m² by counting the number of short-shoot stems and leaf blades in the corners and in the center of the quadrat (corresponding to an area of 500 cm²), and later extrapolating the result. We took four random samples of *Thalassia testudinum* (corresponding to an area of 100 cm²) and preserved them in cold. In the laboratory, we used those samples to determine the length, width, and leaf area for each blade of every short-shoot. We calculated the Leaf Area Index (LAI) following CARICOMP (Caribbean Coastal Marine Productivity Program, 1993-2003) methods (Linton & Fisher, 2004).

**Environmental parameters**. We measured salinity (ppm) using a temperature compensated refractometer, and water temperature (°C) and dissolved oxygen (mg/L) through a multi-parameter probe. We measured the sea level and depth (m) with a graduated pole fixed to the sea bottom. We took all measurements after sunset, before the biological surveys.

**Data analysis**. We calculated decapod abundance as the total number of individuals per site, density as the number of individuals per m², and richness as the number of species per study site. *t-student* tests were done to evaluate differences between localities according to the percentage of vegetation cover and density of decapods. Additionally, in order to determine the dissimilarity between the sites according to species richness and abundance, we used a Bray-Curtis similarity matrix with a non-parametric multidimensional scaling ordination (NMDS), and an analysis of similarities (ANOSIM). Moreover, to distinguish the contribution of each species to the observed differences in the samples, we calculated the similarity percentages (SIMPER). These analyses were implemented through the package *vegan* (Oksanen *et al*., 2017) in R language (R Development Core Team, 2017).

## RESULTS

**Decapod community.** During the surveys we collected a total of 706 individuals of carcinofauna, belonging to the orders Decapoda (584), Amphipoda (69), Isopoda (45), and Stomatopoda (8). In this paper we focus only on the decapods, which were distributed as 531 individuals from the El Supí site and 48 from the Adícora site. The richness was represented by 22 species in 13 families (Tab. I). Overall, the most abundant taxa were the caridean and penaeid shrimps, particularly species of the families Hippolytidae, Alpheidae, and Penaeidae.

**Inter-site comparison.** The most abundant family at El Supí was Hippolytidae, which accounted for 84% of the total decapods in the site; the dominant species were *Latreutes parvulus* (Stimpson, 1866), and *Alpheus packardii* Kingsley, 1880. At Adícora, the most abundant family was Penaeidae, which represented 59% of the total decapods; the dominant species was *Penaeus schmitti* Burkenroad, 1936, occurring mostly as juveniles and only present at this locality. At both sites the second most common family was Alpheidae, contributing to 14% of the total decapods for Adícora and to 2% for El Supí. The least common species were *Clibanarius sclopetarius* (Herbst, 1796), *Clibanarius antillensis* (Stimpson, 1862), and *Omalacantha bicornuta* (Latreille, 1825), which were found exclusively at the Adícora site.

The relative density of decapods was statistically different between the sites (*t*-test, $p < 0.05$), the highest value being found at El Supí ($7.83 \pm 1.28$ ind/m$^2$) and the lowest at Adícora ($0.70 \pm 0.07$ ind/m$^2$). The abundance of decapods was also statistically different between the sites (ANOSIM, $p < 0.01$, $R = 0.084$). The species that contributed the most to the dissimilarity were *Latreutes parvulus*, *Hippolyte obliquimanus* Dana, 1852, and *Alpheus packardii*, which together amounted to 81% of the community (Tab. II). The two localities were separated by a NMDS analysis with 95% confidence intervals (Fig. 2), which showed that dissimilarities in richness, abundance, and species composition enable differentiating the sites.

**Vegetation and physicochemical parameters.** The predominant species of seagrass at both localities was *Thalassia testudinum*. At El Supí the meadow was entirely intermixed with *Halodule wrightii*. Conversely, the meadow at Adícora was formed by continuous and monospecific *T. testudinum*, except for its southernmost portion where it was gradually replaced by a low-density bed of *H. wrightii*. At both sites, the meadows were established on a sandy calcareous substrate, which showed remains of the green calcareous alga *Halimeda* sp. El Supí site was notable because of the presence of flowers in the *T. testudinum*, the occurrence of several species of macroalgae (i.e. *Padina* sp., *Ulva* sp., and *Codium* sp.), and isolated coral boulders (*Porites* sp.).

The percentage of vegetation cover between sampling sites resulted significantly different (*t*-test, $p < 0.05$), with coverage ranging from 87 to 100% for El Supí, and from 69 to 97% for Adícora. The average values of *T. testudinum* leaf length, leaf width, LAI, and short-shoot stem density were overall higher for the bed at El Supí than for the Adícora locality (Tab. III). The depths of the meadows varied approximately from 17 to 60 cm, the shallowest portions occurring at Adícora and the deepest at El Supí. No significant differences were observed between sites in the environmental parameters (*t*-test, $p > 0.05$) (Tab. III).

Tab. I. Decapod species associated with mixed seagrass meadows by sampling site at the eastern Paraguaná Peninsula, Venezuela. Among the collected material, juvenile specimens that could not be identified to species were labeled as sp. The recorded caridean larvae were included in the statistical analyses; however, we omit them for the calculation of total species richness. Species number per family in parentheses; the juvenile individuals were not quantified for the total number of species (*, new addition to the carcinofauna of Falcón State, Venezuela).

| Suborder | Superfamily | Family | Species | El Supí | Adícora |
|---|---|---|---|---|---|
| Dendrobranchiata | Penaoidea | Penaeidae (4) | *Penaeus schmitti* Burkenroad, 1936 | | 23 |
| | | | *Penaeus* **cf.** *brasiliensis* Latreille, 1817 | | 2 |
| | | | *Penaeus* **cf.** *duorarum* Burkenroad, 1939 | 1 | 1 |
| | | | *Penaeus* sp. (juvenile) | 11 | 4 |
| | | | *Metapenaeopsis* sp. | 1 | |
| Pleocyemata | Caridea | Alpheidae (2) | *Alpheus packardii* Kingsley, 1880 | 101 | 2 |
| | | | *Alpheus* **aff.** *floridanus* Kingsley, 1878* | 3 | 2 |
| | | | *Alpheus* sp. (juvenile) | 3 | |
| | | Hippolytidae (3) | *Hippolyte obliquimanus* Dana, 1852 | 180 | |
| | | | *Latreutes parvulus* (Stimpson, 1871)* | 174 | |
| | | | *Thor manningi* Chace, 1972 | 17 | |
| | | Processidae (1) | *Processa fimbriata* Manning & Chace, 1971* | 3 | |
| | | Palaemonidae (2) | *Leander tenuicornis* (Say, 1818) | 10 | |
| | | | *Cuapetes americanus* (Kingsley, 1878) | 10 | |
| | | Sergestidae (1) | Unidentified* | 1 | |
| | Anomura | Diogenidae (2) | *Clibanarius antillensis* (Stimpson, 1859)* | | 3 |
| | | | *Clibanarius sclopetarius* (Herbst, 1796)* | | 1 |
| | | | *Clibanarius* sp. (juvenile) | 1 | 2 |
| | | Paguridae (1) | *Pagurus brevidactylus* (Stimpson, 1859) | 6 | |
| | Brachyura | Portunidae (3) | *Achelous tumidulus* Stimpson, 1871* | 2 | |
| | | | *Cronius sp.* | 1 | |
| | | | *Callinectes* sp. | 1 | |
| | | Panopeidae (1) | *Panopeus occidentalis* Saussure, 1857* | 3 | 4 |
| | | | *Panopeus* sp. (juvenile) | | 1 |
| | | Epialtidae (1) | *Chorinus heros* (Herbst, 1790)* | 1 | |
| | | Majidae (1) | *Omalacantha bicornuta* (Latreille, 1825) | | 1 |
| | Achelata | Palinuridae (1) | *Panulirus argus* (postlarvae) (Latreille, 1804) | 1 | 2 |
| | | | Total number of species per sampling site | 19 | 10 |

Tab. II. Ranking of species cumulative contributions to dissimilarity, in the Paraguaná Peninsula, Venezuela (*, statistically different).

| Species | Mean | SD | Ratio | Cumulative sum | P | |
|---|---|---|---|---|---|---|
| *L. parvulus* | 0.316199 | 0.055269 | 57211 | 0.3233 | 0.004 | ** |
| *H. obliquimanus* | 0.314173 | 0.051399 | 61125 | 0.6445 | 0.004 | ** |
| *A. packardii* | 0.161391 | 0.040321 | 40027 | 0.8095 | 0.004 | ** |
| *P. schmitti* | 0.048169 | 0.047205 | 10204 | 0.8588 | 1000 | |
| *T. manningi* | 0.032165 | 0.029431 | 10929 | 0.8917 | 0.004 | ** |
| *L. tenuicornis* | 0.022105 | 0.028063 | 0.7877 | 0.9143 | 0.004 | ** |
| *C. americanus* | 0.018567 | 0.013723 | 13530 | 0.9333 | 0.004 | ** |
| *P. occidentalis* | 0.008636 | 0.009026 | 0.9568 | 0.9421 | 1000 | |
| *P. brevidactylus* | 0.007857 | 0.010033 | 0.7831 | 0.9501 | 0.004 | ** |
| *A.* **aff.** *floridanus* | 0.007688 | 0.009483 | 0.8107 | 0.9580 | 1000 | |
| *C. antillensis* | 0.006307 | 0.009841 | 0.6409 | 0.9644 | 1000 | |
| *P. argus* | 0.005063 | 0.009722 | 0.5207 | 0.9696 | 1000 | |
| *P. fimbriata* | 0.004824 | 0.009849 | 0.4898 | 0.9745 | 0.004 | ** |
| *P.* **cf.** *brasiliensis* | 0.004273 | 0.009696 | 0.4407 | 0.9789 | 1000 | |
| *C. heros* | 0.003750 | 0.007661 | 0.4895 | 0.9827 | 0.004 | ** |
| *Metapeneopsis* sp. | 0.003750 | 0.007661 | 0.4895 | 0.9866 | 0.004 | ** |
| *A. tumidulus* | 0.003421 | 0.006984 | 0.4899 | 0.9901 | 0.004 | ** |
| *P.* **cf.** *duorarum* | 0.003099 | 0.005129 | 0.6043 | 0.9932 | 1000 | |
| *O. bicornuta* | 0.002192 | 0.005000 | 0.4385 | 0.9955 | 1000 | |
| *C. sclopetarius* | 0.002136 | 0.004848 | 0.4407 | 0.9977 | 1000 | |
| *Cronius* sp. | 0.001140 | 0.002328 | 0.4899 | 0.9988 | 0.004 | ** |
| *Callinectes* sp. | 0.001140 | 0.002328 | 0.4899 | 1.0000 | 0.004 | ** |

## DISCUSSION

In the Caribbean area, the most abundant decapods are usually carideans belonging to the family Hyppolytidae, within the genera *Hippolyte*, *Latreutes*, *Tozeuma* and *Thor* (Heck, 1979; Lewis, 1984; Bauer, 1985a,b; Holmquist *et al.*, 1989; De Grave *et al.*, 2006; Aguirre-Aguirre *et al.*, 2007). Our results partially agree with these reports: individuals in the genera *Latreutes* and *Hippolyte* accounted for 67% of the total individuals for the El Supí locality. However, in Adícora, the species *Penaeus schmitti* (Penaeidae family) contributed to almost 60% of the decapod community.

Of the 23 decapod species reported here, eight are new records for the Falcón state: *Achelous tumidulus* Stimpson, 1871, *Alpheus floridanus* Kingsley, 1878, *Chorinus heros* (Herbst, 1790), *Clibanarius antillensis* (Stimpson, 1859), *Clibanarius sclopetarius* (Herbst, 1796), *Latreutes parvulus* (Stimpson, 1866), *Panopeus occidentalis* Saussure, 1857, and *Processa fimbriata* Manning & Chace, 1971. These records represent habitat extensions and fill gaps in the geographical distribution of the species along the northern coast of South America. Four of these species were known to occur offshore in some of the Venezuelan Leeward Antilles, but not in the mainland coast, these are: *A. tumidulus*, *C. heros*, *L. parvulus* and *P. fimbriata*. Thus, our results expand their distribution to the continental portion of the Venezuelan territory (Appendix 1).

The species richness found in our study was equal or higher with respect to that described for similar seagrass communities, even though this comparison is constrained because the sampling methods are not standardized (Heck, 1979). For example, at Apalachee Bay (Florida, U.S.A., Gulf of Mexico), 19 species of decapods have been reported in association with *Thalassia testudinum* (Lewis, 1984). However, samplings in that survey were done through coring devices, which is a more efficient method to capture organisms of slow movement and smaller size (e.g. peracarids) (Lewis & Stoner, 1983). At Morrocoy National Park, a locality

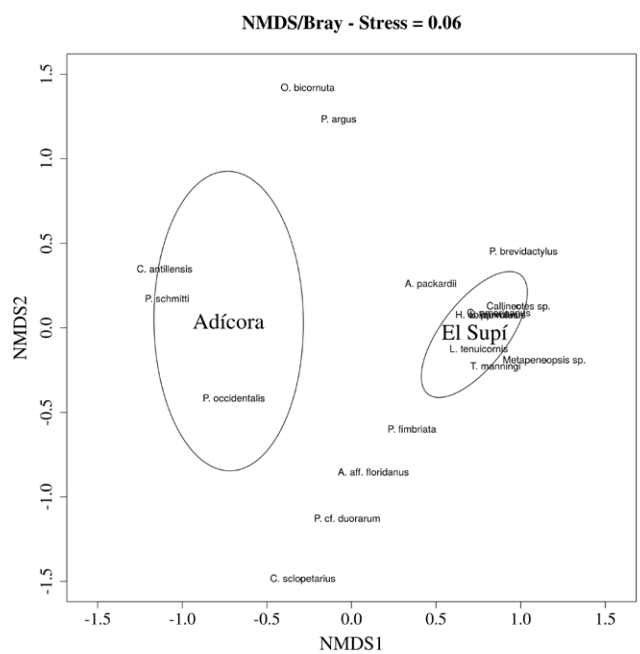


Fig. 2. Non-metric multidimensional scaling ordination (NMDS) for the abundance of decapods associated with two mixed seagrass meadows seagrass meadows at the Paraguaná Peninsula, Falcón State, Venezuela.

Tab. III. Seagrass meadow characteristics and environmental parameters by sampling site, Paraguaná Peninsula, Venezuela.

| | Adícora | El Supí |
|---|---|---|
| Area of meadow ($m^2$) | 1442 | 5860 |
| Leaf length (cm) (Mean ± SE) | 12.93 ± 0.07 | 13.12 ± 0.10 |
| Leaf width (cm) (Mean ± SE) | 1.03 ± 0.00 | 1.05 ± 0.01 |
| Stem density (stem/$m^2$) | 908.89 | 1511.48 |
| Mean LAI ($m^2/m^2$) | 1.23 | 2.18 |
| Substrate | Sandy calcareous sediment | Sandy calcareous sediment with coral boulders (*Porites* sp.) |
| Temperature (ºC) (Mean ± SE) | 27.40 ± 0.00 | 28.37 ± 0.03 |
| Salinity (%) (Mean ± SE) | 35.66 ± 0.33 | 37.00 ± 0.00 |
| Dissolved oxygen (mg/l) (Mean ± SE) | 6.76 ± 0.07 | 6.18 ± 0.01 |
| pH (Mean ± SE) | 8.48 ± 0.09 | 8.54 ± 0.02 |

closer to our study area, the reported richness was of 10 decapod species (Rodríguez & Villamizar, 2000), three of which were also present in our sampling sites: *Alpheus packardii*, *Pagurus* sp. and *Leander tenuicornis* (Say, 1818). Noteworthy, taxa not recorded at El Supí nor Adícora, in comparison with Morrocoy National Park, are the infaunal families Callianassidae and Upogebiidae; such differences are attributed to the sampling method using coring devices (Rodríguez & Villamizar, 2000).

Push net samplings, similar to the one we used, have found richness of 23 species in Puerto Rico (Bauer, 1985a,b) and of 14 species in Honduras (De Grave *et al*., 2006). In both of these sites, the most abundant species was *Latreutes fucorum* (Fabricius, 1798) (Hippolytidae) (Bauer, 1985a,b; De Grave *et al*., 2006). In our study, the dominant species include *Hippolyte obliquimanus* and *Latreutes parvulus* (Hippolytidae). Equivalent samplings in the nearby Colombian Guajira Peninsula have yielded a richness of 23 decapods, the most frequent species being *Tozeuma carolinense* Kingsley, 1878 (Hippolytidae) (Aguirre-Aguirre *et al*., 2007), which is considered one of the most common invertebrates in the epifauna of the western Atlantic (Heck, 1979; Greening & Livingston, 1982). This latter species was notably absent from our study site; however, it has been proposed that other small-sized and morphologically similar species within Hyppolytidae, such as *Thor manningi* Chace, 1972, may be ecologically equivalent to *T. carolinense* in some habitats (Bauer, 1985a). In Venezuela, comparable push net methods have been used to survey caridean shrimps associated with *T. testudinum* meadows at Los Roques Archipelago National Park, recording 24 species (22 Caridea, 2 Dendrobranchiata; B. López-Sánchez, unpubl. data). Among these species, seven were also present in the Paraguaná Peninsula: *Cuapetes americanus, Leander tenuicornis*, *Alpheus packardii*, *A. floridanus*, *T. manningi*, *H. obliquimanus*, and *Processa fimbriata*.

The density of individuals found in our study was inferior to that reported for Puerto Rico (Bauer, 1985a) and Florida (Gore *et al*., 1981). Conversely, our results show similar densities to those encountered in *T. testudinum* meadows from Los Roques Archipelago (7.66 ± 0.78 ind/$m^2$) (B. López-Sánchez, unpubl. data). The seagrass beds in Los Roques are highly similar to those of Paraguaná, as they both lay on a sandy calcareous substrate and are fringed by coral reefs offshore (B. López-Sánchez, pers. comm.). In addition, in Los Roques and in the Paraguaná Peninsula, the influx of freshwater into the sampling sites is only by rainfall (López *et al.*, 2011), unlike the meadows of Puerto Rico for example, where juveniles of two freshwater genera have been found (i.e. *Atya* Leach, 1816 and *Xiphocaris* von Martens, 1872) (Bauer, 1985a). It is likely that such freshwater influx, that constitutes an input of nutrients, promotes higher decapod abundances in Puerto Rico with respect to these sites in Venezuela, which can be considered atypically arid; nonetheless, it would be interesting to evaluate these environments during the rainy season.

A particular feature of the species composition at the Adícora locality is the occurrence of penaeid shrimps. *Penaeus schmitti*, commonly known as the white shrimp, has rarely been recorded in association with similar beds in other surveys, where the Dendrobranchiata genera typically present are *Sicyonia*, *Metapenaeopsis*, and the species *Penaeus duorarum* Burkenroad, 1939 (Heck, 1979; Lewis, 1984; Aguirre-Aguirre *et al*., 2007). *Penaeus schmitti* is considered the most abundant and economically valuable penaeid in Venezuela, forming an essential element in the artisanal and industrial fisheries of the Venezuelan Atlantic, including Lake Maracaibo and the Gulf of Venezuela (SARPA, 1996; Alió, 2000), which are adjacent to the Paraguaná Peninsula region. It has been suggested that the recruits of *P. schmitti* that spawn in the Gulf of Venezuela usually migrate to coastal zones during their final larval stages, and that their most intense reproductive period is the second quarter of the year (Ewald, 1964, 1965); which coincides with our sampling dates and may explain the occurrence of large numbers of *P. schmitti* juveniles within the Adícora meadow.

Another important species for the fisheries industries in Venezuela is the spiny lobster *Panulirus argus* (Latreille, 1804) (Marcano & Bolaños, 2001). According to the IUCN red list of endangered species, *P. argus* has been classified as Insufficient Data (Butler *et al*., 2009). The presence of this species in its postlarval stage at both sampling sites, together with caridean larvae at El Supí and juvenile *Penaeus schmitti* at Adícora, highlights the importance of seagrass meadows as nursery habitats. Furthermore, the simultaneous occurrence of caridean larvae and *P. argus* at El Supí may suggest that they play a role in the pollination of the meadow, since their presence in the area coincided with its flowering period; however, members of this latter superfamily are yet to be confirmed as pollinators of *T. testudinum* (Tussenbroek *et al*., 2016). Altogether, this information should serve to motivate conservation actions of these habitats along the western Venezuelan coast, as well as to prioritize research and monitoring efforts.

Regarding the characteristics of the *T. testudinum* meadows, the short-shoot stem density at both sampling sites was comparatively high with respect to values previously reported for the Caribbean. This was more evident at El Supí, where it was even higher (1511.48 stem/m$^2$) than the previously reported values (~ 1275 stem/m$^2$; Linton & Fisher, 2004). Plant density is considered a good indicator of the state of marine beds, elevated densities corresponding with healthier meadows (Linton & Fisher, 2004); thus, our results strongly suggest that the meadows at Paraguaná were in good physical condition during our sampling period. A further general indicator of the health of a meadow is the LAI, which takes into account the photosynthetic productive portion of the seagrass leaves as well as the short-shoot stem density (Linton & Fisher, 2004). For both of our sampling localities, the LAI was within the reference values for *Thalassia* spp. beds in the Caribbean (ranging from 0.03 to 8.7; Linton & Fisher, 2004); the higher values of LAI for El Supí being related to wider and longer leaves, and also reflecting the higher short-shoot stem density at that site.

In our study, the localities were distinguished by a NMDS analysis, indicating dissimilarities in abundance and species composition. Particularly, the meadow at El Supí showed the highest values of short-shoot stem density, mean LAI, vegetation cover, and total area. In addition, other qualitative aspects of El Supí were notable, such as the presence of *T. testudinum* flowers, several macroalgae species, and dispersed coral boulders; none of which were observed at Adícora. Both findings may suggest that El Supí is an environment with a greater structural complexity, as it has been shown that the structure and shape of macrophytes increases habitat complexity, enhances settlement, provides shelter, and reduces water flow for the benthic community (Heck & Wetstone, 1977; Stoner & Lewis, 1985; Castel *et al*., 1989). This highly heterogeneous environment and the greater area occupied by the meadow should provide additional niches for numerous species (Heck & Wetstone, 1977), and may explain the greater abundance and more diverse species composition that was evident at El Supí. It should also be taken into account that, within Falcón state, the beaches at Adícora are the ones most visited by tourists (Cazorla *et al*., 2010), but the consequences on the benthic ecosystem have not yet been evaluated. Further detailed studies –including comparisons between seasons and among other sites– are needed to clarify which of these hypotheses is more likely to explain the differences in the abundance and richness of decapods associated with *T. testudinum* beds in the Paraguaná Peninsula.

Our study is one of the few surveys of the decapod community of the Paraguaná Peninsula with an ecological approach. Based on our results and on the most recent literature for this zone (i.e. Sánchez *et al*., 1994; Carmona-Suárez & Conde, 1996), we may infer that the seagrass meadows in the area reflect an overall good health, and that they may represent critical habitats for the establishment and development of diverse marine crustacean populations, especially for the juvenile stages of commercially valuable species. These findings should serve to assist policy makers about the importance of non-protected areas that could be monitored more frequently, given that they are likely to serve as nursery habitats for species of economical profit.

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Appendix 1. Taxonomic summary of the new records for Falcón state, considering diagnosis, examined material, measurements, broad geographical distribution, and distribution in Venezuela. Depending on the species, measurements were taken for the following features: CL, length of carapace; SL, length of anterior shield of carapace; CW, width of carapace. When more than one specimen was examined, we give measurements of minimum and maximum for the respective feature.

***Achelous tumidulus* Stimpson, 1871**

Diagnosis. Two spines on palm; row of spinules but no spine on posterodistal margin of merus of each swimming leg. Movable part of antenna excluded from orbit by prolongation of basal segment; anterolateral teeth of carapace, alternatively large and small (Abele & Kim, 1986).
Material examined. CCDGR.– 1 juvenile; 2 ♂.
Measurements. CW: juvenile 8.58 mm; ♂ 16.10–16.85 mm. CL: 6.38 mm; ♂ 11.30–11.50 mm.
Habitat. Sandy intertidal bottoms (Hernandez-Ávila *et al*., 2007). Now in seagrass meadows.
General distribution. Western Atlantic. From Bermuda to Santa Catarina, Brazil; including Florida, the Gulf of Mexico, the Antilles, and the Guyanas (Rodríguez, 1980; Melo, 1999).
Distribution in Venezuela. Cubagua Island (Hernandez-Ávila *et al*., 2007). Now in Paraguaná Peninsula, Falcón state.

***Alpheus* aff. *floridanus* Kingsley, 1878**

Diagnosis. Rostrum dorsally subcarinate. Ocular hoods not spined and messially delimited by adrostral depressions. Antennal scale without prominent tooth of lateral margin. Major first chela with dorsal and ventral margins entire, not notched. Proximal article of carpus of the second periopod shorter than second; merus of third and fourth periopods with distal end of flexor margin rectangular, not produced into prominent tooth; dactyls of the third and fourth periopods subspatulate (Chace, 1972).
Material examined. CCDGR.– ♀; ♂.
Measurements. CL: ♀ 9.90 mm; ♂ 11.99 mm.
Habitat. Mud or sandy muddy bottoms up to 37 m depth, in conch shells *Lobatus gigas* (Linnaeus, 1758), and on seagrass beds (Rodríguez, 1980).
General distribution. Tropical Atlantic. From the Gulf of Mexico to Bahia, Brazil, in the Western Atlantic; and from Guinea to Congo, in the Eastern Atlantic (Rodríguez, 1980).
Distribution in Venezuela. Los Roques National Park (B. López-Sánchez, unpubl. data). Now in Paraguaná Peninsula, Falcón state.

***Chorinus heros* (Herbst, 1790)**

Diagnosis. Oval carapace, three times longer than rostrum. Rostrum divided from the base into two strong and long horns, approximately 1/3 of the carapace length, provided of two rows of hairs on the inner margin. Preorbital spine directed anteriorly, approximately 1/3 of the length of rostral horns. First pair of walking legs much longer than remaining pairs. The anterior third of the dorsal surface of the carapace with short tubercles provided with setae brushes (Rodríguez, 1980).
Material examined. CCDGR.– ♂.
Measurements. CW: 39.50 mm. CL: 18.70 mm.
Habitat. Between rocks in shallow water, up to 20 m depth (Marcano & Bolaños, 2001). Now on seagrass beds.General distribution. Western Atlantic. From Bermuda to Bahia, Brazil; including Florida Keys, the Gulf of Mexico, the Antilles, and Venezuela (Rodríguez, 1980; Melo, 1999).
Distribution in Venezuela. Cubagua and Margarita Islands (Marcano & Bolaños, 2001). Now in Paraguaná Peninsula, Falcón state.

***Clibanarius antillensis* (Stimpson, 1859)**

Diagnosis. Dactyls of walking legs shorter than propodus. Dactyls and propodus with broad longitudinal light stripe on dark background (olive green to brown color). Dense pubescence in the posterior margin of carapace and telson. Telson almost straight or slightly rounded, with no evident calcareous spines (Piñango, 1988).
Material examined. CCDGR.– 1 juvenile; 1 ovigerous ♀; ♂.
Measurements. SL: ovig. ♀ 3.74 mm; ♂ 3.30 mm.
Habitat. On sandy bottoms, near and on *Thalassia testudinum* beds, and on *Arca zebra* banks (Rodríguez, 1980).
General distribution. Western Atlantic. From southern Florida to Brazil (Rodríguez, 1980); including Puerto Rico (Bauer, 1985c), and Curaçao (Hazlett, 1966).
Distribution in Venezuela. Cubagua Island (Hernandez- Ávila *et al*., 2007), and Mochima National Park (Chiussi *et al*., 2001). Now in Paraguaná Peninsula, Falcón state.

***Clibanarius sclopetarius* (Herbst, 1796)**

Diagnosis. Dactyls of walking legs –second and third– of similar length or slightly longer than propodus, never shorter. Dactyls and propodus of the second and third pereiopods with dark (olive green to brown color) stripe laterally, bordered on each side by light stripe of equal thickness (Piñango, 1988; Rodríguez, 1980).
Material examined. CCDGR.– ♂.
Measurements. SL: 5.00 mm.
Habitat. Sandy bottoms (Rodríguez, 1980). Now on seagrass beds.
General distribution. Western Atlantic. From Florida to Santa Catarina, Brazil; including the Antilles, Venezuela and Guyana (Rodríguez, 1980; Melo, 1999).

Distribution in Venezuela. Zapara Island, and Tacarigua Lagoon National Park (Rodríguez, 1980). Now in Paraguaná Peninsula, Falcón state.

***Latreutes parvulus*** **(Stimpson, 1866)**

Diagnosis. Rostrum laterally compressed, almost circular in female, more elongate in male, upper margin with 6–8 teeth in female, 2–3 in male; few small teeth on tip; lower margin unarmed or with up to 5 shallow teeth, ventral part of rostrum produced somewhat backward. Caparace with middorsal row of 5–7 small, erect teeth; making an angle at base of mid dorsal row of teeth in females, upper margin nearly straight in males (Williams, 1984).

Material examined. CCDGR.– 43 ovig. ♀; 67♀; 34♂.

Measurements. CL: ovig. ♀ 2.04–3.47 mm; ♀ 1.32–1.48 mm; ♂ 1.16–2.09 mm.

Habitat. Coastal waters in sponges, among shells, dead coral, hydroids, and on seagrass beds; up to 44 m depth (Williams, 1984).

General distribution. Subtropical and tropical Atlantic. From North Carolina, USA, to Buenos Aires, Argentina (Christoffersen, 1998; Rodríguez-Almaraz *et al*., 2000), in the Western Atlantic; including the Gulf of Mexico, the Antilles, Venezuela and Guyana (Williams, 1984). In the Eastern Atlantic, from Western Sahara to Congo (Williams, 1984; Christoffersen, 1998).

Distribution in Venezuela. Cubagua Island (Hernández-Ávila *et al*., 2007). Now in Paraguaná Peninsula, Falcón state.

***Panopeus occidentalis*** **Saussure, 1857**

Diagnosis. Carapace approximately 2/3 as long as wide, regions well marked, surface sparingly granulated; carapace convex especially in gastric region; front narrow, advanced; anterolateral margins with 5 teeth, first 2 coalescent, second anterolateral tooth narrower and separated by deeper sinus from first tooth, third to fifth teeth thicker, more prominent and widely separated, third blunt, forming almost right angle at tip (Abele & Kim, 1986).

Material examined. CCDGR.– 7♂.

Measurements. CW: 11.4–19.4 mm. CL: 8.3–13.5 mm

Habitat. Between rocks, on mangrove roots, sponges, ascidians, and seaweed, on pilings of piers along shores; shallow waters up to 18.2 m depth (Williams, 1984). Now on seagrass beds.

General distribution. Western Atlantic. From North Carolina, USA, to Rio Grande do Sul, Brazil, including Bermuda, Central America, Antilles, and northern South America (Williams, 1984; Melo, 1999).

Distribution in Venezuela. Cubagua Island (Hernández-Ávila *et al*., 2007), Los Frailes archipelago (Tagliafico *et al*., 2005), and Orinoco River Delta (Pereira *et al*., 2004). Now in Paraguaná Peninsula, Falcón state.

***Processa fimbriata*** **Manning & Chace, 1971**

Diagnosis. Antennal spine present. Stylocerite with lateral spinule. Second pereiopods asymmetrical. Right second pereiopod with 14-16 meral and 31-40 carpal articles, left second pereiopod with 4-6 meral and 15-18 carpal articles. Carpus of fifth pereiopod shorter than propodus. Fifth abdominal somite with posterolateral spine (Manning & Chace, 1971).

Material examined. CCDGR.– 1 ovig. ♀; 2♀.

Measurements. CL: ovig. ♀ 10.89 mm; ♀ 3.19–4.18 mm.

Habitat. Shallow waters up to 37 m depth; on broken shells, corals, and sponges (Manning & Chace, 1971). Now on seagrass beds.

General distribution. Western Atlantic. From North Carolina, USA, to Rio de Janeiro, Brazil (Manning & Chace, 1971). Including the Bahamas, Puerto Rico (Manning & Chace, 1971), the Gulf of Mexico (Chace, 1972), Cuba (Martínez-Iglesias *et al*., 1996) and Tobago (Chace, 1972).

Distribution in Venezuela. Cubagua Island (Hernández-Ávila *et al*., 2007), Los Roques National Park (B. López-Sánchez, unpubl. data). Now in Paraguaná Peninsula, Falcón state.