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Ectoparasitic community of the gills of Pacific sierra *Scomberomorus sierra* Jordan & Starks, 1895 (Actinopteri: Scombridae) from northern Peru

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Abstract: Scombrids have mainly been studied for systematic, zoogeographic and parasitological purposes; however, there are few studies focused on the interaction between ecological parameters and the parasite community of a given host. Therefore, the objective of this research was to analyze the ectoparasite community of *Scomberomorus* from Northern Peru. A total of 58 specimens of *S. sierra* were obtained and were necropsied to search for parasites, which were collected and preserved. The main parasitological indices, degree of aggregation, parasite association with size, weight and sex, and finally, the alpha diversity indices of these parasitic fauna were calculated. 98% of the fish were parasitized by at least one parasitic species. The parasites with the highest prevalence were *Didymocylindrus* sp. (Trematoda) and *Thoracocotyle crocea* (Monogenea), while the parasite with the highest average intensity was *Caligus pelamydis* (Copepoda). The mean intensity and abundance of infection of *T. crocea* and unidentified Didymozoidae. were found to be positively related to the size of *S. sierra*. Sex showed significant differences only with the mean abundance of *T. crocea*, and with the mean intensity of *Didymocylindrus* sp. The five new records of parasites in *S. sierra* from Peru were *Didymocylindrus* sp., *Glomeritrema* sp., unidentified Didymozoidae, *Scomberocotyle scomberomori*, and *C. pelamydis*. This study represents the first ecological-parasitic record for *S. sierra* in northern Peru.

Keywords: Copepoda, ecology, ichthyoparasitology, monogenea, Peru, trematoda

Resumen: Comunidad ectoparasitaria de las branquias del sierra del Pacífico *Scomberomorus sierra* Jordan & Starks, 1895 (Actinopteri: Scombridae), procedente del norte del Perú. Los escómbridos han sido revisados con fines principalmente sistemáticos, zoogeográficos y parasitológicos; sin embargo, son escasos los estudios enfocados en la interacción entre los parámetros ecológicos y la comunidad parasitaria de un determinado hospedero. Es por ello que el objetivo de esta investigación fue analizar la comunidad de ectoparásitos de *Scomberomorus sierra*, procedente del Norte del Perú. Se obtuvieron en total 58 especímenes de *S. sierra* que fueron necropsiados para la búsqueda de parásitos, los cuales fueron recolectados y conservados. Fueron calculados los principales índices parasitológicos, grado de agregación, asociación parasitaria con tamaño, peso y sexo, y finalmente índices de diversidad alfa de la fauna parasitaria. El 98% de los peces estuvieron parasitados por al menos una especie parasita. Los parásitos con mayor prevalencia fueron *Didymocylindrus* sp. (Trematoda) y *Thoracocotyle crocea* (Monogenea); mientras que el parásito con mayor intensidad media fue *Caligus pelamydis* (Copepoda). La intensidad media y la abundancia media de infección de *T. crocea* y Didymozoidae no identificado se encontraron relacionados positivamente con el tamaño de *S. sierra.* El sexo mostró diferencias significativas solo con la abundancia media de *T. crocea,* y con la intensidad media de *Didymocylindrus* sp. Los cinco nuevos registros de parásitos en *S. sierra* para el Perú fueron *Didymocylindrus* sp., *Glomeritrema* sp., Didymozoidae no indentificado, *Scomberocotyle scomberomori*, y *C. pelamydis*. Este estudio, representa el primer registro ecológico-parasitario para *S. sierra* en el norte del Perú.

Palabras claves: copepoda, ecología, ictioparasitología, monogenea, Perú, trematoda

INTRODUCTION

Throughout history parasites have been considered as harmful agents and pathogens; however, it is currently known that they can regulate abundance and alter the structure of the host community and the food chains (Luque & Poulin, 2007; Bautista *et al*., 2013; Iannacone & Alvariño 2013; Chero *et al*., 2016; Cardoso *et al*., 2017). Parasites are also excellent biological indicators to investigate the ecology, migration and population structure of marine fishes (Silva *et al*., 2017).

Scombrids are one of the most popular and edible fish families in the world, and are constituted by mackerel, tuna, and bonito (Paxton, 1998; Bárcenas *et al*., 2021; Yemmen & Gargouri, 2022). Trophic biology studies show that epipelagic scombrids are widely known as opportunistic and generalist predators, which means that their diet is made up of many organisms from different levels of the food chain (Paxton, 1998; Olson *et al*., 2016). Internationally, the species of the Scombridae family have mainly been reviewed for systematic, zoogeographical purposes and some parasitological investigations; however, few studies have focused on the interaction between ecological factors and the parasite community of a specific host (Chero *et al.,* 2016; Miranda-Delgado *et al*., 2019; Santos-Bustos *et al*., 2020, 2021).

Scomberomorus sierra Jordan and Starks, 1895 (Scombridae) is a pelagic fish that is distributed from southern California (United State of America), including the Galapagos Islands (Aguirre-Villaseñor *et al*., 2006) to Paita, Peru (Collette, 1995; Santos-Bustos *et al*., 2020). This species presents a migratory behavior, which is due to its diet based on sardines and anchoveta (Collette & Nauen, 1983, Moreno *et al*., 2011), making it a species that sustains temporary fishery based on migration (Lucano *et al*., 2011; Bárcenas *et al*., 2021).

Some studies on the parasite community of *S. sierra* have been developed from a systematic, taxonomic and ecological perspective in Mexico (Santos-Bustos *et al*., 2020; Bárcenas *et al*., 2021; Morales-Serna *et al*., 2021). In this sense, the annual variation of the helminth community of 151 individuals of *S. sierra* in Mazatlán, Mexico has been analyzed, recording 13 helminth taxa, with the best represented group being digeneans (Barcenas *et al.,* 2021). Similarly, interannual and spatial oscillations in metazoan parasite communities has been evaluated over a 10-year period in 674 *S. sierra* specimens in four locations on the Pacific coast of Mexico, identifying 24 parasitic metazoan taxa. In both studies, the parasite communities were characterized by a high richness of ectoparasite species, with monogeneans and some didymozoid species being numerically dominant (Santos-Bustos *et al*., 2020). In South America and Peru few studies have focused on the metazoan parasitic fauna of *S. sierra*. Therefore, from the first evaluations to date, only 11 species of parasites have been recorded over the last 43 years, nine of them from Peru, three copepods *Acantholochus nudiusculus* (Cressey and Cressey, 1980), *Caligus omissus* Cressey and Cressey, 1980, and *Cybicola buccatus* (Wilson, 1922), one tapeworms *Adenocephalus pacificus* Nybelin, 1931, three monogeneans *Pseudaxine* sp., *Mexicotyle mexicana* (Meserve, 1938) Lebedev, 1984, and *Thoracocotyle crocea* MacCallum, 1913, and finally, two trematodes *Anaporrhutum* sp. and *Didymozoon* sp. (Cressey & Cressey, 1980; Luque *et al*., 2016).

Taking the above into account, the present study aimed to analyze the ecological parameters of the parasitic community of *S. sierra* from Northern Peru.

MATERIAL AND METHODS

Hosts

A total of 58 specimens of S. sierra were obtained from artisanal fishery between October 2019 and August 2022 from Puerto Pizarro, Tumbes, Peru (13° 30' 07" S; 80° 23' 33" W). The fish were preserved and transferred through a cold chain with ice in coolers to the laboratory for further evaluation. The morphometric data of total length (TL) (cm), weight (g) and sex of each fish were recorded. The dissection of each individual consisted of an intensive search for ectoparasites in the gills, eyes, skin, operculum, fins, and oral cavity.

Metazoan parasites

Metazoan parasites were removed, transferred and separated in petri dishes and finally washed with 0.9% saline solution (Suthar *et al*., 2022). All parasites followed standard mounting and staining procedures for each taxon. The helminths were fixed in a mixture of absolute ethyl alcohol (85%), formaldehyde (10%), and acetic acid (5%) for one hour and then transferred to a 14.8 mL glass container with ethanol at 70%. For the preparation of permanent mounting sheets, the helminths were placed for one hour in acetocarmine, and then removed from the dye and washed in 70% ethyl alcohol to eliminate excess dye, followed by dehydration in a graded ethanol series, cleared in clove oil, and finally mounted in Canada balsam. Copepod crustaceans were rinsed in pure glycerin for a period of two weeks (Hayward & Rohde, 1999; Eiras *et al*., 2006; Almeida & Almeida, 2014; Thaenkham *et al*., 2022; Wood *et al*., 2023). The identification of monogeneans, trematodes, and copepods parasites was based on specialized publications (Gibson *et al*., 2002; Kohn *et al*., 2006, 2007; Gibbons, 2010; Cohen *et al*., 2013; Luque *et al*., 2016; Eiras *et al*., 2017; Mendoza-Garfi *et al*., 2017; Smit *et al*., 2019). Each of the species found was deposited in the collection of Parasitic Helminths and Related Invertebrates (HPIA) of the Natural History Museum of the Federico Villarreal National University (MHN-UNFV) under the codes: MUFV: ZOO-HPIA: 206-214.

Data processing and statistical analysis

The ecological parasite prevalence indices (P%), mean abundance (MA) and mean intensity (MI) of infection were calculated for all hosts (Bush *et al*., 1997; Bautista *et al*., 2015). The type of strategy used was determined according to the P% obtained from each parasitic species found in *S. sierra* as follows: 1) core species, strategy for species with a P% greater than 60%; 2) secondary species, strategy for species with P% within the range of 40% to 60%; 3) satellite species for species with P% between 5 and 40%, and finally, 4) rare species with P% less than 5% (Suthar *et al*., 2022). The specific importance index (SII) calculated as the importance of each parasite species in the ecological assemblage was used in order to obtain an integrated infection index of both ecological descriptors: SII = P% + (MA x 100), where: SII= Specific importance index, P% = Prevalence, MA= Mean abundance of infection (Minaya *et al*., 2021a).

The dominance frequency of each parasitic species was determined as the number of times that a parasitic species is dominant in all the fish hosts examined and the relative dominance frequency of each parasitic species was calculated as the number of individuals of a parasitic species divided by the total number of individuals of all taxa in the parasitic infracommunity. Single and multiple parasitic infection (two to three parasitic metazoan species) were determined (Rodhe *et al*., 1995).

For the parasite species presenting prevalences greater than 10% (Esch *et al*., 1990), dispersion indices were used (DI: Variance (S^2) / MA, Poulin discrepancy index (PDI) and K of the negative binomial equation with its respective Chi square value (X^2) to determine the type of distribution and degree of aggregation, which was classified as aggregate, uniform or random (Bego & Von Zuben, 2010). The calculations were made using the Quantitative statistical package. Parasitology 3.0 (Rózsa *et al*., 2000) The inter-annual variation of the parasitic fauna was not evaluated due to the low number of specimens evaluated per year.

The Pearson's correlation coefficient was applied to evaluate the association between TL *versus* P% and Weight *versus* P%, where the P% values were previously transformed to the square root of arcsine. The Spearman's correlation coefficient (rho) was used to determine the relationship between host TL and MA and MI and weight vs. host MA and MI of each parasite species, after calculating four ranges of TL (cm) (I: 13–49; II: 49.1–58; III: 58.1–67; IV: 67.1–78) and seven ranges of weight (g) (I: 301–398; II: 398.1–486; III: 486.1–574; IV: 574.1–662; V: 662.1–750; VI: 750.1–838; VII: 838.1–926). In all cases, the normality of the data was verified using the Kolmogorov-Smirnov test with the Lillierfors modification and the homocesticity of variances based on the Levene test (Stockemer, 2019; Minaya *et al*., 2020).

The Student's t test was used to compare the MA and MI of each parasite and the sex of the host. 2x2 contingency tables were used to calculate the degree of association between the sex of the host and P% of each parasite using the X^2 and the Likelihood Ratio test. The analysis of the parasites in relation to the TL and the sex of the host was carried out only for species with a prevalence greater than 10% (Esch *et al*., 1990).

The following alpha diversity indices were determined: Richness (S), Individuals, Menhinick (D_{Mn}), Margalef (D_{Mg}), Shannon-Weaver (H`), Pielou Equitability (J`), Simpson (D), Berger-Parker (d) and finally Chao-1 for the parasitic community component, for males and females (Salmerón-López *et al*., 2017; Minaya *et al*., 2021a; Negrelli *et al*., 2021). Similarly, to compare the values of H and D between sexes, the Student's t test was used. The level of significance was evaluated at a level of $p \leq 0.05$. To determine the diversity indices, we used the statistical package PAST-Palaeontological STatistics, ver. 4.03, and for the descriptive and inferential statistics, the statistical package IBM SPSS Statistics 27 was used.

RESULTS

The population structure of *S. sierra* was composed of 50% males (n=29) and 50% females (n=29). The TL of the 58 hosts ranged between 13–78 cm (mean ±standard deviation [SD] = 54.1 ± 9.2 cm). Males ranged from 40–78 cm (53.8 ± 8.2 cm) in length while females ranged between 13–76 cm (54.3 ± 10.3 cm).

A total of 58 individuals of *S. sierra* were examined, of which 1085 specimens of ectoparasites distributed in nine morpho-species were collected and identified. The greatest richness was for the group of ectoparasitic trematodes which presented four species (*Didymocylindrus* sp., *Glomeritrema* sp., unidentified Didymozoidae, and *Didymozoon* sp.), followed by monogeneans, with three species [*T. crocea*, *Mexicotyle mexicana*, *Scomberocotyle scomberomori* (Cuvier, 1829)], and finally, the copepods with two species (*C. buccatus* and *Caligus pelamydis* Krøyer, 1863) (Table 1). At least one species of metazoan parasite was found in 98% of the fish (n=57), while the remaining 2% (n=1) did not present any parasite. No endoparasites were recorded in *S. sierra*.

Site of infection, P%, MA, MI of infection, SII and type of strategy of the nine ectoparasitic metazoan species were shown for *S. sierra* (Table 1). The species with the highest P%, and MA was *Didymocylindrus* sp. followed by *T. crocea* with the highest MI (Table 1). Regarding the type of ecological strategy, one species was defined as a core species (11.11%), one as secondary (11.11%) and seven were cataloged as satellite species (77.77%) (Table 1).

The highest frequency of absolute dominance for one species, for two or more species and the relative frequency was for the trematode *Didymocylindrus* sp., followed by the monogenean *T. crocea*. All other species showed a dominance frequency of two or more species, except for *M. mexicana*, *C. buccatus* and *C. pelamydis* (Table 2).

The dispersion of seven ectoparasites of *S. sierra* based on three aggregation indices, DI, PDI and K, the latter with its interpretation by X^2, for species with P% above 10% is shown. The three indices suggest high levels of aggregation for the parasites (Table 3).

A negative correlation between the MA and MI of *T. crocea*, and the TL of the host was found (Table 4). The same situation is observed for the parasite unidentified Didymozoidae. On the other hand, the digenean *Glomeritrema* sp. is the only species showing a degree of association between the weight of the host and the MA of the parasite. Regarding the host sex factor, this was closely associated with the P% and MA of *T. crocea*, and for *Didymocylindrus* sp, sex was associated with the MI (Table 4).

There were slight differences according to sex of *S. sierra* population for the values of the alpha diversity indices (D_{Mn} and D_{Mg}) of the community component of ectoparasitic metazoans with higher values in females than in males. On the other hand, there were similar values for H, J, D, d and Chao-1 for females compared to males (Table 5).

DISCUSSION

The parasitic community of the ectoparasitic metazoan fauna in *S. sierra* was dominated by seven flatworms and two crustaceans. All were host-specialist ectoparasites (monogeneans, didymozoids and copepods). In the case of ectoparasites in *S. sierra*, transmission is associated with factors such as habitat, behavior, diet and host density, as well as environmental characteristics (for example, depth and temperature) (Poulin, 1995; Barber *et al*., 2000; Oliva *et al*., 2004; Miranda-Delgado *et al*., 2019; Santos-Bustos *et al*., 2020). In our research of ectoparasites in *S. sierra,* the highest P% and the highest frequency of absolute dominance for one species, for two or more species and the relative frequency for ectoparasite species was obtained by the digenean *Didymocylindrus* sp. followed by the monogenean *T. crocea*. In the Bay of Mazatlán, Mexico, 11 parasitic species were recorded in *S. sierra*, of which the highest P% were *Didymocylindrus* sp. (92%) and *Didymocystis scomberomori* (MacCallum and MacCallum, 1916) (88%), while the monogenean *T. crocea* achieved the highest MI value (75.2) (Bárcenas *et al*., 2021). Didymozoids are also considered to be highly host-specific with the highest frequency of absolute dominance and the relative frequency; this parasite group mainly parasitises tropical and subtropical scombrids. Five didymozoid species have been reported in *Scomber japonicus* Houttuyn, 1782 from Peru (Cruces *et al*., 2014). *T. crocea* has been recorded in all 18 species of *Scomberomorus* Lacepède (Santos-Bustos *et al*., 2020). Monogeneans are often transmitted directly between individual hosts through contact, exhibit high host-specificity, have a direct life cycle and can reproduce in a wide range of temperatures (Santos-Bustos *et al*., 2020).

Table 1. Ecological descriptors of the gill ectoparasites found in the Pacific sierra *Scomberomorus sierra* from Puerto Pizarro, Tumbes, Peru. Abbreviations: P%, prevalence percentage; MA, mean infection abundance; MI, mean infection intensity; SD, standard error; SII, specific importance index.

Parasitic species	P %	MA ± SD	MI ± SD	SII	Strategy type	Deposit code
TREMATODA						
***Didymocylindrus* sp.**	83	8.62 ± 1.50	10.41 ± 1.71	945	core	HPIA-206
***Glomeritrema* sp.**	22	0.93 ± 0.40	4.15 ± 1.53	116	satellite	HPIA-207
Unidentified Didymozoidae	21	0.97 ± 0.37	4.66 ± 1.66	117	satellite	HPIA-208
***Didymozoon* sp.**	5	0.10 ± 0.06	2.00 ± 0.00	16	satellite	HPIA-209
MONOGENEA						
Thoracocotyle crocea	53	6.33 ± 1.82	11.83 ± 3.09	686	secondary	HPIA-210
Mexicotyle mexicana	12	0.26 ± 0.11	2.14 ± 0.55	38	satellite	HPIA-211
Scomberocotyle scomberomori	7	0.31 ± 0.19	4.50 ± 1.84	38	satellite	HPIA-212
COPEPODA						
Cybicola buccatus	34	0.83 ± 0.22	2.40 ± 0.46	117	satellite	HPIA-213
Caligus pelamydis	29	0.36 ± 0.08	1.23 ± 0.10	66	satellite	HPIA-214
Total	98	18.71 ± 3.08	18.71 ± 3.08	1969		

Table 2. Frequency of absolute dominance and relative dominance for one and two ectoparasitic species in *Scomberomorus sierra* acquired in Puerto Pizarro, Tumbes, Peru.

Parasitic species	Frequency of dominance		
	absolute	2 or more sp.	relative
***Didymocylindrus* sp.**	14	17	0.51±0.40
***Glomeritrema* sp.**	0	3	0.05±0.13
Unidentified Didymozoidae	0	1	0.04±0.11
***Didymozoon* sp.**	0	2	0.01±0.04
Thoracocotyle crocea	1	13	0.22±0.28
Mexicotyle mexicana	0	0	0.01±0.04
Scomberocotyle scomberomori	0	1	0.02±0.08
Cybicola buccatus	0	0	0.05±0.10
Caligus pelamydis	3	0	0.07±0.22

The differences observed between the present research and with Santos-Bustos *et al.* (2020) could be attributed to: (1) host sample size: 59 in our work and 674 in Santos-Bustos *et al.* (2020); (2) host evaluation period: four years of sampling in this work and in Santos-Bustos *et al.* (2020) throughout 10 years of monitoring; (3) number of locations evaluated: one in Peru, in the current work, *versus* four in Mexico (Santos-Bustos *et al.*, 2020); (4) number of biological groups of parasites collected: only three (Trematoda, Monogenea, and Copepoda) in this research, and in contrast in Santos-Bustos *et al.* (2020) were up to seven, also including Cestoda, Acanthocephala,

Table 3. Aggregation indices to evaluate the dispersion of the most prevalent ectoparasites in *Scomberomorus sierra* acquired in Puerto Pizarro, Tumbes, Peru. Abbreviations: *p*, significance value; X^2, Chi-square test value; A, Aggregate. ** Sample too small to verify the fit of the negative binomial distribution.

Aggregation indices	***Didymocylindrus* sp.**	***Glomeritrema* sp.**	**Unidentified Didymozoidae**	***Thoracocotyle crocea***	***Mexicotyle mexicana***	***Cybicola buccatus***	***Caligus pelamydis***
Dispersion Index (DI)	15.23	10.17	8.25	30.21	2.79	3.36	1.04
interpretation	A	A	A	A	A	A	A
Poulin Discrepancy Index (PDI)	0.61	0.89	0.88	0.79	0.90	0.77	0.74
interpretation	A	A	A	A	A	A	A
Negative binomial exponent (K)	0.63	0.11	0.10	0.22	0.10	0.35	14.31
***p*/ interpretation X^2**	0.12/A	0.48/A	1.00/A	0.36/A	**	0.99/A	**

Nematoda and Isopoda, and finally (5) types of parasites: only ectoparasites in this research *versus* ectoparasites, and endoparasites in Santos-Bustos *et al.* (2020).

Aggregation is a typical parasite dispersion pattern in marine fishes (Miranda-Delgado *et al.*, 2019). In all the ectoparasitic species observed in this study, the aggregation indices (DI, PDI, and K) showed a contagious distribution, which is influenced by intrinsic and extrinsic factors such as: (a) spatial heterogeneity of the fish habitat that produces differences in susceptibility; (b) influence of the evolutionary history of the parasite for food, space and reproductive competition; (c) improvement in the opportunity of infecting fish; and (d) prevention of host population collapse due to the effects of parasitism (Iannacone *et al.*, 2012).

Regarding the degree of association between parameters, the TL of the host was negatively related to the MA and MI of *T. crocea* and unidentified Didymozoidae. No correlation was found between the abundance and P% of *Didymocylindrus simplex* (Ishii, 1935) and the TL of scombrid *Katsuwonus pelamis* (Linnaeus, 1758) (Justo *et al.*, 2013). Other studies have described a positive correlation for the abundance of monogenean *T. crocea* in Acapulco, Mexico with the size of the fish (Santos-Bustos *et al.*, 2020). A possible explanation for the fact that the TL of the host was negatively related to the MA and MI of *T. crocea* and unidentified Didymozoidae. may be that the smaller specimens of *S. sierra* correspond to the immature or juvenile forms of the fish, which infers that both species of parasites present a greater burden in juvenile populations. Therefore, it is suggested that the small and juvenile specimens of *S. sierra* are gregarious and form schools, while the adults of the large species are solitary or less gregarious (Santos-Bustos *et al.*, 2020). For example, it is known that ectoparasitic monogenous populations may be more abundant in schooling fish than in solitary species because the probability of a transmission stage (*e.g.*, eggs, larvae) coming into contact with a host increases with a higher host density (Santos–Bustos *et al.*, 2020). In *Sphyraena ensis* it is known that ectoparasite populations may be more abundant in fish with a schooling behavior than in solitary species because the probability of a transmission stage (*e.g.*, eggs, larvae) contacting a host increases with greater host density (Minaya *et al.*, 2021b). This pattern is opposite to that observed in other fish species, in which larger fish can facilitate parasite colonization by ecto- and endoparasites because larger fish offer a greater surface area for gill-attaching parasites, tend to ingest larger amounts of food, and are often older, meaning they have had more time to accumulate parasites than smaller, younger individuals (Miranda-Delgado *et al.*, 2019). Differences in the diet of *S. sierra* have been reported among the different size classes of these fish (juveniles, pre-adults and adults) (Torres-Rojas *et al.*, 2020).

A close relationship was observed between the sex of the host and the ecoparasitological parameters of *T. crocea* and *Didymocylindrus*

Table 4. Association between total length (TL), weight and sex of *Scomberomorus sierra versus* prevalence (P%), mean intensity (MI), mean abundance (MA) ectoparasitic acquired in Puerto Pizarro, Tumbes, Peru. Abbreviations: *p*, significance level; r, Pearson's correlation; rho, Spearman; X^2, Chi-square test; F, Levene test. Values in bold of *p* indicate statistically significant differences.

Parasitic species		***Thoracocotyle crocea***	***Didymocylindrus* sp.**	***Caligus pelamydis***	***Cybicola buccatus***	***Glomeritrema* sp.**	**Unidentified Didymozoidae**	***Mexicotyle mexicana***
TL *vs.* P%	**r**	-0.17	-0.23	-0.73	-0.79	-0.72	-0.91	-0.55
	p	0.84	0.77	0.27	0.21	0.28	0.09	0.45
TL *vs.* MA	**rho**	-1.00**	-0.40	-0.40	-0.80	-0.80	-0.95	-0.40
	p	**0.00**	0.60	0.60	0.20	0.20	**0.05**	0.60
TL *vs.* MI	**rho**	-1.00**	-0.40	-0.32	-0.80	-0.80	-0.95	-0.80
	p	**0.00**	0.60	0.68	0.20	0.20	**0.05**	0.20
Weight *vs.* P%	**r**	0.54	-0.49	-0.15	0.32	0.55	-0.53	0.73
	p	0.35	0.40	0.81	0.61	0.34	0.36	0.16
Weight *vs.* MA	**rho**	-0.30	-0.70	-0.10	0.30	0.90	-0.70	0.62
	p	0.62	0.19	0.87	0.62	**0.04**	0.19	0.27
Weight *vs.* MI	**rho**	-0.40	-0.40	0.21	0.70	0.20	-0.70	0.26
	p	0.51	0.51	0.74	0.19	0.75	0.19	0.67
Sex *vs.* P%	**X^2**	5.61	0.00	0.08	0.31	0.10	1.68	0.16
	p	**0.02**	1.00	0.77	0.58	0.75	0.19	0.69
Sex *vs.* MA	**Student's-t**	1.49	1.97	0.64	0.63	0.17	1.70	0.46
	p	0.14	0.06	0.53	0.53	0.87	0.10	0.65
	F (Levene)	4.41	8.04	2.01	0.56	0.04	10.04	0.76
	p	**0.04**	0.01	0.16	0.46	0.84	0.00	0.39
Sex vs. MI	**Student's-t**	0.52	2.12	1.00	0.34	0.01	1.58	0.21
	p	0.61	**0.04**	0.33	0.74	0.99	0.15	0.85
	F (Levene)	1.01	7.68	4.53	1.70	0.001	21.24	1.12
	p	0.32	0.01	0.05	0.21	0.98	0.00	0.34

sp. (Table 4). In other studies, no significant differences were found for the P% and MI of *Didymocylindrus filiformis* Ishii, 1935 between the sexes of scombrid *K. pelamis* (Silva *et al.*, 2017). Our results are surprising, because biological differences between males and females of *S. sierra* have not previously been reported in the literature (Aguirre-Villaseñor *et al.*, 2006; Lucano *et al.*, 2011; Espino-Barr *et al.*, 2017; Justo & Kohn, 2014; Torres-Rojas *et al.*, 2020). Thus, there is a clear indication of the preference of the parasites for one of the sexes of the host fish. However, all that has been published to date in the scientific literature does not show differences in the ecological relationships (habitat, behavior, and feeding) of males and females of *S. sierra* and does not help us to adequately explain the differences found between the sex of the host and the ecoparasitological parameters of *T. crocea* and *Didymocylindrus* sp. (Sandoval-Ramírez *et al.*, 2020; Torres-Rojas *et al.*, 2020). This interpretation would also apply the differences observed for the parasitological indices of

Table 5. Alpha diversity indices for the community component of metazoan ectoparasites according to the sex of *Scomberomorus sierra* collected in Puerto Pizarro, Tumbes, Peru. Abbreviations: *p,* significance level; t, Student's-t; S, Richness; D_{Mn}, Menhinick index; D_{MG}, Margalef index; H, Shannon-Wiener index; J, Equitability of Pielou index; D, Dominance of Simpson index; d, Berger-Parker index.

Alpha diversity indices	Total	Males	Females	t(*p*)
Richness (S)	9	9	9	
Individuals	1085	720	365	
Menhinick (D_{Mn})	0.27	0.34	0.47	
Margalef (D_{MG})	1.15	1.22	1.36	
Shannon-Wiener (H´)	1.40	1.31	1.51	0.66 (0.50)
Equitability of Pielou (J)	0.64	0.60	0.69	
Dominance of Simpson (D)	0.33	0.35	0.30	1.74 (0.08)
Berger-Parker (d)	0.46	0.46	0.45	
Chao-1	9	9	9	

T. crocea and *Didymocylindrus* sp. and for D_{Mn} and D_{Mg} (Iannacone *et al*., 2013; Rey *et al*., 2022). It should be remembered that for ectoparasites of *S. sierra,* S, H, J, D, d and Chao-1 did not show differences between sexes of hosts. The Chao-1 index shows that the size of the host sample was adequate.

In Peru, the monogeneans *T. crocea* and *M. mexicana* are species that have been reported in *S. sierra*, *T. crocea* from Trujillo in northern Peru (Tantaleán *et al*., 1985; Luque *et al*., 2016) and *M. mexicana* from Chimbote in northern Peru (Tantaleán *et al*., 1988; Luque *et al*., 2016). Likewise, the presence of these two monogeneans has also been recorded in Mexico Lamothe *et al*., 1997; Pérez *et al*., 1999; Mendoza-Garfi *et al*., 2017; Bárcenas *et al*., 2021). The finding of both species of monogeneans in both Peru and Mexico confirms their specificity towards *S. sierra* (Costello, 2016). In Mexico, *T. crocea* reached the highest MI levels probably related to the anomalous warm conditions since *S. sierra* were collected during the "El Niño" event and monogeneans may be more abundant during times of prolonged heat (Bárcenas *et al*., 2021).

The digeneans of the Didymozoidae family, are considered scombrid specialists and are transmitted by ingestion (Pozdnyakov & Gibson, 2008). They are a group with high P% that is part of the helminthofauna of *S. sierra* (Bárcenas *et al*., 2021). Digeneans of the family Didymozoidae are parasites of marine fish with high host specificity. They mainly parasitize tropical and subtropical scombrids (Miranda-Delgado *et al*., 2019). The high vagility and endothermy of scombrids require the need for high metabolic energy which is met by foraging large quantities of food items (*e.g*., crustaceans, fish of the Engraulidae and Clupeidae families, molluscs, and finally, polychaetes) and can function as intermediate and paratenic hosts for didymozoids. This indicates that this species act as tertiary consumers, or mesopredators, in the food network (Miranda-Delgado *et al*., 2019; Sandoval-Ramírez *et al*., 2020). The high prevalence and medium abundance levels of *Didymocylindrus* sp., could be explained by the preference of *S. sierra* to prey on fish (Moreno *et al*., 2011), since these actinopterygians are intermediate or paratenic hosts for didymozoids of this group of trematodes (Bárcenas *et al*., 2021). In northern Peru, *S. sierra* has a record for a representative of the Didymozoidae family, which is the species *Didymozoon* sp. (Tantaleán *et al*., 1992; Luque *et al*., 2016) that were also recorded in the present study.

In the Mexican Pacific, two species of flukes of the Bucephalidae family have been recorded as parasitizing *S. sierra*: *Bucephalus heterotentaculatus* Bravo and Sogandares, 1956 in the state of Guerrero and *Prosorhynchoides cybii* (Park, 1939) in Colima (Bravo & Sogandares, 1956), while in northern Peru, *Anaporrhutum* sp. a digenean of the Gorgoderidae family (Tantaleán *et al*., 1992; Luque *et al*., 2016) has been described. However, in the present study no members of either the Bucephalidae family or the Gorgoderidae family were found. This could be explained by the variations in abiotic factors such as local fluctuations in surface temperature are known to affect many ecological processes, including the productivity of food webs, and the transmission rates of many trophically transmitted endoparasites as Bucephalidae family and Gorgoderidae family due to population decreases in their potential intermediate hosts (Santos-Bustos *et al*., 2020).

On the Pacific coast of Mexico, 24 parasitic metazoan taxa which were collected from four sampling sites were determined in *S. sierra* (3 monogeneans, 8 trematodes, one cestode, one acanthocephala, 4 nematodes, 5 copepods, and 2 isopods). Trematodes presented the highest richness, representing 34% of the total species recovered, followed by copepods (29%). According to the infection site, 13 species of parasites were classified as ectoparasite and 11 as endoparasites (Santos-Bustos *et al*., 2020). The present study also presented a greater richness in trematodes, which represented 57% of the total species found. However, according to the infection site, all the specimens recovered in this study were ectoparasites, since they were all collected from the gills of their hosts. These results could suggest that there are variations in local environmental factors of Peruvian marine waters (*i.e.*, temperature, salinity and other abiotic factors) that have a substantial effect on community structure of important intermediate potential hosts for intestinal helminths endoparasites (Santos-Bustos *et al*., 2020).

Copepods are the second largest parasitic group in marine fish. Members of the Caligidae family being the most frequent ectoparasites, due to their ability to swim and move (Morales *et al*., 2016). Apparently, crustaceans are neither abundant nor frequent in scombrid fish (Miranda-Delgado *et al*., 2019). Only two species have been recorded in the parasite communities of *S. sierra*. A study carried out in Veracruz, Mexico recorded the copepods *C. pelamydis* and *C. buccatus* in the fish *Scomberomorus cavalla* (Cuvier, 1829) (Villar-Beltrán *et al*., 2019). In our study, *S. sierra* presented both copepods, which suggesting a possible affinity for the Scombridae family. Likewise, *C. pelamydis* has not previously been recorded in *S. sierra*, and this is the first study to report this association. In Peru, the copepods *Acantholochus nudiusculus* (Cressey & Cressey, 1980), *Caligus omissus* Cressey & Cressey, 1980 and *C. buccatus* (Luque *et al*., 2016) have been previously recorded.

As suggested by Bárcenas *et al*. (2021), we agree that two main factors seem to determine the structuring of the parasitofauna of *S. sierra*: the food chain network and the phylogenetic affinities of certain groups of helminths (*i.e.*, Didymozoidae at a family level and Thoracocotylidae at a host genus level). The nine species recorded in *S. sierra* in the present study are considered specialist species as they are only present in the Scombridae family (Santos-Bustos *et al*., 2020).

CONCLUSIONS

In conclusion, the ectoparasitic metazoan community of *S. sierra* was made up of monogeneous specialist ectoparasites, didymozoid flukes, and copepods, which are taxa of parasites common to various species of scombrids, and of these only *T. crocea*, *Didymocylindrus* sp. and unidentified Didymozoidae. showed dependence (positive and negative) on the morphological parameters of their host. *Didymocylindrus* sp., *Glomeritrema* sp., unidentified Didymozoidae, *S. scomberomori*, and *C. pelamydis* are five new records of parasites in *S. sierra* for Peru.

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