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ORIGINAL ARTICLE

Effects of environmental factors on the abundances of the basket stars *Astrocaneum spinosum* and *Astrodictyum panamense* (Ophiuroidea: Gorgonocephalidae) in the northern Gulf of California, Mexico

María Dinorah Herrero-Pérezrul [a], Héctor Reyes-Bonilla[b] and Rebeca Granja-Fernández [c]

[a]Centro Interdisciplinario de Ciencias Marinas, Instituto Politécnico Nacional, La Paz, Mexico; [b]Departamento Ciencias Marinas y Costeras, Universidad Autónoma de Baja California Sur, La Paz, Mexico; [c]Doctorado en Ciencias Biológicas y de la Salud, Universidad Autónoma Metropolitana, Ciudad de México, Mexico

ABSTRACT
Gorgonocephalid ophiuroids, or basket stars, reside in diverse ecosystems of all oceans, but there is limited information on their basic ecology worldwide; therefore, this study provides the first detailed numerical analysis published to date of the abundances and spatial distributions of gorgonocephalids from the eastern Pacific Ocean. We analysed the relevance of geography (latitude, longitude), oceanographic factors (temperature, chlorophyll *a* concentration) and bottom type (coral, rock, sand, fleshy algae, coralline algae and turf) on the abundances of *Astrocaneum spinosum* and *Astrodictyum panamense* in Los Angeles Bay, Mexico (29°N, 113°W), in 2006–2007. Depth did not influence the number of individuals per census, but an elevated chlorophyll *a* concentration resulted in a higher abundance during the autumn (possibly the reproductive season of *Astrodictyum panamense* and *Astrocaneum spinosum*). The abundances of both species were positively linked to the presence of rocky bottoms and decreased in sandy areas. Additionally, the presence of live coral favoured the occurrence of *Astrodictyum panamense*, while high macroalgal cover decreased its abundance. The spatial distributions of both ophiuroids were aggregated at most sites, and they were always associated with different species of octocorals, which are abundant in the area. *Astrocaneum spinosum* is considered among the 30 most important invertebrates in the aquarium trade in Mexico; therefore, its permanence in the study area could be affected by excessive extractions.

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Introduction

Ophiuroids are among the most numerically abundant and diverse echinoderms on rocky and coral reefs around the world (Stöhr et al. 2012) and contribute significantly to the total species richness, abundance and biomass of benthic communities (Birkeland 1988; Dahm 1999). These echinoderms range widely in size and many are extremely mobile, but others have cryptic lifestyle habits. For this reason, the specimens are usually difficult to identify by visual means and to collect or manipulate (Ambrose 1993; Summers & Nybakken 2000). The logistical difficulty of sampling ophiuroids in the field has hampered the advance of ecological studies about this class, particularly if interest is focused on the species where populations reside in protected areas and where sampling must be conducted while causing the least possible damage to the environment.

Among the most recognizable of the ophiuroid families is the Gorgonocephalidae Ljungman, 1867, the so-called basket stars, which comprise approximately 34 genera distributed worldwide (Rosenberg et al. 2005; Stöhr et al. 2012). Members of this family are often gregarious, epizoic on cnidarians and sponges, and feed on plankton using their branched arms to capture prey with the help of mucous glands (Patent 1970; Hendler & Miller 1984). These organisms have increased their importance as the producers of ecosystem services because some species generate steroid-type substances with antiviral activity against human viruses, such as simple herpes and polio (Maier et al. 2000).

There are seven representatives of Gorgonocephalidae in the eastern Pacific (Maluf 1988; Lara de Castro-Manso 2010; Herrero-Pérezrul et al. 2014); two species are exclusively tropical (*Gorgonocephalus diomedeae*

CONTACT Rebeca Granja-Fernández beckygranja@gmail.com Doctorado en Ciencias Biológicas y de la Salud, Universidad Autónoma Metropolitana, San Rafael Atlixco 186, Col. Vicentina, CP 09340, Ciudad de México, Mexico

Lütken & Mortensen, 1899 from Panama, and *Astrodendrum galapagensis* A.H. Clark, 1916, endemic to the Galapagos Islands, Ecuador); three others are restricted to higher latitudes (*Gorgonocephalus eucnemis* (Müller & Troschel, 1842), resident of rocky areas from Guadalupe Island, Mexico (29°N) to the Bering Sea); and two species are from Chile, *Gorgonocephalus chilensis* (Philippi, 1858) and *Astrotoma agassizii* Lyman, 1875). The two remaining species have a more widespread distribution and can be found from Central and South America to Mexico to as far north as the Gulf of California (Honey-Escandón et al. 2008; Alvarado et al. 2010; Granja-Fernández et al. 2015). One of these species belongs to the genus *Astrocaneum* Döderlein, 1911, which exclusively inhabits shallow waters in tropical and subtropical areas of the Caribbean Sea and the eastern and western Pacific; and the second species is a member of *Astrodictyum* Döderlein, 1928, a group of gorgonocephalids that lives only in the Pacific Ocean (Kroh 2002).

According to Hendrickx et al. (2005), *Astrocaneum spinosum* (Lyman, 1875), the spiny basket star, is an ophiuroid distributed throughout the Gulf of California, although its full geographic range extends south to Panama in the eastern Pacific (Maluf 1988). The species is not considered a resident of the western coast of the Baja California Peninsula; nevertheless, one specimen collected at Tortugas Bay (27°N, 114°W) was deposited at the Invertebrate Collection of the Scripps Institution of Oceanography (catalogue number SIO E 801; Luke 1982). In the Gulf of California, *Astrocaneum spinosum* has been found on muddy and sandy bottoms as deep as 183 m, but also in shallow waters (∼4 m depth) associated with octocorals from reef communities (Brusca 1980, 2005). Although no data exist describing its biology and ecology, Piña-Espallargas et al. (2002) included this species as one of the 30 most important species in the aquarium trade in Mexico, an indication of a possible risk due to the high level of removal from its local habitat.

On the other hand, *Astrodictyum panamense* (Verrill, 1867) is reported at depths from 3 to 64 m on coral and rocky reefs of the Galapagos Islands (Ecuador), Pearl Islands (Panama), Malpelo Island (Colombia), and Zorritos (Peru) (Verrill 1867; Birkeland et al. 1975; Cohen-Rengifo et al. 2009), as well as in the oceanic Revillagigedo Islands (18°N; Ayala-Bocos et al. 2011; Granja-Fernández et al. 2015) and the Gulf of California (Brusca 1980; Granja-Fernández et al. 2015). In this region, the Panamanian basket star has its northern distributional limit at La Paz (24°N, 110°W) and Mazatlán (23°N, 109°W) (Verrill 1867; Maluf 1988; Caso et al. 1996; Hendrickx et al. 2005). Solís Marín et al. (2005) indicated that the species also occurs in Sonora (northeastern coast of the Gulf of California; no locality mentioned), and it has also been reported at Tortugas Bay, on the west coast of Baja California (Ayala-Bocos et al. 2011). The species *Astrodictyum panamense* is a suspension feeder, mostly residing on rocky and sandy bottoms where it usually lives entangled in the branches of gorgonians. According to Ayala-Bocos et al. (2011), they are associated with common ophiuroids such as *Ophionereis annulata* (Le Conte, 1851), *Ophiocoma aethiops* Lütken, 1859, *Ophioderma sodipallaresi* Caso, 1986, *Ophiolepis pacifica* Lütken, 1856, and *Ophiactis simplex* (Le Conte, 1851).

With the goal of improving our knowledge about the basic biology of species of the family Gorgonocephalidae, in this study we present data on the abundances of *Astrocaneum spinosum* and *Astrodictyum panamense* in Los Angeles Bay (a Biosphere Reserve located in the northwestern Gulf of California, Mexico), complemented with an analysis of the relationship of the abundances of these gorgonocephalids with selected environmental factors. The study area was selected because it is the only place in Mexico (and probably in the eastern Pacific Ocean) where these two species are common and relatively numerous in shallow water (less than 20 m; M. Dinorah Herrero-Pérezrul 2007, personal observation); therefore, detailed underwater surveys could be conducted with SCUBA equipment.

Material and methods

Study area

Los Angeles Bay is located at a latitude of 29°N on the eastern margin of the Baja California Peninsula (Figure 1). The region is relatively deep (less than 1500 m) and is influenced by intense tides of over 6 m that produce current speeds up to 3 m/s (Simpson et al. 1994; Alvarez-Borrego 2007). The bay is also in direct contact with the Ballenas Channel, a narrow passage between the mainland and Angel de la Guarda Island, which works as a wind funnel. The continuous outward transport of surface water by the wind, together with tidal mixing, generates frequent upwelling events, and as a result, the area is recognized as among the most productive in the eastern Pacific Ocean (Alvarez-Borrego 2007). The bay has such a high photosynthetic pigment concentration that Round (1967) and Santamaría-del Angel et al. (1994) proposed it as an independent biogeographic province.

According to information from the World Ocean Atlas 2013, the quadrat of 1°× 1° latitude–longitude

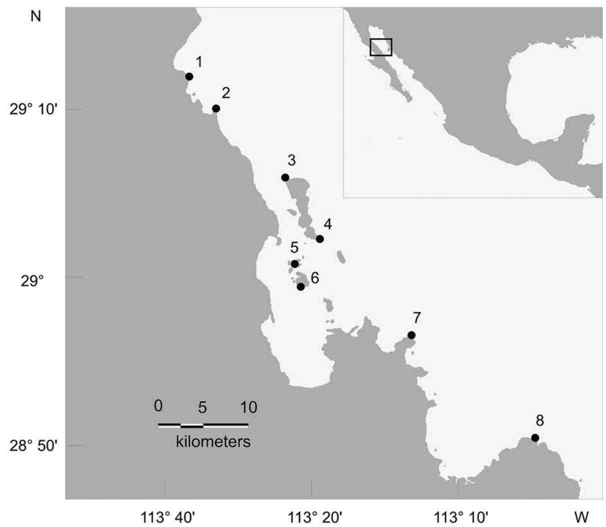

Figure 1. Study area. Key to locations: (1) Los Cantiles; (2) Alcatraz; (3) Coronados Island; (4) Tijeretas; (5) El Rasito; (6) La Ventana; (7) El Pescador; (8) Los Choros.

that includes Los Angeles Bay and the Ballenas Channel has an annual temperature (average and standard deviation) of 21.2 ± 2.53°C, the lowest in the Gulf of California as a result of a local upwelling. Hence, nutrient concentration is very high (phosphate 1.07 ± 0.13 µmol, silicate 13.98 ± 2.41 µmol and nitrate 4.35 ± 1.75 µmol), while salinity and oxygen ranges in the Gulf are 35.14 ± 0.11 UPS and 5.02 ± 0.19 mg/l. Because of the elevated productivity of the water (1.4–2.1 g C/m^2/day; Alvarez-Borrego 2007), the region harbours large populations of marine mammals, reef fish and invertebrates (Danemann & Ezcurra 2007), which are present throughout the year.

Field work

For this study, in the months of July and October 2006, and February and June 2007, we counted marine invertebrates at eight sites located in Los Angeles Bay and surrounding areas (Figure 1). Counts of the gorgonocephalids *Astrodictyum panamense* and *Astrocaneum spinosum* were performed using SCUBA dive equipment in 25 × 2 m belt transects (50 m^2 total; $N = 132$), parallel to the coastline, and at depths from 4 to 6 m ('shallow') and 10 to 12 m ('deep'). The data on population density of each species were analysed to detect differences related to three factors: depth (two levels: shallow and deep), location (eight sites) and time (four monthly visits), using three-way analyses of variance with interaction, model II, as the data were homoscedastic according to Levene's test (Zar 2009). Significant differences were tested using Tukey's post-hoc test (Zar 2009). In addition, we applied the variance/mean method (Krebs 1999) and its significance test (Brower et al. 1997) to establish whether the spatial arrangement of the individuals of each species was aggregated, random or uniform, based on Student's *t*-test. According to this statistical test, when the ratio is not significantly different from 1, the individuals are randomly distributed; if larger than 1, they are aggregated; and if less than 1, the ophiuroids were considered to be uniformly distributed.

The next procedure calculated simple Pearson correlations of the abundances of *Astrodictyum panamense* and *Astrocaneum spinosum* against oceanographic factors and bottom features that may influence them. We analysed latitude and longitude (decimal degrees) as indicators of general conditions of each site, as well as sea-surface temperature (°C) and chlorophyll *a* concentration (mg/m^3), both measured by the OBGP MODIS-AQUA satellite at the eight sample sites (precision of 0.1° latitude–longitude) and in the specific months of field sampling. In addition, the percentage of cover of stony corals, rock, sand, algal turf, coralline algae and macroalgae (fleshy fronds) was measured on the same transects where the gorgonocephalids were observed by counting the bottom-type observed under 100 points marked homogeneously along the plot line (one each 25 cm).

For the environmental data, we performed a forward stepwise multiple regression (Neter et al. 1996) to determine, in an optimal way (that is, selecting the fewest number of factors), the relative relevance of bottom type, photosynthetic pigments and temperature on the abundance of each species. Finally, we performed a canonical correspondence analysis (CCA; McCune et al. 2002) to define which environmental conditions were preferred or avoided by *Astrodictyum panamense* and *Astrocaneum spinosum*.

Results

The species *Astrocaneum spinosum* and *Astrodictyum panamense* were found at all visited locations (with the exception of La Ventana), although they appeared in only 15% and 11% of the transects, respectively; both species were usually attached to gorgonians of the genera *Muricea* Lamouroux, 1821, *Eugorgia* Verrill, 1868 and *Pacifigorgia* Bayer, 1951, but more commonly attached to the former two (M. Dinorah Herrero-Pérezrul 2007, personal observation). At Coronados Island, at a depth of 12 m, it was common to find at least two *Astrodictyum panamense* specimens per 50 m^2, with a maximum of nine per transect (Figure 2).

Analysing each species individually, *Astrocaneum spinosum* showed differences in density per census

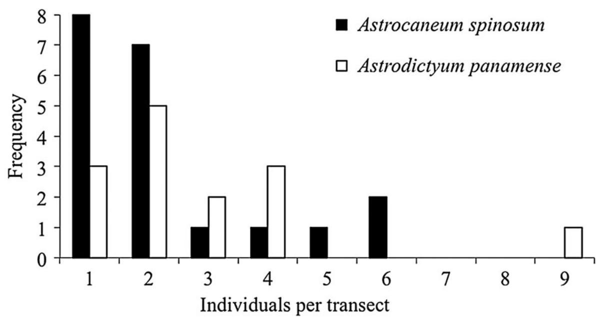

Figure 2. Frequency distribution of density (ind/50 m^2 transect) of *Astrocaneum spinosum* and *Astrodictyum panamense*.

only among sites (Coronados Island had the highest density of *Astrocaneum spinosum* of all other sites, except for Rasito and Choros; Figure 3c), but not by depth or month (Figure 3a and 3b), and there was no interaction effect other than for Coronados/12 m depth, a treatment which differed from all others because it had the highest average abundance at its transects (mean value 2.38 ± 0.78; Table I).

On the other hand, there were significant differences in density of *Astrodictyum panamense* among months and sites (Figure 4a and 4c), but not between depths (Figure 4b, Table I). According to the Tukey's tests, this species was more abundant in October than in the remainder of the sampling months and was more abundant at Coronados Island than at all other sites, except at Cantiles, Choros and La Ventana, where no individuals were found (Figure 4c). The two-way interaction factor (Table I) and a-posteriori tests determined that the combination Coronados/October (mean value 3.25 ± 1.13 ind/50 m^2) had the highest density of all possible interactions, and the same occurred with the interaction variable Coronados/12 m depth (mean value 2.25 ± 1.11 ind/50 m^2). Finally, the three-way interaction showed that Coronados/12 m depth/October differed from the rest of the interactions (mean value 6.50 ± 2.50 ind/50 m^2). In general, we observed that the interactions were affected by an apparently unusual group of transects with high density of *Astrodictyum panamense* found at a single site, depth and month.

When comparing *Astrodictyum panamense* and *Astrocaneum spinosum,* there were no significant differences in number of individuals per census ($t_{262} = 0.345$, $p = 0.730$; Figure 5) and in addition, the abundance per transect of both species was significantly and positively correlated (Pearson $r = 0.582$, $p < 0.001$, $N = 132$). The population density per sampling unit of both species in 2006–2007 was significantly correlated with live coral cover, while rock cover of the bottom was

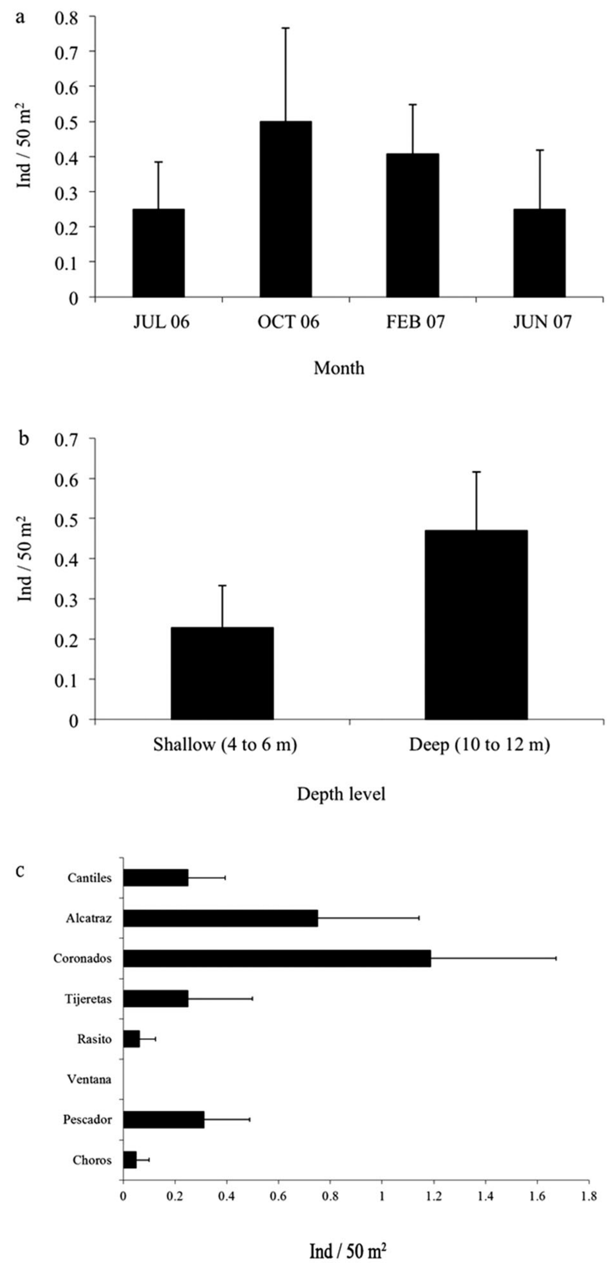

Figure 3. Population density of *Astrocaneum spinosum* comparing (a) time; (b) depth level; (c) site.

linked only to the number of *Astrocaneum spinosum*. The remainder of the environmental or geographic factors (latitude or longitude) were independent of the abundances of these gorgonocephalids (Table II). However, an interpolation analysis (spline cubic polynomial fit; Eubank 1999) showed that *Astrocaneum spinosum* was usually found in higher numbers when chlorophyll *a* concentration ranged from 2 to 5 mg/m^3 and surface temperature was lower than 24°C. Apparently, the ideal conditions for both species are 2.5–3.4 mg/m^3 and 14–15°C. The absence of both ophiuroids was noted when the temperature was excessively low (< 14°C) or high (> 28°C).

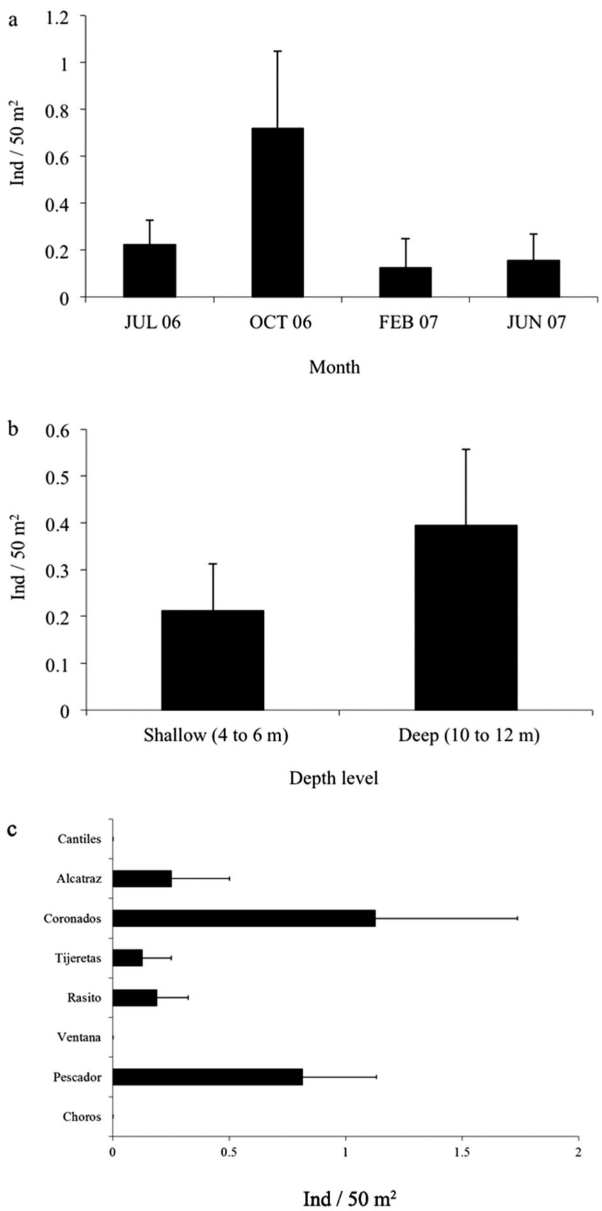

Figure 4. Population density of *Astrodictyum panamense* comparing (a) time; (b) depth level; (c) site.

The stepwise regression for *Astrodictyum panamense* (Table III) had a determination coefficient of 0.594 and was significant ($F_{4,27} = 9.876$, $p < 0.001$). This shows that the abundance of this species was principally related to the percentage of rocky bottom and stony corals (in a positive correlation) and negatively correlated with sand and macroalgae, although algal cover (composed mostly of the genera *Sargassum* C. Agardh and *Padina* Adanson) explained most of the variance in the equation. The regression analysis was also significant for *Astrocaneum spinosum* ($R^2 = 0.579$, $F_{3,28} = 12.866$, $p < 0.001$), but in this case, abundance was positively linked to rock cover and geographic longitude (more individuals along the peninsular coast at the west than at adjacent islands to the east) and negatively with the presence of sandy bottom (Figure 6; Table III). Finally, the CCA was significant and explained 76.7% of the variance. The

Table I. ANOVA table of the density of the two studied species.

Effect	SS	DF	MS	*F*	*P*
Density of *Astrocaneum spinosum* (ind/50 m²)					
Month	1.29	3	0.431	0.458	0.713
Depth	1.94	1	1.939	2.061	0.156
Site	19.00	7	2.714	2.884	**0.011**
Month × Depth	0.93	3	0.311	0.330	0.803
Month × Site	13.47	21	0.641	0.681	0.836
Depth × Site	25.89	7	3.698	3.930	**0.001**
All factors	15.33	21	0.730	0.776	0.738
Density of *Astrodictyum panamense* (ind/50 m²)					
Month	7.30	3	2.434	3.448	**0.021**
Depth	1.09	1	1.091	1.545	0.218
Site	20.34	7	2.905	4.116	**0.001**
Month × Depth	2.18	3	0.728	1.032	0.384
Month × Site	24.07	21	1.146	1.624	0.069
Depth × Site	21.05	7	3.008	4.261	**0.001**
All factors	33.69	21	1.604	2.273	**0.006**

Note: SS, sum of squares; DF, degrees of freedom; MS, mean squares. In bold: significant differences.

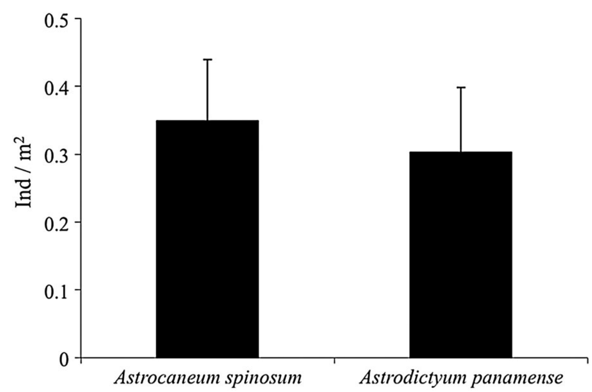

Figure 5. Comparison of overall species density in the study area.

Table II. Pearson correlation of basket star abundance (ind/m²) and oceanographic parameters in Los Angeles Bay ($N = 32$).

	Species			
	A. panamense		*A. spinosum*	
Oceanographic parameter	*r*	*P*	*r*	*P*
Surface temperature (°C)	0.185	0.312	−0.049	0.790
Chlorophyll *a* concentration (mg/m³)	−0.210	0.510	−0.234	0.197
Latitude (decimal degrees)	0.004	0.981	0.339	0.058
Longitude (decimal degrees)	−0.036	0.846	0.255	0.159
Bottom type				
Stony coral	**0.655**	**< 0.001**	**0.494**	**0.004**
Rock	−0.245	0.177	0.007	0.971
Sand	−0.186	0.308	**−0.513**	**0.003**
Fleshy algae	−0.069	0.704	−0.045	0.806
Coralline algae	−0.177	0.333	−0.229	0.207
Diversity of components (H′)	0.226	0.213	0.169	0.356

Note: Bold numbers: significant relationship.

Table III. The results of the stepwise regression to predict the abundance of the studied basket stars and environmental conditions.

Factor	Beta	SD Beta	*t*	*P*	Explained variance (%)	Cumulative variance (%)
Astrodictyum panamense						
Macroalgae	−0.369	0.127	−2.899	0.007	0.263	0.263
Coral	0.349	0.169	2.480	0.019	0.167	0.430
Rock	0.619	0.141	3.659	0.001	0.144	0.574
Sand	−0.213	0.183	−1.164	0.254	0.020	0.594
Astrocaneum spinosum						
Rock	0.979	0.164	5.957	<0.001	0.429	0.429
Sand	−0.532	0.169	−3.143	0.004	0.133	0.562
Longitude	0.139	0.129	1.077	0.291	0.017	0.579

first axis (63.6%) was related to coral cover ($r = -0.881$) and rock ($r = 0.401$), while the second axis (13.1% of variance) was related to sand ($r = -0.784$) and latitude ($r = 0.639$).

The spatial distribution of both species on the rocky reefs was aggregated, both taking the entire set of transects and separating months and depth levels (Table IV). Considering sites, the trend was the same everywhere but in two cases (Choros and Rasito) where *Astrocaneum spinosum* was randomly distributed.

Discussion

This is the first detailed numerical analysis of the abundances and spatial distributions of gorgonocephalid ophiuroids from the eastern Pacific published to date. The lack of available data makes comparisons difficult, as the only direct references for the presence of this family in this region appear in taxonomic studies or checklists (Maluf 1988; Caso et al. 1996; Neira & Cantera 2005; Solís-Marín et al. 2005; Honey-Escandón et al. 2008; Cohen-Rengifo et al. 2009; Alvarado et al. 2010; Granja-Fernández et al. 2015). In addition, we found no publications studying the population biology of this family in the Pacific Ocean, and elsewhere in the world there are only a few reports focused on species from different genera (Hendler & Miller 1984; McClintock et al. 1993; Domenico et al. 2006). This situation calls for more attention by researchers to the study of basket star assemblages and populations, as these animals are widespread in shallow and deep waters of all latitudinal belts, and may be dominant in cryptic reef habitats.

In relation to the results from Los Angeles Bay, the first remark is that both species appeared in low numbers of individuals per transect (Figures 3 and 4), and they appear with low frequency in the sampling units (Figure 2). In total, 24 days of field work produced 86 observations of single individuals or groups, adding 132 specimens for both species inside the census belts. Additionally, according to the field notes, we observed 70 other individuals in total of *Astrodictyum panamense* and *Astrocaneum spinosum* in the area outside the transects. The only other study that mentions abundance data of *Astrodictyum panamense* (Caso et al. 1996) indicated that they collected 350 individuals in 104 sampling days at Mazatlán Bay between 1977 and 1984. Comparing the data between the two studies, it can be suggested that even at a low density, the local populations at the subtropical Los Angeles

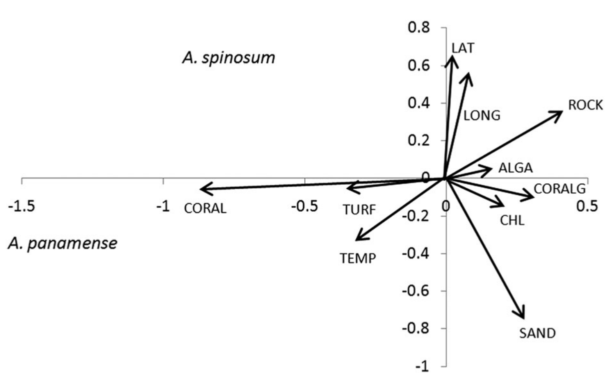

Figure 6. Canonical correspondence analysis of the gorgonocephalid species and environmental factors tested. Key: ALGA, Fleshy algae; CHL, chlorophyll *a* concentration in surface water; CORAL, live coral; CORALG, coralline algae; LAT, latitude; LONG, longitude; ROCK, rocky bottom; SAND, sandy bottom; TEMP, sea-surface temperature; TURF, algal turf.

Table IV. The results of the variance/mean test for spatial distribution of the studied species.

Factor	Sampling size	*A. panamense*	*A. spinosum*
Total	132	3.977	3.109
July 2006	36	1.828	2.600
October 2006	32	4.868	4.116
February 2007	32	4.000	1.565
June 2007	32	2.522	3.612
Shallow (4–6 m)	66	3.121	3.221
Deep (10–12 m)	66	4.442	3.028
Choros	20	–	1.001 (*)
Pescador	16	2.005	1.587
Ventana	16	–	–
Rasito	16	1.578	1.000 (*)
Tijeretas	16	2.000	4.000
Coronados	16	5.318	3.168
Alcatraz	16	4.000	3.289
Cantiles	16	–	1.333

Notes: In all cases, the distribution was aggregated, except in (*), where it was random. (–) indicates no specimens observed during the field work conducted at that specific location.

Bay (about seven to eight ophiuroids observed per day) appear to be more numerous than at the tropical Mazatlán (an average of three per day). This is likely to be as a result of the high primary and planktonic production in Los Angeles Bay (Alvarez-Borrego 2007). Finally, it is interesting to note that in a study of another member of the family Gorgonocephalidae (*Asteroporpa annulata* Örsted & Lütken in Lütken, 1856) in Florida, USA, a total of four submersible dives at depths of 56–83 m resulted in approximately 10 hours of observation and 45 specimens detected (Hendler & Miller 1984), which is over four specimens per hour. If we consider that the dives at Los Angeles Bay took approximately 80 effective hours and observed approximately 200 individuals of both species of gorgonocephalids (less than three per hour), this indicates a clear difference in numbers when comparing both species, as the Atlantic species was more abundant than the Pacific species presented in this study.

From the previous paragraphs, it is clear that the numbers of *Astrocaneum spinosum* and *Astrodictyum panamense* are relatively low in absolute terms in our study area (Figure 5), even with the potentially high food input derived from the local upwelling. We suggest that this condition is in part due to limitations in the number of resting places for the ophiuroids, which as adults are obligate residents of the branches of gorgonian corals (Baker 1980). The basket stars studied here are heavy, growing to over 25 cm in disk diameter (Kerstitch & Bertsch 2007), and for that reason octocoral species that reside in Los Angeles Bay, such as sea fans (*Pacifigorgia* spp.; Breedy & Guzmán 2002, 2007), cannot function adequately as resting places for these ophiuroids. This might explain the preference for the basket stars to be found clinging most frequently on *Muricea* sp. and *Eugorgia* sp., which are more sturdy and resistant corals than sea fans (Brusca 1980; Kerstitch & Bertsch 2007). One particular coral species found in the area, *Muricea austera* Verrill, 1869, has powerful allelopathic compounds (Murillo-Álvarez & Encarnación-Dimayuga 2003; Gutiérrez et al. 2006), and it is able to successfully compete for space with other species; moreover, its colonies usually appear in patches or groups over the rocks, probably because its larvae may recruit nearby; therefore, this might explain why the variance/mean tests (Table IV) showed that *Astrocaneum spinosum* and *Astrodictyum panamense* aggregate in the field.

The data analyses using the ANOVAs showed that for both species depth had no effect on population density (Table I). Additionally, the month of the year only affected the numbers of *Astrodictyum panamense* (there was a higher abundance in October; Figure 4). We suggest that depth and season of the year had few effects (if any) on population density of these species because the ophiuroids are capable of living in a range of ocean zones, from very shallow water to the edge of the continental shelf (Maluf 1988). The observed effect could also be because gorgonians of the genus *Muricea* do not have zooxanthellae, which allows them to reside from the lower intertidal to areas deeper than 30 m (Hendrickx et al. 2005; Abeytia et al. 2013). The specific case of the high density of *Astrodictyum panamense* in October is probably related to the movement of individuals to stay as close to other individuals as they can for reproductive reasons. Patent (1969) and McClintock et al. (1993) indicated that other species of the same family, such as *Gorgonocephalus eucnemis* and *Asteroporpa annulata*, produce mature gametes from June to November and from September to November, respectively; this is during summer and autumn. In the area of Los Angeles Bay, October is the warmest month of the year (Alvarez-Borrego & Lara-Lara 1991). Taking into consideration the fact that temperature has a key role in larval development of ophiuroids in general (Hendler 1991), it is possible that the Panamanian and spiny basket stars also reproduce at this time.

All statistical analyses conducted noted that temperature, chlorophyll *a* concentration and geographic indicators (latitude and longitude) had limited influence on the number of basket stars in Los Angeles Bay (Tables II and III), although *Astrocaneum spinosum* were more abundant when temperature was low and chlorophyll *a* values were intermediate. This species was more common along the coast (in the west; Table III) and in the northern part of the study area (higher latitude; Figure 6). Considering that during a typical year in the study area the temperature fluctuates between 15 and 29°C, chlorophyll *a* concentration changes from 6 mg/m^3 to less than 1 mg/m^3 (Alvarez-Borrego 2007), and both species are distributed from the Gulf of California to the southernmost eastern tropical Pacific Ocean (Maluf 1988), it can be argued that their wide tolerance to oceanographic conditions can explain our findings.

In contrast and according to the correlation, stepwise regression and CCAs (Tables II and III, Figure 6), the abundances of both species are favoured by coral and rock cover, while at the same time the presence of sand had a negative correlation on the gorgonocephalid abundances. Because *Astrodictyum panamense* and *Astrocaneum spinosum* depend on the presence of *Muricea austera* and other gorgonians and these coelenterates can only settle on hard substrata (Breedy & Guzmán 2002, 2007), this may explain the positive relationship between the coral and rock cover and basket star abundance, and the deleterious effect of sand bottoms on the occurrence and population density of the two species. Finally, coral cover was actually very low in Los Angeles Bay (less than 5% on average), and likely the positive relationship of this factor and the number of basket stars was indirect and resulted from the common need of both species for rocky bottoms to establish populations.

There is another observation worth noting about the relation of oceanographic conditions and abundance of *Astrodictyum panamense* and *Astrocaneum spinosum*, and this pertains to the fact that both species were more abundant at Coronados Island (Figures 1, 3 and 4) than elsewhere. There is a small volcanic land mass located north of Los Angeles Bay, which, according to data from the MODIS-AQUA satellite, is characterized by the highest chlorophyll *a* concentration in the study area (3.263 mg/m^3; monthly average from 1998 to 2010, compared to an average of 1.839 mg/m^3). We suggest that although, in general, chlorophyll *a* is not a major influence in determining population sizes in the eight visited areas (Table II), the productivity of Coronado clearly favours the resident basket star populations.

Finally, it is remarkable that although *Astrocaneum spinosum* is not abundant in the Gulf of California and it usually does not reside in shallow waters, nevertheless it is considered as among the 30 most important invertebrates in the aquarium trade in Mexico (Piña-Espallargas et al. 2002). Because of the low density of individuals, the populations of this ophiuroid could be affected in locations where the species is being removed as a result of excessive extractions. This is a situation that needs to be monitored by environmental authorities in Mexico. This work is one of the first to study the ecology of gorgonocephalids in the eastern Pacific Ocean. Our key conclusions are that the number of individuals of these species per census was not affected by bathymetry, but was very possibly influenced by chlorophyll *a* concentration and also increased during the autumn (possible reproductive season). The abundance of *Astrocaneum spinosum* and *Astrodictyum panamense* was higher on rocky bottoms and decreased in sandy areas. Last, the spatial distribution of both ophiuroids was aggregated in all study locations, possibly because they were associated with a gorgonian with high allelopathic activity.

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ORCID

María Dinorah Herrero-Pérezrul http://orcid.org/0000-0002-2239-6056
Rebeca Granja-Fernández http://orcid.org/0000-0001-7119-0567

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