Institute of Parasitology, Biology Centre CAS
Folia Parasitologica 2025, 72: 017
doi: 10.14411/fp.2025.017

Folia Parasitologica
http://folia.paru.cas.cz

Research Article

OPEN ACCESS

Species richness and similarity of parasite communities in ten species of carangid fish (Carangiformes) from the Mexican Southern Pacific

Shirley S. Salas-Villalobos[2], **Juan Violante-González**[1,2], **Edgar F. Mendoza-Franco**[3], **Yesenia Gallegos-Navarro**[1], **Erick Rodríguez-Ibarra**[4], **Carlos Valencia-Cayetano**[1], **Jonatan Carbajal-Violante**[1] and **Sergio García-Ibáñez**[1]

[1] Facultad de Ecología Marina, Universidad Autónoma de Guerrero, Acapulco, Guerrero, México;

[2] Centro de Ciencias de Desarrollo Regional, Universidad Autónoma de Guerrero, Acapulco, México;

[3] Instituto de Ecología, Pesquerías y Oceanografía del Golfo de México (EPOMEX), Universidad Autónoma de Campeche (UAC), Campeche, México;

[4] Postdoctoral Conahcyt. Facultad de Ecología Marina, Universidad Autónoma de Guerrero, Acapulco de Juárez, Guerrero, México

Abstract: Species richness and similarity in metazoan parasite communities of fish can be influenced by several biotic (age, body size, vagility, social and feeding behaviour, among others), and local abiotic factors (temperature, salinity, climatic events, etc.). The parasite communities of ten species of the family Carangidae from Acapulco Bay, Mexico, were quantified and analysed between May 2014 and August 2024. A total of 1,148 fish specimens were examined and 78 parasite species were identified (44 endoparasites and 34 species of ectoparasites). At the component community level, species richness ranged from 11 in *Euprepocaran*x *dorsalis* (Gill) to 27 in *Caranx caninus* Günther. Parasite communities were dominated mainly by monogenean species. The richness and parasite species composition differed between the ten species of host. The habitat type, body size and host diet variety were the main factors responsible of these differences. Similarity in species composition varied even between hosts of the same genus, suggesting that phylogenetic relatedness and sympatry were not important determinants of parasite communities in these carangid fish. Therefore, host ecology has a greater influence on the structure and species composition of parasite communities than its phylogenetic history.

Keywords: marine fish, parasite fauna, heteroxenous/monoxenous, determinants of species richness, Acapulco Bay, Mexico

Parasite communities are considered products of acquisitions and/or losses of parasite species during the evolutionary history of their hosts (Poulin and Rohde 1997). Metazoan parasite communities in marine fish are constituted mainly of ectoparasites (monogeneans, copepods and isopods) and endoparasites (digeneans, cestodes, nematodes and acanthocephalans). Both parasite groups exhibit different transmission strategies to infect their hosts; for example, ectoparasites are often transmitted between individual hosts through contact, whereas endoparasites use trophic transmission routes (Marcogliese 2002, Rohde 2005).

Species richness and diversity in each of these parasite groups vary substantially among different species of host (Poulin and Rohde 1997, Rohde 2005, Bellay et al. 2015). However, in most parasite communities studied, species richness of endoparasites is generally higher than that of ectoparasites (Bellay et al. 2015). For example, in species of many tropical marine fish the dominance of digenean parasites has been well documented (e.g., Cribb et al. 2016, Santos-Bustos et al. 2018, Villalba-Vasquez et al. 2018). Examining parasite species in host assemblages rather than in a single host species may provide a better understanding of the factors that influence the species composition and structure in parasite communities (Carrassón et al. 2019).

Several studies focused on exploring structuring patterns of parasite community in marine and freshwater fish populations, have highlighted the importance of the host-phylogeny and/or the influence of ecological factors on the similarity recorded among some parasite communities (Marcogliese 2002, Luque and Poulin 2008, Valtonen et al. 2010, Bellay et al. 2011, Baia et al. 2018, Carrassón et al. 2019, Osuna-Cabanillas et al. 2024). Sympatric and phylogenetically related fish species tend to harbour communities of parasites very similar in diversity and species richness, unlike those of unrelated host species (Luque et al. 2004, Tavares and Luque, 2008, Pantoja et al. 2016).

However, the parasite community structure can be influenced by environmental factors (e.g., local or regional

Address for correspondence: Juan Violante-González, Facultad de Ecología Marina. Gran Vía tropical Núm. 20, Fracc. Las Playas, C. P. 39390. Universidad Autónoma de Guerrero, Acapulco, México. E-mail: viojuang@yahoo.com.mx; ORCID-iD: 0000-0001-6291-8763

Table 1. Main characteristics of 10 species of carangid fish from Acapulco Bay, Mexico.

Fish species	n	Max length (cm)*	Mean length (cm)	CV	Kn	Habitat type*	Feeding type*
Euprepocaranx dorsalis	66	67	21.5 ± 4.5	21.1	1.48	BD	CF
Caranx caballus	237	55	26.2 ± 4.6	17.7	0.98	NP	FC
Caranx caninus	122	101	25.5 ± 4.1	16.6	1.27	NP	FC
Caranx sexfasciatus	110	120	26.5 ± 5.0	22.3	1.21	NP	FC
Decapterus muroadsi	52	50	23.6 ± 3.2	13.6	0.93	OP	Zoop
Oligoplites altus	64	56	37.3 ± 8.6	23.1	0.87	NP	FC
Oligoplites refulgens	114	28	21.9 ± 2.5	11.4	0.66	ND	FC
Selar crumenophthalmus	95	30	19.8 ± 0.9	4.4	1.03	NP	Zoop
Selena peruviana	142	40	28.8 ± 28.7	18.7	1.06	PD	CF
Trachinotus rhodopus	146	61	25.4 ± 5.2	20.5	1.01	BD	MC

Abbreviations: n – sample size; CV – coefficient of variation; Kn – condition factor. Habitat: BD – bentho-demersal, ND – neritic-demersal, NP – neritic-pelagic, OP – oceanic-pelagic, PD – pelagic-demersal. Feeding type: CF – crustraceans-fish, FC – fish-crustraceans, MC – mollusks-crustaceans, Zoop – zooplanktivore. *Data according to Allen and Robertson (1998) and Palacios-Salgado et al. (2014).

fluctuations in surface temperature, salinity or dissolved oxygen concentrations, substrate texture, climatic events, etc.), and some host traits such as: age, body size, social and feeding behaviour, trophic level, vagility, habitat use, and depth distribution. These abiotic and biotic factors are considered as important determinants of species richness in parasite communities (Poulin 1995, Timi and Poulin 2003, Violante-González et al. 2019, 2020).

The marine ichthyofauna along the Mexican Pacific coasts is very species-rich and diverse, and many species represent sizable and economically important fisheries. Carangidae (jacks and pompanos) is one of the most diverse families among the marine fishes of this tropical region, and includes 34 species (Palacios-Salgado et al. 2014, Osuna-Cabanillas et al. 2024). Many species of carangid fish are considered coastal pelagic predators that feed mainly on benthic invertebrates and small fish (Velasco-Reyes et al. 2022).

The structure and species composition of the parasite communities of eight carangid species, namely *Caranx caballus* Günther, *Caranx caninus* Günther, *C. sexfasciatus* Quoy et Gaimard, *Decapterus muroadsi* (Temminck et Schlegel), *Oligoplites altus* (Günther), *Oligoplites refulgens* Gilbert et Starks, *Selar crumenophthalmus* (Bloch), and *Trachinotus rhodopus* Gill from of the southern Pacific coasts of Mexico, have already been examined (Gallegos-Navarro et al. 2018, 2019, Santos-Bustos et al. 2018, Violante-González et al. 2019, 2020, Osuna-Cabanillas et al. 2024). However, no study has been carried out at the level of populations (assemblages) of carangid fish, focused on comparing the richness, diversity and level of similarity of their parasite communities.

Here, we use published and unpublished data on *Euprepocaranx dorsalis* (Gill) and *Selene peruviana* (Guichenot) and data on ten carangid fish species, obtained over a 10-year period (2014–2024) by several of the co-authors. The objective of this study was to test two hypotheses: 1) the species richness and diversity of parasite communities would vary among the ten species of carangid fish due to differences in the body size, habitat use and their feeding habits, 2) similarity in species composition would be high, mainly between congeneric fish species with similar ecological traits.

MATERIALS AND METHODS

Study area

Santa Lucia Bay, also known as Acapulco Bay, is located on the tropical southern Pacific coast of Mexico, in the state of Guerrero. The bay has a semi-circular (6.3 km diameter), amphitheater-like shape created by low hills (< 500 m) surrounding the south-facing bay. It is considered to be very climatologically protected (Rojas-Herrera et al. 2012). This bay constitutes a natural habitat that provides protection and food to many species of both resident and temporal fish. However, since this bay is one of the most important touristic destinations in México, for several years it has evidenced a high level of environmental deterioration. During the period covered by this study, five climatic events were recorded in the study area: three warming phases of the ENSO (El Niño 2015–2016, 2018–2019 and 2023–2024), and two cooling phases (La Niña 2016–2017 and 2020–2021). Therefore, the multivariate El Niño index values (MEI) for each sampling date were obtained from the National Oceanic and Atmospheric Administration (NOAA) database.

Fish collection and biometric data

This study used a total of 1,148 fish specimens belonging to ten species of Carangidae, eight previously examined (*Caranx caballus*, n = 237; *Caranx caninus*, n = 122; *Caranx sexfasciatus*, n = 110; *Decapterus muroadsi*, n = 52; *Oligoplites altus*, n = 64; *Oligoplites refulgens*, n = 114; *Selar crumenophthalmus*, n = 95; and *Trachinotus rhodopus*, n = 146), and two species examined for the first time (*Euprepocaranx dorsalis*, n = 66; *Selene peruviana*, n = 142), which were obtained of commercial fishermen between May 2014 and August 2024 from Acapulco Bay (16.8524N, 99.8823W).

In the laboratory, *E. dorsalis* and *S. peruviana* were measured, weighed and sexed. The Fulton's condition factor (Kn) was calculated using the equation: $Kn = Wt/Lt^3 \times 100$ where Wt (g) is total weight, and Lt = total length (cm). The coefficient of variation (CV) was used to assess the variability in the total length of fish populations during each sampling. Contents of the digestive tract were examined to identify prey items consumed by each fish species; the diet was analysed using the frequency of occurrence method (Lima-Junior and Goitein 2001). The diet diversity of these two fish species was calculated as the number of prey items consumed by the populations of each species. All fish species were classified according to their habitat and feeding types based on Palacios-Salgado et al. (2014) (Table 1).

Parasite collection methods

Fish necropsy and parasite recovery procedures were described in the corresponding publications (Gallegos-Navarro et al. 2018, 2019, Santos-Bustos et al. 2018, Violante-González et al. 2019, 2020, Osuna-Cabanillas et al. 2024). The same procedures were applied to the two newly examined host species. Parasites of the carangids *E. dorsalis* and *S. peruviana* were morphologically identified to the lowest possible taxonomic level using specialised literature. Vouchers of the most abundant and best-preserved parasite specimens of these two new hosts were deposited in the Colección Nacional de Helmintos (CNHE), Universidad Nacional Autónoma de México, Mexico City (voucher numbers: 12266–12278, and 176–178).

Parasite species were classified based on the traits of their life cycle as monoxenous (single-host life cycle) and heteroxenous (multi-host life cycle) parasites. The infection levels for each parasite specie were described using prevalence and mean abundance following the terminology of Bush et al. (1997). Possible differences in the infection levels between host species were determined using *G*-tests for prevalence and Factorial Anovas (General Lineal Model, GLM) for abundance.

Study levels

Analyses were made at the levels of component community (i.e., total number of parasite species in a population of a fish species) and infracommunity (i.e., total number of parasite species in a specimen of each species of fish). Component community parameters included total species richness, total number of individuals of each species of parasite, the exponential of Shannon-Wiener index (Hill number, ^{1}D) as a measure of parasite diversity, species evenness (equitability), and the Berger-Parker Index (BPI) as a measure of numerical dominance (Magurran 2004). Rank-abundance curves were used to visualise changes in the species composition of parasite communities between species of host. Similarity analysis, based on Bray-Curtis similarity coefficients (square root transformed abundance data), were used to evaluate similarity and difference in species composition of parasite community between host species.

Non-metric multidimensional scaling (nMDS) based on the Bray-Curtis similarity index was used to rank the component parasite communities according to their relative similarities and visualise possible differences in species composition. One-way analysis of similarity (ANOSIM) was used to determine the significance of possible grouping patterns in the nMDS ranking. When a Global R-value of the ANOSIM was > 0.75, the species composition of the parasite communities was considered to be different, and when a Global R value < 0.25, the communities exhibited high similarity in species composition. Differences between component community parameters were identified using the non-parametric Kruskal-Wallis test, or the Student *t* test, considering data of the total population of each fish species as a component community.

Infracommunities were described in terms of mean number of parasite species per host species, mean number of individuals of each species, and the mean Brillouin Diversity index (H') value per host species. The multivariate general linear model (GLM) and PERMANOVA analysis were used to identify possible differences in infracommunity parameters (dependent variables) between species of host. Spearman's correlation coefficient (r_s) was used to determine possible relationships between total fish length and infracommunity parameters, as well as with the abundance of component species (parasite species with a prevalence ≥ 10%).

The significance of all statistical analyses was established at $\alpha = 0.05$, unless stated otherwise. Principal Component Analysis (PCA) was applied to identify biotic or abiotic factors that influence species richness and diversity of parasite infracommunity. The variables included were: Fulton's condition factor (Kn), sex, host diet diversity, habitat type, climatic season (dry and rainy seasons), MEI values, sampling year, and infracommunity parameters. The statistical packages SPSS (IBM SPSS Statistics for Windows, Ver. 20.0), R package Ver. 2.5-7, and PRIMER v6. software, were used for all statistical analyses.

RESULTS

Species composition

The parasite fauna of the ten carangid fish species included in this study (eight already examined and two new host species) consisted of 78 species/taxa of metazoan parasite (58 helminths, 19 crustaceans and one pentastomid); of these parasite species six represent new host records (Table 2). These species included: 15 species of 'Monogenea' (adults), 27 Digenea (25 adults and two metacercariae), one Aspidogastrea (adult), three Acanthocephala (adult), five Cestoda (larvae), eight Nematoda (six adults and two larvae), 16 Copepoda and three Isopoda (Table 2).

Species richness was highest among the digeneans, which represented 35% of the total species, followed by the copepods (21%). Based on infection site, 34 species were ectoparasites (monoxenous), and 44 were endoparasites (heteroxenos). Thirty-three parasite species infected a single host species, 23 infected two-host species, and only nine were recovered from up to five or more host species (Fig. 1). Only larvae of the nematode *Anisakis* sp. were recovered from 10 examined hosts.

Variation in the parasite infection levels

Nine parasite species most widely distributed among host species (*Pseudempleurosoma* sp.; *Pseudomazocraes selene* Hargis, 1957; *Bucephalus margaritae* Ozaki et Ishibashi, 1934; *Ectenurus virgula* Linton, 1910; *Lecithochirium microstomum* Chandler, 1935; *Phyllodistomum carangis* (MacCallum, 1913); *Anisakis* sp.; *Caligus mutabilis* Wilson, 1905; and *Lernanthropus giganteus* Krøyer, 1863) recorded significant variations in their infection levels (Table 2).

The prevalence values of the monogenean *Pseudempleurosoma* sp. (*G*-test = 69.6, $p < 0.01$) and the digenean *B. margaritae* (*G*-test = 67.6, $p < 0.01$) were higher in *Caranx caballus*; the digeneans *E. virgula* (*G*-test = 38.8, $p < 0.01$) and *Ph. carangis* (*G*-test = 23.5, $p < 0.01$) were most prevalent in *Euprepocaranx dorsalis*, while the monogenean *Ps. selene* (*G*-test = 152.7, $p < 0.01$) and the nematode *Anisakis* sp. (*G*-test = 184.6, $p < 0.01$) had their highest prevalence in *Selar crumenophthalmus*. The copepods *C. mutabilis* (*G*-test = 28.8, $p < 0.01$) and *L. giganteus* (*G*-test = 6742, $p < 0.01$) were more prevalent in *Oligoplites refulgens* and *Oligoplites altus*, respectively, while the

Table 2. Parasite infection parameters (prevalence and abundance – in parentheses) for 10 species of carangid fish from Acapulco Bay, México. Significantly different measurements of prevalence (*G*-test) and abundance (Factorial Anova) ($p < 0.05$) are in bold.

Parasite taxa	Site	Ccab	Ccan	Csex	Dmur	Edor	Oalt	Oref	Scru	Sper	Trho
Monogenea											
Ahpua piscicola	G						4.7 (0.08)	**85.1** (**7.09**)			
Allopyragraphorus caballeroi	G	**40.1** (**2.25**)	16.4 (0.45)								
Capsala sp.*	G									0.70 (0.01)	
Hargicola oligoplites	G						4.7 (0.30)				
Heteromicrocotyla carangis	G			0.91 (0.01)							
Neobenedenia melleni	G			0.91 (0.01)							
Neomicrocotyle pacifica	G		5.7 (0.25)	**80.9** (**25.6**)							
Probursata veraecrusis	G						1.6 (0.03)				
Protomicrocotyle manteri	G		**95.9** (**10.3**)	60 (2.4)							
Pseudaxine trachuri	G				7.7 (0.10)						
Pseudempleurosoma sp.	G	45.1 (**2.78**)	0.8 (0.01)		7.7 (0.10)	**36.4** (0.74)			17.3 (0.38)	9.9 (0.18)	24 (0.66)
Pseudobicotylophora lopezochoterenai	G										28.8 (1.05)
Pseudomazocraes monsivaisae	G				65.4 (5.27)						
Pseudomazocraes selene	G		1.6 (0.02)	12.7 (0.17)	1.9 (0.02)	62.1 (1.45)			**74.3** (**6.33**)	53.5 (1.61)	
Pyragraphorus hollisae	G		4.9 (0.61)								74.7 (2.98)
Digenea											
Anacetabulum-type (larvae)	I										24 (0.44)
*Bucephalopsis longovifera**	I					36.4 (2.98)					
Bucephalus margaritae	I	**64.6** (**6.59**)	13.1 (1.01)	19.1 (1.43)		48.5 (3.83)				9.1 (0.15)	
Bucephalus sp.	I		2.5 (0.04)	3.6 (0.09)							
Dactylostomum winteri	I	12.7 (0.21)									
Dinurus scombri	I		1.6 (0.02)		9.6 (0.12)					1.4 (0.01)	
Ectenurus lepidus	I						10.9 (0.31)	5.3 (0.12)			
Ectenurus virgula	I		9.8 (0.11)	13.6 (0.35)	17.3 (0.25)	47 (1.0)	26.6 (0.86)	9.6 (0.19)			**39** (**1.39**)
Gonocercella pacifica	I							0.88 (0.01)			**47.9** (**1.79**)
Hirudinella ventricosa	I			0.9 (0.01)							2.1 (0.02)
Lecithocladium angustiovum	I		0.8 (0.01)						**78.9** (**0.73**)		5.5 (0.15)
Lecithocladium excisum	I			1.8 (0.03)	1.9 (0.02)						
Lecithochirium microstomum	I		3.3 (0.09)	5.4 (0.06)					1.1 (0.01)	7.1 (0.07)	**36.3** (**0.89**)
Manteria brachiderus	I						90.6 (**10.5**)	88.6 (5.8)			
Mecoderus oligoplitis	I			0.9 (0.01)			**15.6** (**0.27**)	5.3 (0.15)			
Monascus filiformis	I								12.6 (0.18)		
Nematobothrium sp.	I						**10.9** (**0.17**)	2.6 (0.03)			
Opechona faringodactyla	I										3.4 (0.34)
Phyllodistomum carangis	I		1.6 (0.02)			**13.6** (**0.33**)			2.1 (0.02)	1.4 (0.01)	10.3 (0.24)
Proctoeces sp.	I										24.7 (1.27)
*Pseudopecoeloides carangis**	I					33.3 (1.15)				3.5 (0.04)	
Pseudopecoelus sp.	I										0.7 (0.03)
Stephanostomum casum	I										6.2 (0.06)
Stephanostomum ditrematis	I			1.8 (0.02)							
Stephanostomum megacephalum	I	2.1 (0.08)	4.1 (0.04)								
Tergestia laticollis	I	2.1 (0.02)									
Torticaecum-type (larvae)	I			2.7 (0.03)	**7.7** (**0.08**)				1.1 (0.01)	1.4 (0.01)	
Acanthocephala											
Bolbosoma sp.	I				1.9 (0.02)						
Nipporhynchus sp.	I						7.8 (0.16)	12.3 (0.23)			
Rhadinorhynchus sp.	I		3.3 (0.03)	1.8 (0.02)			10.9 (0.33)				**76.7** (**18.8**)
Cestoda											
Acanthobothrium sp. (larvae)	I				7.7 (0.65)						
Nybelinia sp. (larvae)	I	1.3 (0.01)								2.1 (0.02)	
Onchoproteocephalidea gen. sp. (larvae)	I			0.9 (0.01)	1.9 (0.02)				3.2 (0.03)		10.3 (0.18)
Otobothrium sp. (larvae)	I						1.6 (0.06)				
Trypanorhyncha gen. sp. (larvae)	I						7.8 (1.4)				6.2 (0.07)
Nematoda											
Anisakis sp. (larvae)	I		8.5 (0.15)	6.4 (0.09)	9.6 (0.10)	4.5 (0.05)	40.6 (**2.22**)	66.7 (5.55)	**71.3** (1.8)	23.2 (0.33)	26.7 (0.64)
Contracaecum sp. (larvae)	I	28.7 (0.47)	0.8 (0.01)								
Cucullanus sp.	I	0.8 (0.02)	2.5 (0.02)								
Hysterothylacium sp.	I										4.1 (0.05)
Philometra sp.	I	1.3 (0.02)								2.1 (0.02)	
Procamallanus sp.	I	1.3 (0.01)		0.9 (0.01)			1.6 (0.25)				
*Pseudocapillaria carangi**	I					9.1 (0.18)				2.1 (0.02)	
Spinitectus sp.	I	4.2 (0.07)			1.9 (0.02)		4.7 (0.08)				

Copepoda											
Bomolochus bellones	G	0.4 (0.01)	0.8 (0.01)					1.7 (0.02)			47.5 (1.16)
Caligus aesopus	G		1.6 (0.02)								
Caligus alalongae	G	**52.3 (1.03)**	34.4 (0.65)	0.91 (0.01)							
Caligus asperimanus	G						4.7 (0.05)				85.6 (3.18)
Caligus chorinemi	G			8.2 (0.09)							
*Caligus haemulonis**	G					36.4 (0.47)					
Caligus hoplognathi	G		2.5 (0.02)								
*Caligus isonyx**	G					65.1 (1.38)					
Caligus mutabilis	G	3.8 (0.04)					18.7 (0.33)	20.2 (0.28)	**75.8 (1.92)**	7.1 (0.08)	
Caligus robustus	G	4.6 (0.06)	8.2 (0.10)	**50.9 (0.81)**					8.4 (0.11)		
Ergasilus cf. *gibbus*	G	1.3 (0.01)									
Ergasilus sp.	G	0.8 (0.01)		1.8 (0.02)							
Hatschekia longibrachium	G										0.7 (0.01)
Lernanthropus giganteus	G	4.6 (0.05)	11.5 (0.15)				**45.3 (1.13)**	2.6 (0.03)	1.1 (0.01)	31 (0.46)	
Lernanthropus ilishae	G		0.8 (0.01)	15.4 (0.17)							
Taeniacanthodes gracilis	G	0.4 (0.01)									
Isopoda											
Ancinus depressus	G										5.5 (0.05)
Gnathia sp. (larvae)	G	0.4 (0.01)		2.7 (0.03)							
Rocinella signata	G	0.4 (0.01)	4.1 (0.04)	0.9 (0.01)						7.1 (0.08)	
Pentastomida											
Sebekia sp. (larvae)	M						4.7 (0.05)				0.7 (0.01)

Abbreviations: Ccab – *Caranx caballus*, Ccan – *Caranx caninus*, Csex – *Caranx sexfasciatus*, Dmur – *Decapterus muroadsi*, Edor – *Euprepocaranx dorsalis*; Oalt – *Oligoplites altus*, Oref – *Oligoplites refulgens*, Scru – *Selar crumenophthalmus*, Sper – *Selene peruviana*, Trho – *Trachinotus rhodopus*. Site of infection: G – gills, I – intestine, M – mesentery. * – new records of parasite species.

parasite species more prevalent in *Trachinotus rhodopus* was the digenean *L. microstomum* (*G*-test = 53.6, $p < 0.01$).

All these parasite species exhibited significant variation in their mean abundance (GLM: $p < 0.01$), being most abundant on the same host species in which they were most prevalent. A positive correlation between the prevalence and mean abundance values of these parasite species ($r_s = 0.973$, $p < 0.01$) confirmed that the most prevalent species were also the most abundant.

Diet composition of the fish species

Diet composition varied significantly ($t = 4.47$, $p < 0.01$) among the fish species from 3 to 15 prey items (Table 3). Species of the genus *Caranx*, as well as *O. altus* and *Selene peruviana*, included higher percentages of small fish in their diet (mean = 61%). In contrast, crustaceans were better represented (mean = 66 %) in fish species such as *E. dorsalis*, *Decapterus muroadsi*, *S. crumenophthalmus* and *O. refulgens.* Only the diet of *T. rhodopus* was completely different, as snails (37%) were the most important prey.

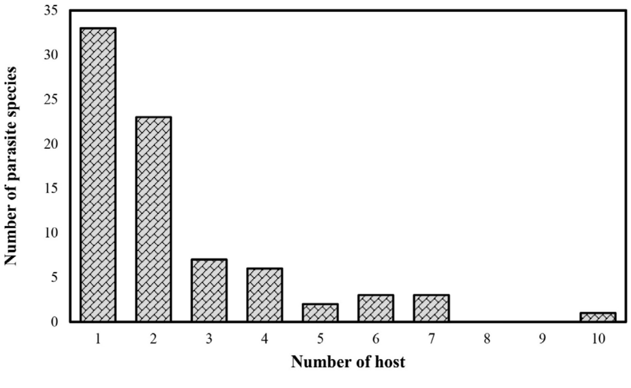

Fig. 1. Distribution of parasite species between the examined hosts.

Component communities

Parasite species richness at component community level (Table 3) varied significantly from 11 in *E. dorsalis* to 27 in *Caranx caninus* ($t = 3.73$, $p < 0.01$). Parasite communities of *Caranx* hosts were more similar in species richness (23 to 27 species, Table 3). The overall ratio of heteroxenous to monoxenous species of parasite (Hsp/Msp = 2.29) favoured the first group of parasites.

The total number of individual parasites ranged from 345 in *D. muroadsi* to 5,176 in *T. rhodopus* ($t = 3.27$, $p < 0.01$), and the diversity index values from 4.70 in *Caranx sexfasciatus* to 26.08 in *E. dorsalis* ($t = 3.59$, $p < 0.01$). No correlation was observed between the sample size and these parameters at this level ($p > 0.05$), indicating that the different sample sizes used in the analyses had no effect on the results. Eight helminth species (five monogeneans, two digeneans and one acanthocephalan) numerically dominated the parasite communities of the 10 host species (Table 3). Only the digenean *B. margaritae* (in *E. dorsalis* and *C. caballus*), and the monogenean *Pseudomazocraes selene* (in *S. crumenophthalmus* and *Se. peruviana*), dominated in up to two parasite communities (Table 3). Rank-abundance curves indicated that the distribution of species abundance varied notably among the host species (Fig. 2).

The greatest differences in relative abundance between the first and second parasite species were registered among the communities of *C. caninus*, *C. sexfasciatus* and *D. muroadsi* (Fig. 2); indicating that these communities were mostly dominated by a species of parasite (the monogeneans *Protomicrocotyle manteri* Bravo-Hollis, 1966, *Neomicrocotyle pacifica* (Meserve, 1938) and *Pseudomazocraes monsivaisae* Caballero et Bravo Hollis, 1955, respectively).

Similarity between component parasite communities varied widely from 0.61% (*C. caballus*–*D. muroadsi*) to 52.2% (*O.altus*–*O. refulgens*) (mean = 8.05%). The nMDS ranking of the component communities showed

Table 3. Characteristics of parasite component communities of carangid fish from Acapulco Bay, Mexico.

Year	Date	MEI	Fish species	No. of fish	Length (cm)	Diet variety	Species richness	Parasite group		No. of parasites	BPI	Dominant species	^{1}D
								REcto	REndo				
2016	Aug^{r}	-0.3	Ccab	237	26.2 ± 4.6	12	23	12	11	3266	0.479	Buce	13.20
2018	Apr^{d}	-1.3	Ccan	122	25.5 ± 4.1	7	**27**	15	12	1730	0.724	Prot	8.58
2019	Mar^{d}	0.3	Csex	110	26.5 ± 5.0	12	25	12	13	3465	0.813	Neom	4.70
2014	Aug^{r}	0.3	Dmur	52	23.6 ± 3.2	11	13	4	9	345	0.794	Psmo	5.15
2014	May^{d}	0.2	Edor*	66	21.5 ± 4.5	4	11	4	7	896	0.282	Buce	**26.08**
2016	Feb^{d}	1.8	Oalt	64	**37.3 ± 8.6**	3	20	6	14	1207	0.556	Mant	17.44
2016	Jul^{r}	-0.5	Oref	114	21.9 ± 2.5	4	12	4	8	2219	0.364	Ahpu	10.00
2018	Apr^{d}	-0.9	Scru	95	19.8 ± 0.9	11	12	5	7	933	0.685	Psse	6.42
2024	Aug^{r}	-0.7	Sper*	142	28.8 ± 28.7	9	16	6	10	440	0.518	Psse	16.45
2020	May^{d}	-0.7	Trho	146	25.4 ± 5.2	**15**	24	7	17	**5176**	0.53	Rhad	**20.94**

Abbreviations: Ccab – *Caranx caballus*; Ccan – *Caranx caninus*; Csex – *Caranx sexfasciatus*; Dmur – *Decapterus muroadsi*; Edor – *Euprepocaranx dorsalis**; Oalt – *Oligoplites altus*; Oref – *Oligoplites refulgens*; Scru – *Selar crumenophthalmus*; Sper – *Selene peruviana**; Trho – *Trachinotus rhodopus*; * – New data; MEI – Multivariate El Niño index (positive values represent the warm phase, while negative values the cooling phase); Length – total length; Diet variety – number of prey ítems per fish species; BPI – Berger-Parker index; Buce – *Bucephalus margaritae*; Prot – *Protomicrocotyle manteri*; Neom – *Neomicrocotyle pacifica*; Psmo – *Pseudomazocraes monsivaisae*; Mant – *Manteria brachiderus*; Ahpu – *Ahpua piscicola*; Psse – *Pseudomazocraes selene*; Rhad – *Rhadinorhynchus* sp.; ^{1}D – exponential of Shannon's entropy index. Letters as superscripts represent climatic seasons (d – dry; r – rainy). Significantly different values are in bold ($p < 0.05$).

a strong clustering (7/10 communities) at a similarity level of 40% but there was a clear separation of three parasite communities (*D. muroadsi*, *T. rhodopus* and *C. caballus*, Fig. 3). The ANOSIM also shows significant differences in the similarity of parasite communities between species of host (Global R = 0.741, $p < 0.01$), suggesting large differences in species composition.

The results of the PERMANOVA analysis indicated that abundance of component parasite species varied significantly between host species. The interactions between size × host and weight x host, explained high percentages of the variability in the abundance of these parasite species (Table 4).

Infracommunities

Body size of fish species ranged from 19.8 ± 0.9 cm (*S. crumenophthalmus*) to 37.3 ± 8.6 cm (*O. altus*, Table 3), and differed among host species (Anova $F_{9,1147} = 16.85$, $p < 0.01$). Host body size was positively or negatively correlated with some infracommunity parameters. A greater number of significant correlations (two negative and four positive) were recorded between the body size of the hosts and the number of ectoparasite individuals (Table 5). The highest numbers of correlations per host species were observed between the infracommunities of *C. sexfasciatus* and *T. rhodopus* (5 and 6, respectively).

All infracommunity parameters varied significantly among host species. Mean species richness of parasites (Fig. 4A) varied from 1.42 ± 0.63 to 5.86 ± 1.90 (GLM: Anova $F_{9,1147} = 77.27$, $p < 0.001$), the mean number of individual parasites (Fig. 4B) from 3.09 ± 4.06 to 35.45 ± 32.54 (GLM: Anova $F_{9,1147} = 18.14$, $p < 0.001$), and the Brillouin diversity index (H') values (Fig. 4C) varied from 0.19 ± 0.34 to 1.43 ± 1.4 (GLM: Anova $F_{9,1147} = 51.58$, $p < 0.001$). All parameters were higher for infracommunities of *T. rhodopus* (Figs. 4A–C).

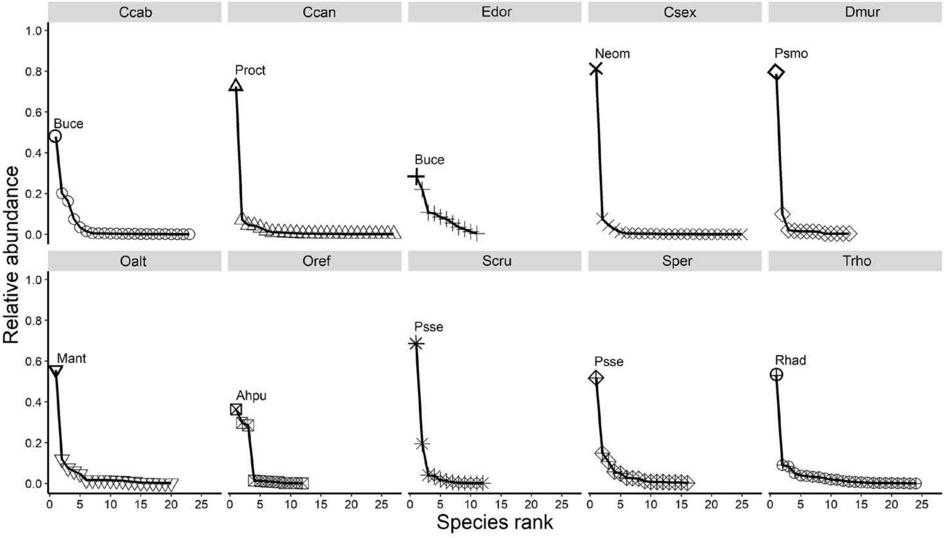

Fig. 2. Range-abundance curves for parasite component communities of carangid fish from Acapulco Bay, Mexico. Fish species: Ccab – *Caranx caballus*, Ccan – *Caranx caninus*, Csex – *Caranx sexfasciatus*, Dmur – *Decapterus muroadsi*, Edor – *Euprepocaranx dorsalis*; Oalt – *Oligoplites altus*, Oref – *Oligoplites refulgens*, Scru – *Selar crumenophthalmus*, Sper – *Selene peruviana,* Trho – *Trachinotus rhodopus*. Dominant parasite species: Buce – *Bucephalus margaritae*, Prot – *Protomicrocotyle manteri*, Neom – *Neomicrocotyle pacifica*, Psmo – *Pseudomazocraes monsivaisae*, Mant – *Manteria brachiderus*, Ahpu – *Ahpua piscicola*, Psse – *Pseudomazocraes selene*, Rhad – *Rhadinorhynchus* sp.

Table 4. Results of the PERMANOVA analysis based on Bray-Curtis dissimilarities of host traits that explain variation in the abundance of component species and infracommunity parameters for parasites of carangid fish species, from Acapulco Bay, Mexico.

Source	df	SS	MS	Pseudo-*F*	p-value	Variation components (%)
Abundance of component species						
Host	9	1,638,800	182900	136.3	0.001	40.13
Size	229	373,000	1628.8	1.38	0.001	11.14
Size × host	335	454,560	1356.9	79.43	0.001	9.93
Weight	766	1,051,200	1372.3	1.14	0.001	11.11
Weight × host	121	166,050	1372.3	1.34	0.001	11.57
Infracommunity parameters						
Diversity	439	634,390	1445.1	1.33	0.001	13.81
Diversity × host	237	298,140	1258	1.16	0.001	9.36
Richness	12	70,760	5896.7	4.95	0.001	11.09
Richness × host	50	97,791	1955.8	1.64	0.001	7.58
Load	99	229,990	2323.2	2.27	0.001	13.44
Load × host	261	411,190	1575.4	1.54	0.001	13.56

Size – host body size (total length); Weight – host weight; Richness – number of parasite species per host; Load – total number of parasites per infracommunity; Diversity – Brillouin diversity index values. *Abbreviations*: df – degrees of freedom; SS – sums of squares; MS – mean squares. Only significant effects are listed.

Multivariate analyses

In the PCA used to identify the possible influence of biotic and abiotic factors on parasite infracommunity structure (Fig. 5), the host sex and Fulton's condition factor (Kn) were eliminated as "predictor" variables, because of its low contribution to total explained variance. The first two principal component axes explained 47.3% of total variance: they contributed 29.1% (eigenvalue = 4.23) and 18.2% (eigenvalue = 2.58), respectively.

The first component variable associated to the habitat type of the fish species and the climatic season, along with the infracommunity parameters (Table 6). This variable suggests that fish from bentho-demersal or neritic-demersal habitats had infracommunities with greater species richness and diversity; these fish were collected mainly during the dry season in some years (Table 3). The second variable associated the traits of the host species (body size, weight and diet variety) with climatic events (multivariate El Niño index), and the year of sampling. According to this second variable, the larger species of host had a less varied (more specialised) diet, mainly during some years when the temperature was slightly higher than normal (Table 3).

DISCUSSION

Although it has been observed that sympatric host species that are phylogenetically closely related tend to exhibit parasite communities with very similar diversity and species richness, the metazoan parasite communities of the carangid fishes examined here varied significantly in their structure and species composition even between species of the same genus. Some host traits, such as body size, habitat type and differences in the type of diet, possibly increased by the effect of climatic events, were considered to be the main factors responsible for these variations. These results

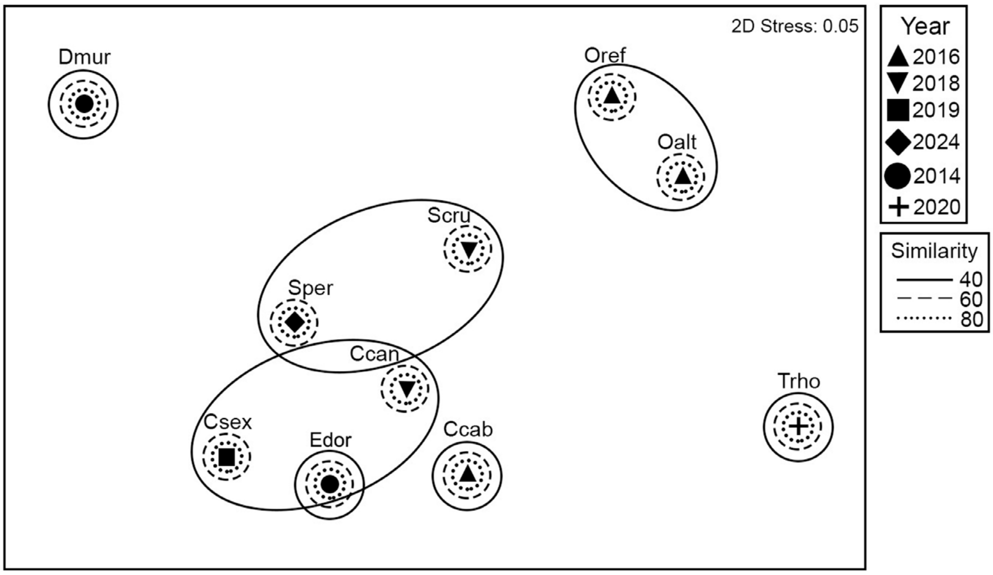

Fig. 3. Non-metric multidimensional scaling (nMDS) plot for parasite communities of carangid fish from Acapulco Bay, Mexico. Ellipses represent similarity levels between fish species. *Abbreviations*: Ccab – *Caranx caballus*; Ccan – *Caranx caninus*; Csex – *Caranx sexfasciatus*; Dmur – *Decapterus muroadsi*; Edor – *Euprepocaranx dorsalis*; Oalt – *Oligoplites altus*; Oref – *Oligoplites refulgens*; Scru – *Selar crumenophthalmus*; Sper – *Selene peruviana;* Trho – *Trachinotus rhodopus*.

Table 5. Values of the Spearman rank correlation coefficient between the total length of the fish and the population and parasite infracommunity parameters.

Fish species	REcto	REndo	TEcto	TEndo	Richness	Evenness	Diversity	Load
Caranx caballus	-0.128	0.406	-0.248	0.316	0.181			
Caranx caninus			0.373					0.261
Caranx sexfasciatus			0.562	-0.189		-0.518		0.508
Decapterus muroadsi	0.675	-0.428	0.678	-0.379				0.653
Euprepocaranx dorsalis					0.252	-0.254		0.269
Oligoplites altus		0.270						
Oligoplites refulgens	0.189		0.263		0.188			
Selar crumenophthalmus								
Selene peruviana								
Trachinotus rhodopus	-0.159		-0.163	-0.142		0.184	0.165	-0.154

Abbreviations: REcto – number of ectoparasite species; REndo – number of endoparasite species; TEcto – total number of ectoparasites; TEndo – total number of endoparasites; Richness – Number of parasite species per host; Evenness – species evenness; Diversity – Brillouin diversity index values; Load – total number of parasites per infracommunity. Only significant values are listed.

suggest, therefore, that ecology of the host has a greater influence on the structure and species composition of the parasite community than its phylogenetic history (Vickery and Poulin 1998, Muñoz et al. 2006).

Richness of parasite fauna

The parasite fauna of the ten fish species of Carangidae collected from Acapulco Bay was composed of 78 parasite species (58 helminths, 19 crustaceans and one pentastomid). The mean number of parasite species per examined host species (7.8 species) was higher than that reported for other fish species from Chamela Bay, Mexico (mean = 1.2 species; 92 parasite species in 114 host species, Pérez-Ponce de León et al. 1999), Tres Palos lagoon (mean = 3.0 species; 39 parasite species in 13 host species, Violante-González et al. 2007), and Gulf of California (mean = 4.0 species; 40 parasite species in 10 host species, Osuna-Cabanillas et al. 2024).

The rich parasite fauna reported here for carangids from Acapulco Bay is probably due to the long-term (ten years) sampling effort extending through different seasons (dry and rainy), which allowed detection of a higher number of rare species within the parasite communities of each species of host (Zander 2005, Villalba-Vasquez et al. 2022). However, the parasite fauna must probably be much richer, since only 29% of the carangid species reported for the coasts of the Mexican southern Pacific (34 species; Palacios-Salgado et al. 2014, Osuna-Cabanillas et al. 2024) have been examined for parasites so far.

Species composition of parasite communities

The parasite communities of *Euprepocaranx dorsalis* and *Selene peruviana* from Acapulco Bay had not been

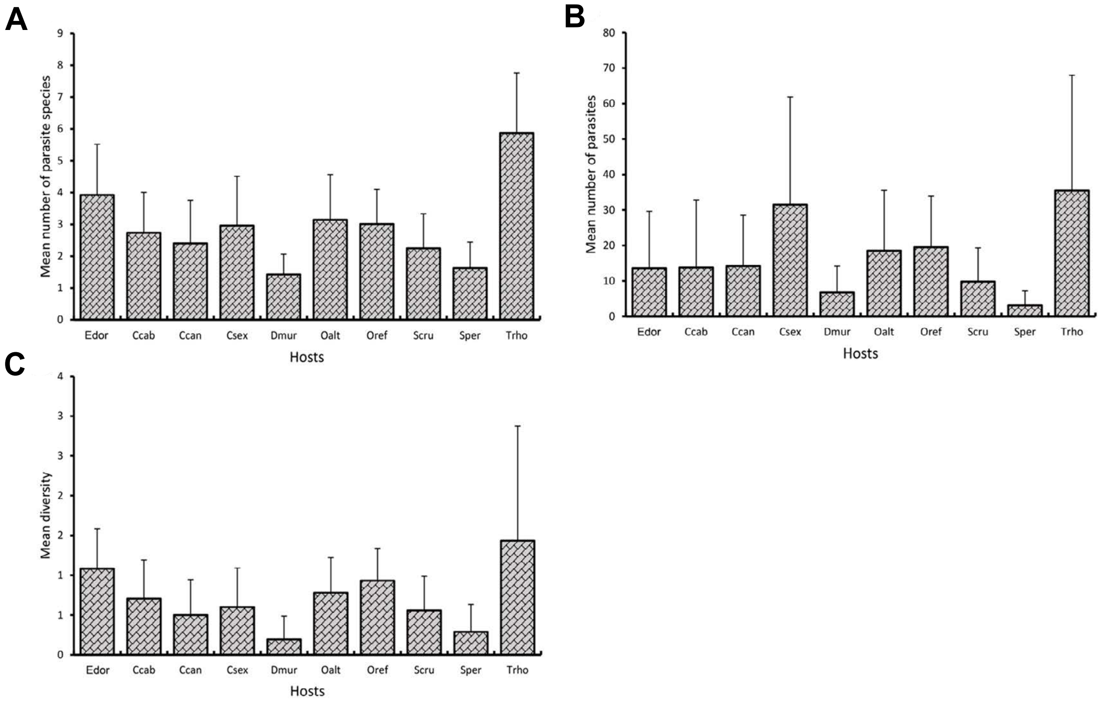

Fig. 4. Mean values of the infracommunity parameters (± standard deviation) of carangid fish, from Acapulco Bay, Mexico. *Abbreviations*: Ccab – *Caranx caballus*; Ccan – *Caranx caninus*; Csex – *Caranx sexfasciatus*; Dmur – *Decapterus muroadsi*; Edor – *Euprepocaranx dorsalis*; Oalt – *Oligoplites altus*; Oref – *Oligoplites refulgens*; Scru – *Selar crumenophthalmus*; Sper – *Selene peruviana;* Trho – *Trachinotus rhodopus*.

Table 6. Summary of the Principal Component Analysis results (PCA) on biotic and abiotic factors that influence the diversity and species richness of the parasite infracommunities of carangid fish species. The first and second principal component axes are indicated by PC 1 and PC 2, respectively. Variables that contribute more to the total explained variance in each PC are indicated by an asterisk. Eigenvalues, percentage of variance and cumulative variance are shown at the end of the table.

			Communality	Uniqueness
Variables	PC 1	PC 2	R^2	% not predicted
Richness	0.949*	-0.121	0.915	0.085
Diversity	0.846*	-0.127	0.731	0.269
REndo	0.809*	0.065	0.658	0.342
TEndo	0.630*	0.079	0.403	0.597
REcto	0.596*	-0.281	0.434	0.566
Habitat	0.575*	-0.362	0.462	0.538
Load	0.575*	0.092	0.339	0.661
Evenness	0.459*	-0.109	0.223	0.777
Season	-0.335*	-0.016	0.113	0.887
Size	0.198	0.817*	0.706	0.294
Weight	0.184	0.812*	0.693	0.307
MEI	0.090	0.729*	0.540	0.46
Host	0.346	-0.558*	0.431	0.569
Diet	0.249	-0.386*	0.211	0.789
Year	0.173	-0.350*	0.153	0.847
Eigenvalue	4.23	2.58		
% total variance	29.10	18.20		
Cumulative variance	29.10	47.30		

Communality – Total influence of the variable with respect to all other associated variables. Uniqueness – percentage of variability that is not predicted by the variable in the model. Diversity – Brillouin diversity index values; Richness – Number of parasite species per host; REcto – number of ectoparasite species; REndo – number of endoparasite species; TEcto – total number of ectoparasites; Diet – host diet variety; MEI – Multivariate El Niño index values; Year – Sampling year; TEndo – total number of endoparasites; Load – total number of parasites per infracommunity; Size – host body size (total length); Evenness – species evenness; Weight – total weight of the host.

examined, so their parasites represent new geographical records for these fishes on the southern Mexico's Pacific coast (Table 2). The overall dominance pattern of the parasite fauna reported here was: Digenea > Copepoda > Monogenea > Nematoda > Cestoda = Acanthocephala > Isopoda > Pentastomida. In tropical regions, digeneans are usually the most diverse group of helminths in fish from all environments (fresh, marine and brackish water) (Luque and Poulin 2007). Species richness of this group of parasites ranged from 4 to 11 among the fish species, and was highest in *Trachinotus rhodopus*.

However, digeneans were not the most species-rich group in all host species, because copepods were the dominant or co-dominant parasite group in *C. caballus* and *Caranx caninus* (Table 2). Copepods are also a highly diverse group that mainly parasitise marine fish (Rohde 2005, Morales-Serna et al. 2014, Soler-Jiménez et al. 2019). In the Neotropics, copepods constitute the second largest group of parasites in marine fish, and the third largest in freshwater fish (Luque and Tavares 2007).

González and Poulin (2005) point out that richness of ectoparasite copepod species in the Pacific Ocean presents a latitudinal gradient related to extrinsic factors such as the number of interactions with fish species, and the water temperature. For example, in tropical regions there is a greater diversity of fish species, so a greater number of ectoparasite-fish interactions can occur. In addition, temperatures below 10 °C affect the development time of caligid copepod populations.

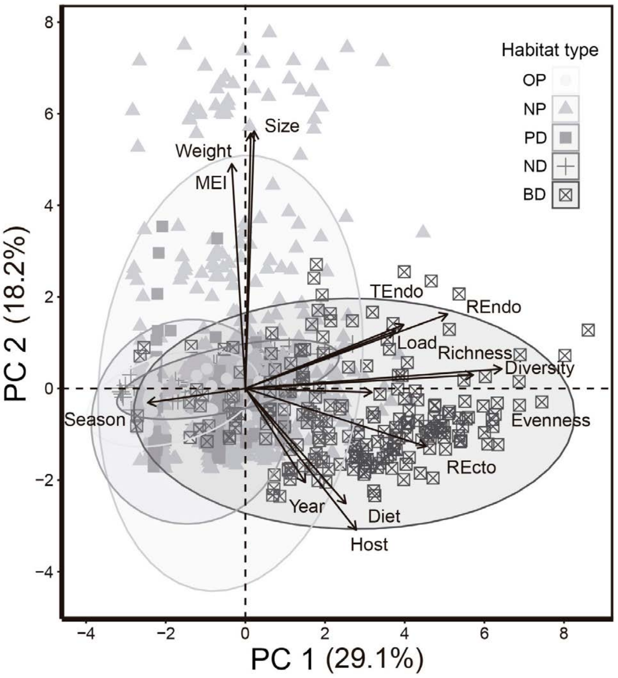

Fig. 5. Scatter plot of Principal Component Analysis (PCA) of factors that influence the species richness and diversity of the parasite infracommunities of carangid fish species, from Acapulco Bay, Mexico. Diversity – Brillouin diversity index values, Richness – number of parasite species per host, REcto – number of ectoparasite species, REndo – number of endoparasite species, TEcto – total number of ectoparasites, Diet – host diet variety, MEI – Multivariate El Niño index values, Year – sampling year, TEndo – total number of endoparasites, Load – total number of parasites per infracommunity, Size – host body size (total length), Evenness – species evenness, Weight – total weight of the host. Habitat type: OP – oceanic-pelagic, NP – neritic–pelagic, PD – pelagic–demersal, ND – neritic–demersal, BD – bentho-demersal.

Conversely, in regions with warm climates the life cycles of these ectoparasites are shorter, although they reach smaller sizes compared to copepod species from temperate regions. Therefore, in warmer water regions located between latitudes 30º S and 40º S, it is possible to find communities of parasite copepods with greater species richness (González and Poulin 2005). In the Mexican Pacific carangid fish are frequently parasitised by copepods, mainly Caligidae (Morales-Serna et al. 2014, Gallegos-Navarro et al. 2018, Violante-González et al. 2019, 2020). In this study, the genus *Caligus* Müller, 1785 was the most represented (9 species, Table 2) of the copepods. The species richness of *Caligus* was very similar to that reported for the same number of carangid fish from the Mexican North Pacific (8 species; Osuna-Cabanillas et al. 2024).

Monogeneans were also an important group in the structuring of the parasite communities of some hosts such as *C. caninus*, *Caranx sexfasciatus* and *Decapterus muroadsi* (Table 2). Monogeneans, like copepods, are transmitted by contact, which increases their transmission probabilities, especially in gregarious fish such as the carangids (Sasal et al. 1999, Mendlová and Šimková 2014). Most monogenean species exhibit high host-specificity at the level of family, genus or host species and by a particular infection site or microhabitat (Sasal et al. 1999, Mendlova and Šimková 2014, Theisen et al. 2017).

According to the number of infected hosts, it is possible to suggest that *Pseudomazocraes selene* (registered in six hosts), can be considered a specialist-parasite of carangid fish at the family level (Table 2). *Ahpua piscicola* Caballero et Bravo-Hollis, 1973, *Allopyragraphorus caballeroi* (Zerecero, 1960), *Neomicrocotyle pacifica* and *Protomicrocotyle manteri* are specialist at genus level (Rohde 2005).

On the other hand, monogeneans generally infect the gills, fins and scales of fish, but also the eyes and nostrils. Very few species are considered endoparasites, i.e. found inside the host's body (Theisen et al. 2017). The monogenean *Pseudempleurosoma* sp. was recovered from the oesophagus of seven host species, although it exhibited higher infection levels in *E. dorsalis* and *C. caballus* (Table 2). *Pseudempleurosoma* spp. are considered generalist parasites, because they infect different species of host, genus or family (Theisen et al. 2017).

Importance of intermediate host

Metazoan parasite communities of marine fish can include both adults and larval stages of several endoparasite groups, which use fish as intermediate or paratenic hosts (Marcogliese 2002, Luque and Poulin 2004, Poulin and Leung 2011). Ten of the 78 parasite species identified were larvae (two digeneans, five cestodes, two nematodes and one pentastomid). Larvae of the nematode *Anisakis* sp. were most prevalent in the carangids *Selar crumenophthalmus* and *Oligoplites refulgens*, and digenean larvae of Anacetabulum-type and cestode larvae of onchoproteocephalideans in *D. muroadsi* and *T. rhodopus* respectively.

Helminth larvae that use fish as intermediate or paratenic hosts are transmitted to their definitive hosts by predation. The fish species used as intermediate hosts are generally small in body size, which means they readily serve as prey for larger top predators (Marcogliese 2002, Luque and Poulin 2004, Poulin and Leung 2011). The carangids *S. crumenophthalmus*, *O. refulgens*, *D. muroadsi* and *T. rhodopus* had the lowest mean sizes in the present study (Table 2). These fish are some of the smallest species in the family Carangidae (Allen and Robertson 1998, Argente et al. 2014); therefore, these carangids are at an intermediate level within the trophic network.

Component communities

The component parasite communities of sympatric carangid fishes from Acapulco Bay represent communities assembled from a pool of locally available parasite species (Valtonen et al. 2001, Tavares and Luque 2008). Species richness at this study level (11–27 species, Table 3) was greater or similar than that reported for the same or other carangid species of the Mexican Pacific coasts (9 species – Martínez-Flores et al. 2023; 4–21 species – Osuna-Cabanillas et al. 2024).

The parasite communities with the highest species richness were registered in *C. caninus* and *C. sexfasciatus* (27 and 25 species, respectively, Table 3). In these communities the number of rare species, represented by only one or two parasite individuals was greater (9 and 11, respectively). This is certainly a pattern observed in many fish parasite communities, in which parasite species associated with a limited species number of hosts tend to occur in hosts with greater species richness (Strona et al. 2013, Bellay et al. 2015).

The structure and species composition of parasite communities varied among host species. Although the species richness of endoparasites in component communities was higher in most cases, suggesting that host diet was the main determinant of parasite community structure, a marked balance between endoparasite and ectoparasite species richness was observed in *Caranx* species (*C. caballus*, *C. caninus* and *C. sexfasciatus*) (Table 3). Therefore, social behaviour may also be an important factor in structuring the parasite communities of these carangid fish.

For example, ectoparasite populations (monogeneans and copepods) may be more abundant in fish species that form large schools (Morand and Poulin 1998, Luque et al. 2004, Palacios-Fuentes et al. 2015), because the probability of a transmission stage (e.g., eggs, larvae) coming into contact with a host increases as host density rises. The contact transmission processes in these *Caranx* spp. may have been reinforced by the high host-specificity exhibited by some monogenean species (e.g., *A. caballeroi*, *N. pacifica*, and *P. manteri*) and copepods (*Caligus alalongae* Krøyer, 1863, and *Caligus robustus* Bassett-Smith, 1898) which only parasitise these carangid species (Table 2).

Rank-abundance curves of parasite species have been used to represent changes in parasite community structure (Norton et al. 2004, Poulin et al. 2008). The rank-abundance curves constructed for each component parasite community suggest that the relative abundance of numerically dominant species changed remarkably among host species (Fig. 2). For example, the degree of dominance of the monogeneans *P. manteri*, *N. pacifica* and *Pseudomazocraes monsivaisae* was higher among the parasite communities of *C. caninus*, *C. sexfasciatus* and *D. muroadsi.* As a consequence of this greater dominance, the parasite communities of these hosts had the lowest diversity values ($^1D < 9$, Table 3). Although up to five monogenean species dominated parasite communities (Table 3), the dominance of one acanthocephalan species (*Rhadinorhynchus* sp.) in *T. rhodopus* is a pattern rarely reported in studies of marine parasite communities (Martínez-Flores et al. 2023, Osuna-Cabanillas et al. 2024).

Studies on parasite ecology indicate that phylogenetically related hosts can harbour similar parasite assemblages that were acquired through evolutionary events such as co-speciation or host-switching (Janovy et al. 1992). Therefore, phylogenetically close hosts, living in sympatry and having the potential to access the same local parasite pool, are expected to show high similarity in the structure and species composition of their parasite communities (da Silva et al. 2022, Osuna-Cabanillas et al. 2024).

However, only the component communities of *Oligoplites altus* and *O. refulgens* presented a high similarity (52.2%), but not the *Caranx* species (mean = 9.6%). In fact, Poulin (2010) pointed out that within a single fish family, the decay in similarity of parasite communities between fish species is not well explained by phylogenetic relationships. The low global similarity (mean = 8%) recorded between parasite communities can therefore be attributed to a different habitat use by the carangid species, as well as a possible influence of different host specificity of some parasite species such as the monogeneans (Locke et al. 2013, Osuna-Cabanillas et al. 2024).

Infracommunities

Several biotic (e.g., body size, social and feeding behaviour, trophic level, vagility, etc.) and abiotic factors (depth distribution, substrate type, climatic events, etc.) are considered important determinants of species richness and diversity in parasite communities (Timi and Poulin 2003, Luque et al. 2004, Violante-González et al. 2019, 2020). The results of the PCA analysis (Table 6) indicate that some host traits, such as habitat type, body size and diet variety, were the most important factors contributing to the structuring of their parasite communities.

The type and breadth of habitats used by the hosts increase exposure to different groups of parasites and should also lead to higher colonisation rates (Luque and Poulin 2004, Osuna-Cabanillas et al. 2024). Carangid fish with bentho-demersal habits such as *E. dorsalis* and *T. rhodopus* had richer and more diverse parasite infracommunities (Fig. 4A,C). Unlike the pelagic carangid species examined in this study, *E. dorsalis* and *T. rhodopus* remain close to the seafloor in coastal areas (Danemann 1993, Cruz-Escalona and Abitia-Cárdenas 2004, Goicochea et al. 2019), so they can acquire more parasite species from infected prey that inhabit benthic or demersal zones.

Influence of host body size

Host body size has proved to be an important predictor of total parasite load and species richness of marine parasite communities (Sasal et al. 1997, Luque et al. 2004). Positive or negative correlations between fish total length and the abundance of several parasite species, as well as with the infracommunity parameters, showed that this host trait was also an important structuring factor of the parasite infracommunities of most carangid species (Table 5).

In the PCA and PERMANOVA analysis, the host body size explained a high percentage of the variability recorded by the infracommunity parameters, and abundance of component species between host species (Tables 4, 6). According to the largest number of correlations recorded, our results suggest that carangid body size can be an excellent predictor of ectoparasite abundance (Table 5).

Diet of the hosts

Host diet is also an important factor in structuring intestinal parasite communities in marine fish (Sasal et al. 1997, Luque et al. 2004, Villalba-Vasquez et al. 2018). The parasite fauna included 74% (58 species) of intestinal species, confirming that the feeding habits of carangid fishes were an important determinant of the species richness of their parasite communities. Many carangid species are considered coastal pelagic predators that feed mainly on benthic invertebrates and small fish (Velasco-Reyes et al. 2022). Species of *Caranx* (*C. caballus*, *C. caninus* and *C. sexfasciatus*) and *O. altus* had a more specialised diet based mainly on small fish. In *Caranx* spp. the number of intestinal parasite species was lower (as in *C. caninus*), or equal to that of ectoparasites (*C. caballus* and *C. sexfasciatus*, Table 2). However, in fish with a more varied diet (15 prey items) based mainly on mollusks and benthic crustaceans such as *T. rhodopus*, the richness of intestinal species was higher (17 parasite species).

In conclusion, the hypotheses tested in this study were supported by the results. The variety of diet and bentho-demersal habits of some carangid fishes such as *E. dorsalis* and *T. rhodopus* may explain the greater species richness and diversity of their parasite infracommunities. Similarity in species composition varied even between hosts of the same genus, suggesting that phylogenetic relatedness and sympatry were not important determinants of parasite communities in these carangid fishes. Climatic episodes such as El Niño and La Niña that occurred during the study period possibly generated notable changes in the structure of local food webs, causing irregular variations in the diet of the hosts, and thus, indirectly influencing the transmission rates of intestinal parasites, due to the reduction or population increase of potential intermediate, paratenic or definitive hosts.

Acknowledgements. The authors thank the fishermen who caught the fish in each sampling date, as well as to the students of the Marine Ecology Faculty (UAGro) for their assistance with field, and laboratory work. The Consejo Nacional de Humanidades, Ciencia y Tecnología (CONAHCYT) provided a scholarship (no. 1005288) to S.S.S. -V. Two anonymous reviewers provided useful comments that substantially improved this manuscript.

Author contribution. Y. Gallegos-Navarro, J. Carbajal-Violante and Erick Rodríguez-Ibarra participated in the fish dissections and parasite collections. Y. Gallegos-Navarro and C. Valencia-Cayetano performed some statistical analysis and edited the figures. S. S. Salas-Villalobos, J. Violante-González, E. F. Mendoza-Franco and S. García-Ibáñez wrote the first version of the manuscript. All authors reviewed the manuscript and contributed to its final editing.

REFERENCES

Allen G.R., Robertson D.R. 1998: Peces del Pacífico Oriental Tropical. Second edition. University of Hawaii Press, Honolulu, 327 pp.

Argente F.A.T., Narido C.I., Palla H.P., Celedonio M.A. 2014: A review on the biology and parasites of the big-eye scad, *Selar crumenophthalmus* (Bloch, 1793). J. Multidiscip. Sci. Res. 2: 3–8.

Baia R.R.J., Florentino A.C., Silva L.M.A., Tavares-Dias M. 2018: Patterns of the parasite communities in a fish assemblage of a river in the Brazilian Amazon region. Acta Parasitol. 63: 304–316.

Bellay S., Lima D.P. Jr., Takemoto R.M., Luque J.L. 2011: A host-endoparasite network of Neotropical marine fish: are there organizational patterns? Parasitology 138: 1945–1952.

Bellay S., Oliveira E.F., Almeida-Neto M., Abdallah V.D., Azevedo R.K., Takemoto R.M., Luque J.L. 2015: The patterns of organisation and structure of interactions in a fish-parasite network of a neotropical river. Int. J. Parasitol. 45: 549–557.

Bush A.O., Lafferty K.D., Lotz J.M., Shostak A.W. 1997: Parasitology meets ecology on its own terms: Margolis et al. revisited. J. Parasitol. 83: 575–583.

Carrassón M., Dallarés S., Cartes J.E., Constenla M., Pérez-del-Olmo A., Zucca L., Kostadinova A. 2019: Drivers of parasite community structure in fishes of the continental shelf of the Western Mediterranean: the importance of host phylogeny and autecological traits. Int. J. Parasitol. 49: 669–683.

Cribb T.H., Bray R.A., Diaz P.E., Huston D.C., Kudlai O., Martin S.B., Yong R.Q., Cutmore S.C. 2016: Trematodes of fishes of the Indo-west Pacific: told and untold richness. Syst. Parasitol. 93: 237–247.

Cruz-Escalona V.H., Abitia-Cárdenas L.A. 2004: General characteristics of the diet of *Trachinotus paitensis* (Teleostei: Carangidae) from San Ignacio Lagoon, Baja California Sur, Mexico. Rev. Biol. Trop. 52: 139–141.

Danemann G. 1993: Características generales de la dieta de la palometa, *Trachinotus rhodopus* (Perciformes: Carangidae). Rev. Biol. Trop. 41: 811–815.

Gallegos-Navarro Y., Violante-González J., Monks S., García-Ibáñez S., Rojas-Herrera A.A., Pulido-Flores G., Rosas-Acevedo J.L. 2018: Factors linked to temporal and spatial variation in the metazoan parasite communities of green jack *Caranx caballus* (Günther 1868) (Pisces: Carangidae) from the Pacific coast of Mexico. J. Nat. Hist. 52: 2573–2590.

Gallegos-Navarro Y., Violante-González J., Monks S., García-Ibáñez S., Rojas-Herrera A.A., Rosas-Acevedo J.L. 2019. Metazoan parasite communities of *Selar crumenophthalmus* and *Decapterus muroadsi* (Pisces: Carangidae) from Mexican Pacific coasts. N. Z. J. Mar. Freshw. Res. 53: 377–396.

Goicochea C., Atoche-Suclupe D., Paredes J., Vásquez C. 2019: Biological and fisheries aspects of *Carangoides otrynter* (Jordan & Gilbert, 1883) a non-native species of Peru. Bol. Inst. Mar. Perú 34: 128–134.

González M.T., Poulin R. 2005. Nested patterns in parasite component communities of a marine fish along its latitudinal range on the Pacific coast of South America. Parasitology 131: 569–577.

Janovy J., Clopton R.E., Percival T.J. 1992. The roles of ecological and evolutionary influences in providing structure to parasite species assemblages. J. Parasitol. 74: 630–640.

Lima-Junior S.E., Goitein R. 2001: A new method for the analysis of fish stomach contents. Acta Sci. 23: 421–424.

Locke S.A., McLaughlin J.D., Marcogliese D.J. 2013. Predicting the similarity of parasite communities in freshwater fishes using the phylogeny, ecology and proximity of hosts. Oikos 122: 73–83.

Luque J.L., Mouillot D., Poulin R. 2004: Parasite biodiversity and its determinants in coastal marine teleost fishes of Brazil. Parasitology 128: 671–682.

Luque J.L., Poulin R. 2004: Use of fish as intermediate hosts by helminth parasites: a comparative analysis. Acta Parasitol. 49: 353–361.

Luque J.L., Poulin R. 2007: Metazoan species of parasite richness in Neotropical fishes: hotspots and the geography of biodiversity. Parasitology 134: 865–878.

Luque J.L., Poulin R. 2008: Linking ecology with parasite diversity in Neotropical fishes. J. Fish Biol. 72: 189–204.

Luque J.L., Tavares L.E. 2007: Checklist of Copepoda associated with fishes from Brazil. Zootaxa 1579: 1–39.

Magurran A. 2004: Ecological Diversity and its Measurement. Princeton University Press, Princeton, New Jersey, 178 pp.

Marcogliese D.J. 2002: Food webs and the transmission of parasites to marine fish. Parasitology 124: 83–99.

Martínez-Flores G., García-Prieto L., Bastida-Zavala J.R., Oceguera-Figueroa A. 2023: Temporal variation in helminth infracommunities of the gafftopsail pompano, *Trachinotus rhodopus* (Pisces: Carangidae) off the Pacific coast of Mexico. Parasitol. Int. 95: 102755.

Mendlová M., Šimková A. 2014: Evolution of host specificity in monogeneans parasitizing African cichlid fish. Parasit. Vect. 7: 69.

Morales-Serna F.N., Pinacho-Pinacho C.D., Gómez S., Pérez-Ponce de León G. 2014: Diversity of sea lice (Copepoda: Caligidae) parasitic on marine fishes with commercial and aquaculture importance in Chamela Bay, Pacific coast of Mexico by using morphology and DNA barcoding, with description of a new species of *Caligus*. Parasitol. Int. 63: 69–79.

Morand S., Poulin R. 1998: Density, body mass and parasite species richness of terrestrial mammals. Evol. Ecol. 12: 717–727.

Muñoz G., Grutter A.S., Cribb T.H. 2006: Endoparasite communities of five fish species (Labridae: Cheilininae) from Lizard Island: how important is the ecology and phylogeny of the hosts? Parasitology 132: 363–374.

Norton J., Lewis J.W., Rollinson D. 2004: Temporal and spatial patterns of nestedness in eel macroparasite communities. Parasitology 129: 203–211.

Osuna-Cabanillas J.M., Marín-Enríquez E., Martínez-Falcón A.P., Timi J.T., Morales-Serna F.N. 2024: Low similarity between parasite communities of ten sympatric carangid species. Parasitol. Int. 101: 102885.

Palacios-Fuentes P., Landela M.F., Gonzalez M.T., Plaza G., Ojeda F.P., Muñoz G. 2015: Is ectoparasite burden related to host density? Evidence from nearshore fish larvae off the coast of central Chile. Aquat. Ecol. 49: 91–98.

Palacios-Salgado D.S., Ramírez-Valdez A., Rojas-Herrera A.A., Granados-Amores J. Melo-García M.A. 2014. Marine fishes of Acapulco, Mexico (Eastern Pacific Ocean). Mar. Biodiv. 44: 471–490.

Pantoja W.M. de F., Silva L.V.F., Tavares-Dias M. 2016: Are similar the parasite communities structure of *Trachelyopterus coriaceus* and *Trachelyopterus galeatus* (Siluriformes: Auchenipteridae) in the Amazon basin? Braz. J. Vet. Parasitol. 25: 46–53.

Pérez-Ponce de León G., García-Prieto L., Mendoza-Garfias B., Léon-Règagnon V., Pulido-Flores G., Aranda-Cruz C., García-Vargas F. 1999: Biodiversidad de Helmintos Parásitos de Peces Marinos y Estuarinos de la Bahía de Chamela, Jalisco. Universidad Nacional Autónoma de México, Mexico City, 53 pp.

Poulin R. 1995: Phylogeny, ecology, and the richness of parasite communities in vertebrates. Ecol. Monogr. 63: 283–302.

Poulin R. 2010. Decay of similarity with host phylogenetic distance in parasite faunas. Parasitology 137: 733–741.

Poulin R., Leung T.L. 2011: Body size, trophic level, and the use of fish as transmission routes by parasites. Oecologia 166: 731–738.

Poulin R., Luque J.L., Guilhaumon F., Mouillot D. 2008: Species abundance distributions and numerical dominance in gastrointestinal helminth communities of fish hosts. J. Helminthol. 82: 193–202.

Poulin R., Rohde K. 1997. Comparing the richness of metazoan communities of marine fishes: controlling for host phylogeny. Oecologia 110: 278–283.

Rohde K. 2005: Ecology of Marine Parasites. Second Edition. CABI Publishing, Wallingford, UK, 590 pp.

Rojas-Herrera A.A., Violante-González J., García-Ibáñez S., Sevilla-Torres V.M.G., Gil-Guerrero J.S., Flores-Rodríguez P. 2012: Temporal variation in the phytoplankton community of Acapulco Bay, México. Microbiol. Res. 3: 13–19.

Santos-Bustos N.G., Violante-González J., Monks S., Rojas-Herrera A.A., García-Ibáñez S., Flores-Rodríguez P., Almazán-Núñez R.C., Moreno-Díaz G. 2018: Species richness and similarity of metazoan parasite communities in three species of leatherjacket (*Oligoplites*: Pisces: Carangidae) from the Pacific coast of Mexico. Invertebr. Biol. 137: 205–220.

Sasal P., Morand S., Guegan J.F. 1997: Determinants of species of parasite richness in Mediterranean marine fishes. Mar. Ecol. Prog. Ser. 149: 61–71.

Sasal P., Trouvé S., Müller-Graf C., Morand S. 1999: Specificity and host predictability: a comparative analysis among monogenean parasites of fish. J. Anim. Ecol. 68: 437–444.

da Silva R.D., Benicio L., Moreira J., Paschoal F., Pereira F.B. 2022. Parasite communities and their ecological implications: comparative approach on three sympatric clupeiform fish populations (Actinopterygii: Clupeiformes), off Rio de Janeiro, Brazil. Parasitol. Res. 121: 1937–1949.

Soler-Jiménez L.C., Morales-Serna F.N., Aguirre-Macedo M.L., McLaughlin J.P., Jaramillo A.G., Shaw J.C., James A.K., Hechinger R.F., Kuris A.M., Lafferty K.D., Vidal-Martínez V.M. 2019: Parasitic copepods (Crustacea, Hexanauplia) on fishes from the lagoon flats of Palmyra Atoll, Central Pacific. ZooKeys 833: 85–106.

Strona G., Galli P., Fattorini S. 2013: Fish parasites resolve the paradox of missing coextinctions. Nat. Commun. 4: 1718.

Tavares L.E.R., Luque J.L. 2008: Similarity between metazoan parasite communities of two sympatric brackish fish species from Brazil. J. Parasitol. 94: 985–989.

Theisen S., Palm H.W., Al-Jufaili S.H., Kleinertz S. 2017: *Pseudempleurosoma haywardi* sp. nov. (Monogenea: Ancyrocephalidae (*sensu lato*) Bychowsky & Nagibina, 1968): an endoparasite of croakers (Teleostei: Sciaenidae) from Indonesia. PLoS One 12: e0184376.

Timi J.T., Poulin R. 2003: Parasite community structure within and across host populations of a marine pelagic fish: how repeatable is it? Int. J. Parasitol. 33: 1353–1362.

Valtonen E.T., Marcogliese D.J., Julkunen M. 2010: Vertebrate diets derived from trophically transmitted fish parasites in the Bothnian Bay. Oecologia 162: 139–152.

Valtonen E.T., Pulkinen K., Poulin R., Julkunen M. 2001: The structure of parasite component communities in brackish water fishes of the northeastern Baltic Sea. Parasitology 122: 471–481.

Velasco-Reyes L.E., Aguilar-Betancourt C.M., González-Sansón G., Flores-Ortega J.R., Ambriz-Casillas M.F. 2022: Feeding and diet overlap of six estuarine fishes (family Carangidae) from the Mexican Pacific region. Estuar. Coasts 45: 302–313.

Vickery W.L., Poulin R. 1998: Parasite extinction and colonisation and the evolution of parasite communities: a simulation study. Int. J. Parasitol. 28: 727–737.

Villalba-Vasquez P.J., Violante-González J., Monks S., Marino-Romero J.U., García-Ibáñez S., Rojas-Herrera A.A., Flores-Garza R., Rosas-Guerrero V. 2018: Temporal and spatial variations in the metazoan parasite communities of the Panama spadefish, *Parapsettus panamensis* (Pisces: Ephippidae), from the Pacific coast of Mexico. Invertebr. Biol. 137: 339–354.

Villalba-Vasquez P.J., Violante-González J., Pulido-Flores G., Monks S., Rojas-Herrera A.A., Flores-Rodríguez P., Rosas-Acevedo J.L., Valencia-Cayetano C., Santos-Bustos N.G. 2022: Parasite communities of the spotted rose snapper *Lutjanus guttatus* (Perciformes: Lutjanidae) off the Mexican Pacific coasts: spatial and long-term inter-annual variations. Parasitol. Int. 88: 102551.

Violante-González J., Aguirre-Macedo M.L., Mendoza-Franco E.F. 2007: A checklist of metazoan parasites of fish from Tres Palos lagoon, Guerrero, Mexico. Parasitol. Res. 102: 151–161.

Violante-González J., Monks S., Gallegos-Navarro Y., Santos-Bustos N.G., Villalba-Vasquez P.J., Miranda-Delgado J.E., Carpio-Hernández D.I. 2019: Metazoan parasite communities of the Pacific jack *Caranx caninus* (Pisces: Carangidae): exploring the variability of their parasite communities. J. Nat. Hist. 53: 1131–1151.

Violante-González J., Monks S., Gallegos-Navarro Y., Santos-Bustos N.G., Villalba-Vasquez P.J., Padilla-Serrato J.G., Pulido-Flores G. 2020: Interannual variation in the metazoan parasite communities of bigeye trevally *Caranx sexfasciatus* (Pisces, Carangidae). Parasite 27: 6.

Zander C.D. 2005: Four-year monitoring of parasite communities in gobiid fishes of the southwest Baltic. III. Species of parasite diversity and applicability of monitoring. Parasitol. Res. 95: 136–144.

Received 15 December 2024 Accepted 2 April 2025

Cite this article as: Salas-Villalobos S.S., Violante-González J., Mendoza-Franco E.F., Gallegos-Navarro Y., Rodríguez-Ibarra E., Valencia-Cayetano C., Carbajal-Violante J., García-Ibáñez S. 2025: Species richness and similarity of parasite communities in ten species of carangid fish (Carangiformes) from the Mexican Southern Pacific. Folia Parasitol. 72: 017.