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ORIGINAL ARTICLE

Dynamics of a parasite assemblage of the Vermilion Rockfish *Sebastes miniatus* from northwestern Baja California, México

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Abstract A parasite assemblage of *Sebastes miniatus* from northwestern Baja California, México, was composed of a total of 12 species: five ectoparasites (two monogeneans and three parasitic copepods) and seven endoparasites (two digeneans, one cestode, three nematodes, and one acanthocephala). Five of these parasites constituted new genera records to the genus *Sebastes*, and nine were new geographic records. The most abundant species were the endoparasites *Parabothriocephalus sagitticeps*, *Hysterothylacium* sp., and *Anisakis* sp., and the specific richness ranged from 1 to 8 parasite species per host. The most important parasite species in terms of prevalence were *Microcotyle sebastis* (93 %) and *Anisakis* sp. (92 %). The mean abundance of parasites found in *S. miniatus* showed significant variations over the year, with maximum values (31.7 individuals/host) in August, and minimum (0.39 individuals/host) in February. *P. sagitticeps* showed the highest mean intensity of infection (190.4 parasites/host), followed by *Anisakis* sp. (127.2 parasites/host) and *Hysterothylacium* sp. (46.6 parasites/host). The presence of larval stages of the nematodes *Anisakis*, *Pseudoterranova*, and *Hysterothylacium* is particularly important due to their high abundance and prevalence and because they may represent a human health risk (anisakiasis). Rockfishes (family *Scorpaenidae*) of the genus *Sebastes* constitute one of the most important groundfish resources in the American and Mexican northern Pacific Ocean, both for recreational and for the commercial fisheries of California and Baja California. These rockfish species makes up a substantial part of the Mexican cuisine.

Keywords Mexico · *Sebastes miniatus* · Metazoan parasites · Helminths

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Introduction

In the northwestern coasts of Mexico, the vermillion rockfish, *Sebastes miniatus*, Jordan and Gilbert 1880 (Scorpaenidae), is a highly valued marine fish species for its white meat, and it is caught all year by the coastal commercial and the recreational fishing (Siri-Chiesa and Moctezuma-Hernández 1989; Elorduy-Garay and Ruiz-Córdova 1998; Rosales-Casián and González Camacho 2003; Rodríguez-Santiago and Rosales-Casián 2008). Currently, few parasite studies in marine fishes from the Mexican Pacific coasts are available, and particularly in Baja California. The identification of parasite species and the community description at northern Baja California have been conducted in other different six rockfish species of the genus *Sebastes* (Alvarado-Villamar and Ruiz-Campos 1992), also in the California halibut *Paralichthys californicus* (Castillo-Sánchez et al. 1998), and in the ocean whitefish, *Caulolatilus princeps* (Rodríguez-Santiago and Rosales-Casián 2011).

The rockfishes from the Pacific coast of North America are conformed by at least by 65 species; however, the greatest diversity (56 species) is found within the Southern California Bight (Love et al. 2002). This fish group comprised a large proportion in the coastal fisheries catch of Baja California (Rodríguez-Medrano 1993; Hernández-Hernández 2002; Rosales-Casián and González Camacho 2003), and California, USA (Eschmeyer et al. 1983; Love 1996; Stephens et al. 2006).

The vermillion rockfish *S. miniatus* is found from the Prince William Sound in south Alaska to central Baja California. They inhabit rocky reefs, kelp forests, and canyons at depths of 15–467 m, but are commonly found at 50–150 m (Love et al. 2002; O'Connell et al. 1992). The vermillion rockfish represents a potential intermediate host for many parasites, and the prey of a final host like the California sea lion (Lowry et al. 1991). However, in spite of its economic importance and its role as a staple in the local diet, no studies describing the parasite assemblage of *S. miniatus* at Baja California have been conducted. Therefore, the aim of the present work was (1) to determine the assemblage of parasite species in the red rockfish *S. miniatus*, (2) to determine the prevalence, abundance, and intensity of parasite infection across 1 year, (3) to determine the habitat (organ) preferences of the parasite species, and (4) to determine the relationships between parasite abundance and host size, condition factor, and water temperature.

Materials and methods

Vermillion rockfish specimens were bimonthly obtained from sportfishing catches (during 2005) at San Quintín bay and adjacent areas, Baja California, México (between 30°29′52″N–116°07′54″W and 30°20′25″N–115°59′20″W) (Fig. 1). A total of 210 individuals with a range of 210–610 mm total length were analyzed. The sea surface temperature was provided by the boat captains, and temperatures from 50 to 140 m depth were obtained from the IMECOCAL monitoring program of Centro de Investigacion Cientifica y de Educacion Superior de Ensenada (CICESE) (García-Córdova et al. 2005).

All vermillion rockfish individuals were measured for total length using an ictiometer (mm) and weighed (g) with a digital balance Accu-Lab. The Fulton's Condition Factor (KLP) was calculated as $K = [W/TL3]$ 10,000, where: W = weight (g) and TL = total length (mm), to describe the physiological condition of each individual fish (Ricker 1975).

The specimens were examined for external parasites on skin and fins. They were then dissected, and the internal organs were transported on ice to the laboratory for examination under a stereoscopic microscope to collect parasites (gill cavity, intestinal cecum, mesentery, coelomic cavity, stomach wall, stomach, intestine, and gall bladder).

Helminths were fixed in AFA (acetic acid–formaldehyde–alcohol) solution for 2–24 h. Then, they were preserved in ethyl alcohol (70 %) and stained with *Gomori's trichromic* stain. Nematodes were fixed in Berland's liquid, preserved in ethyl alcohol (70 %), and cleared with a solution of phenol–ethanol (Lent's solution) and mounted on slides covered with glycerin-gelatin. Copepods were first fixed in ethyl alcohol (70 %), and then, they were

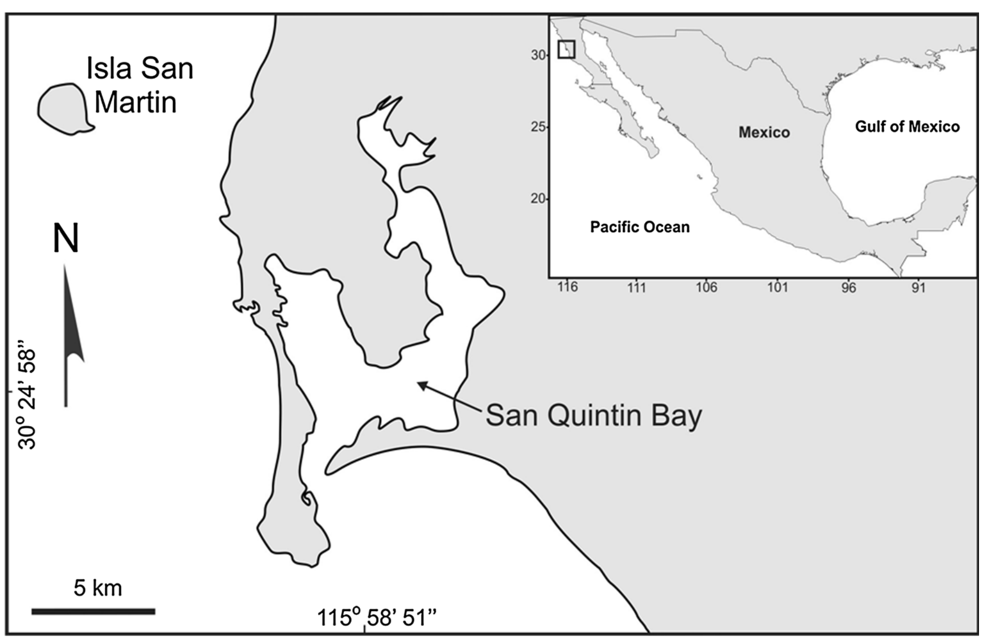

Fig. 1 Location of the study area at San Quintín, Baja California, Mexico

cleared using a solution of glycerin-alcohol and mounted on slides covered with glycerin-gelatin (Yamaguti 1961).

After obtaining the morphological data, identification of helminths was identified according to keys proposed by Yamaguti (1963); Vidal-Martínez et al. (2002); Yamaguti (1971); Bravo-Hollis (1967, 1982a, b); Mendoza-Garfias and Pérez-Ponce de León (1998); Kuchta et al. (2008); Yamaguti (1961); and Anderson et al. (1974–1983) for nematodes. To identify the parasitic copepods, keys of Cressey and Boyle-Cressey (1980, 1985); Kabata (1979, 1992a, b); and Boxshall (2004) were used.

Species richness, prevalence (%), abundance (parasite number/host), and intensity (parasite number/infected hosts) of parasites were determined according to Bush et al. (1997). The presence of parasite species in the different internal organs was used as habitat preferences. Due to the non-normal distribution of the parasitological data and heteroscedasticity of variances, nonparametric analyses were used. To assess significant variations in parasite abundance over time, a Kruskal–Wallis (KW) one-way analysis of variance was performed for each parasite species (Steel and Torrie 1986). Spearman rank correlations were used to assess relationships between the parasite abundance and the host size and weight, fish condition, and seawater temperature.

Results

At the San Quintín fishing area, the sea surface temperature averaged (±SE) 16.0 ± 0.3 °C. The highest temperature (18.2 ± 0.5 °C) was in August, and the lowest (14.9 ± 0.3 °C) in February. At the fishing depth of 50–140 m, the average annual temperature was 10.9 ± 0.09 °C with higher values in October (11.5 ± 0.20 °C) and lower in June (10.2 ± 0.08 °C).

From the 210 individuals of vermillion rockfish, a total of 29,640 parasites were found belonging to 12 species (from which, eight were identified to species level and the rest to genus). Cestodes were the most abundant group with 50.3 % of the total (Table 1). The identified species were seven endoparasites (two digeneans, one cestode, three larval stages of nematodes, and one acanthocephalan) and five ectoparasites (two monogeneans and three copepods) (Table 2). The digeneans, cestodes, acanthocephalan, and ectoparasites were found in adult stage.

The most infested organs were the stomach, pyloric cecum, and intestine, with a presence of seven species (Table 2). Larvae of the nematode *Hysterothylacium* sp. showed less organ specificity; they were found in most organs within the host (mesentery, stomach, pyloric cecum, and intestine). Trematodes and cestodes were mainly restricted to the digestive tract (mainly in the stomach). The acanthocephalan species were found only in the mesentery. Ectoparasites were abundant in the gill cavity, except *Benedenia derzhavini,* which was also frequent in the skin and fins (Table 2).

All the fish examined were parasitized with a minimum of three individuals of copepods to a maximum of 6,373 cestodes (Table 1). In general, the most abundant parasite species was *Parabothriocephalus sagitticeps* (14,879 individuals), followed by *Hysterothylacium* sp. (6,373 ind), *Anisakis* sp. (3,942 ind), and *M. sebastis* (2,696 ind) (Table 2). The highest abundance of parasites was detected in August, and the lowest in December (Fig. 2a). Six of the 12 species recorded (*M. sebastis*: Kruskal–Wallis, $p = 0.000$; *B. derzhavini*: KW, $p = 0.035$; *N. escorpaenae*: KW, $p = 0.002$; *Clavellostis sebastidis*: KW, $p = 0.000$; *Corynosoma strumosum*: KW, $p = 0.000$ and *Anisakis* sp.: KW, $p = 0.001$) showed temporal variations in their abundance (Fig. 2a). Also, the overall mean abundance of parasites showed significant variations (KW, $p = 0.047$) over the year.

The species with higher values of prevalence were *M. sebastis* (92.6 %), *Anisakis* sp. (91.8 %), and *Hysterothylacium* sp. (60.1 %) (Fig. 2b). Consequently, these

Table 1 Groups and total number of parasites recorded in *Sebastes miniatus* caught on the coasts of San Quintín, B.C., Mexico

	Hosts	Endoparasites				Ectoparasites		
		Digeneans	Nematodes	Cestodes	Acanthocephales	Monogeneans	Copepods	Total
Feb	15 (25–29)	7	627	622	105	128	3	1,507
Apr	28 (25.5–28)	25	1,071	1,688	49	557	26	3,444
Jun	62 (37–61)	23	4,589	6,073	231	997	40	12,015
Aug	35 (32–48)	16	1,465	2,401	302	499	11	4,729
Oct	29 (30–48.5)	5	1,011	1,940	229	395	46	3,655
Dec	41 (30–55)	17	1,560	2,155	206	406	54	4,439
Total	210	93	10,323	14,879	1,122	2,982	180	29,789
%		0.3	34.9	50.3	3.8	10.1	0.6	100.0

Groups of endoparasites (digeneans, nematodes, cestodes, acanthocephales) and ectoparasites (monogeneans and copepods). In brackets the size range of the fish in cm

Table 2 Parasite species found in *Sebastes miniatus* ($n = 210$)

	Species	Organ	Total	%*P*	MA	MI
Digenea	*Fellidostomum sebastodis*	G	28	11.2	0.3 ± 0.2	1.1 ± 0.1
	Parahemiurus merus	S, I	65	17.9	0.6 ± 0.4	1.5 ± 0.3
Cestoda	*Parabothriocephalus sagitticeps*	S, I, IC	14,879	32.8	80.8 ± 33.4	190.4 ± 48.1
Nematoda	*Anisakis* sp.*	CC, Stw, I, Me	3,942	91.8	15.0 ± 3.9	15.8 ± 4.1
	Hysterothylacium sp.*	Me, S, I	6,373	60.1	37.9 ± 18.0	46.6 ± 18.1
	Pseudoterranova sp.*	S, Me, I, IC	8	2.9	0.2 ± 0.2	0.6 ± 0.3
Acanthocephala	*Corynosoma strumosum*	Me, CC, I	1,112	37.5	5.3 ± 1.8	13.3 ± 4.4
Monogenea	*Microcotyle sebastis*	GC	2,696	92.6	11.2 ± 2.7	11.6 ± 3.0
	Benedenia derzhavini	S, F, GC	286	40.9	1.7 ± 0.5	2.8 ± 0.6
Copepoda	*Lepeoptheirus* sp.	GC, S, F	67	15.8	0.5 ± 0.3	1.5 ± 0.2
	Clavellostis sebastidis	GC	60	18.8	0.5 ± 0.2	1.2 ± 0.4
	Neobranchia scorpaenae	GC	53	15.5	0.4 ± 0.2	1.1 ± 0.4

Organ preference, prevalence (%*P*), mean abundance (MA), mean intensity (MI)

Location in the body of the host: * larval stage, *F* fins, *S* skin, *GC* gill cavity, *IC* intestinal cecum, *Me* mesentery, *CC* coelomic cavity, *Stw* stomach wall, *S* stomach, *I* intestine, *G* gall bladder

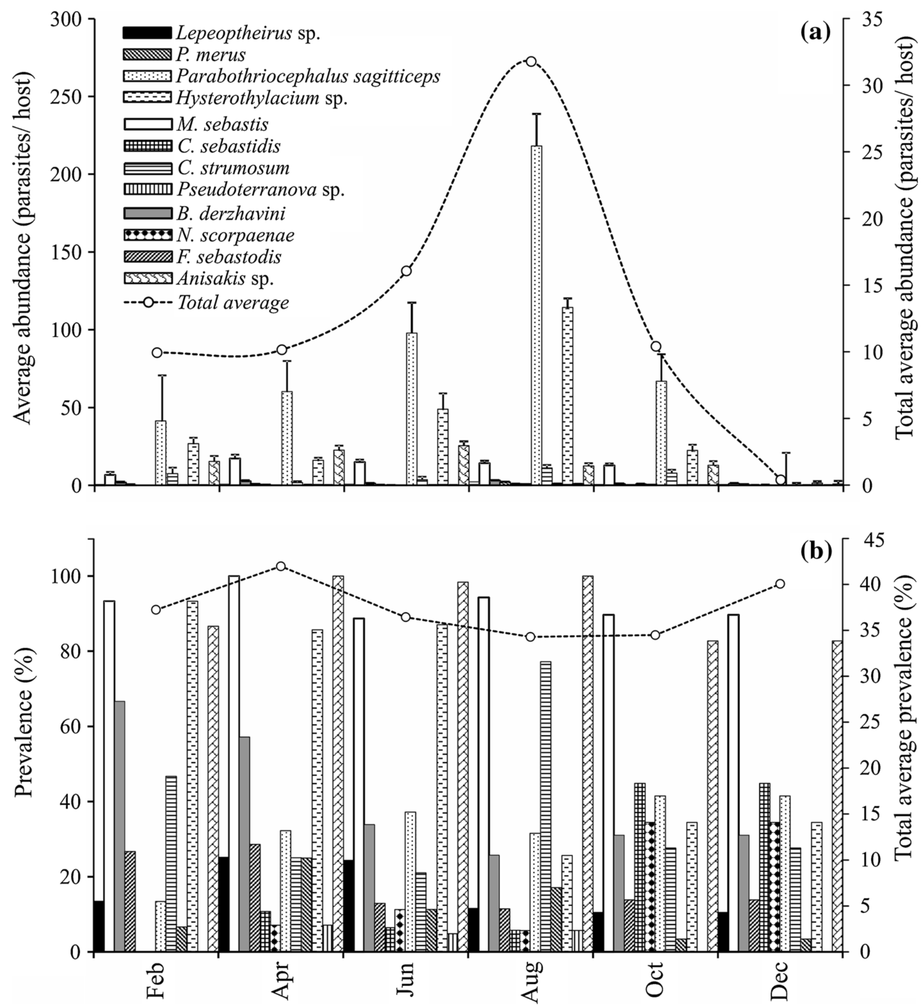

Fig. 2 **a** Average abundance (parasites/host ± SE) and **b** prevalence (%) of parasites on specimens of *Sebastes miniatus* collected at San Quintín, Baja California, from February to December 2005

three were identified as the most common species of the parasite assemblage in *S. miniatus*. The rest of the species had prevalences lower than 60 %.

From late spring to autumn (April–October), *Anisakis* sp. showed a prevalence of 100 % and a decrease (80 %) in early winter (December) (Fig. 2b). Similarly, *M. sebastis* sp. exhibited prevalences of up to 90 % across the year. The species *B. derzhavini*, *C. strumosum*, and *C. sebastidis* showed a decrease in prevalence from spring to summer of 40.6, 16, and 39.2 %, respectively (Fig. 2b).

The species with highest intensity was *P. sagitticeps* (average intensity = 190.4 ± 48.1) followed by *Anisakis* sp. (15.8 ± 4.1) and *Hysterothylacium* sp. (46.6 ± 18.1) (Table 2). There were not significant changes in the overall mean intensity of parasites throughout the year. The intensity was higher in February and lower in December.

A significant positive correlation (Spearman rank) was found between the prevalence and the average abundance of parasites ($R = 0.73$, $p = 0.000$), indicating that the species with high values of prevalence were also the most abundant. Nonsignificant correlations between abundance of parasites and total length ($R = 0.1033$, $p = 0.134$), weight ($R = 0.196$, $p = 0.087$), condition of fish ($R = -0.0108$, $p = 0.876$), or bottom temperature ($R = -0.103$, $p = 0.6004$) were found.

Discussion

In the present study, a total of 12 parasite species were identified for *S. miniatus.* Three of them (*M. sebastis, Anisakis* sp., and *Pseudoterranova* sp.) had already been reported for this rockfish in the coasts of California, USA (Love et al. 2002; Love and Moser 1983), while the other nine species constitute new parasites for this host and a new locality record.

Rockfishes of the genus *Sebastes* sp. from the Southern California Bight (western coast of Baja California, México, and California, USA) are composed of 56 species and are a potential intermediate host for many parasites (Love et al. 2000; González and Acuña 1998). This rockfish species reach 76 cm in length, 6.8 kg in weight, and up to 60-year old (Leet et al. 1992; Love et al. 2002). According to Love (2002), females grow larger than males and probably live longer. It has also been found that 50 % of these fish reach sexual maturity at 5 years (37 cm) (Love 2002). The specimens collected in this study ranged in length from 21 to 61 cm, indicating that different age groups were included.

In this study, nematodes and parasitic copepods were the most diverse groups (three species of each). However, compared with other studies, this diversity was relatively low. For example in *S. alutus* from the coasts of California, eight species of nematodes and 12 species of copepod species were recorded (Love et al. 2000). Larvae of *Anisakis* sp. and *Hysterothylacium* sp. have been recorded from most of the fishes studied in the Mexican Pacific coasts, as well as in many pelagic and demersal fishes from other areas of the world (Aranda-Cruz 2006; Laffon-Leal et al. 2000). The percentage of *S. miniatus* specimens infected by *Anisakis* larvae was relatively high (prevalence = 91.8 %) in comparison with that reported in other congeneric species (*Sebastes capensis,* 2.9–4.8 %) (Domínguez Ortega et al. 2001).

Differences in parasite prevalences between *Sebastes* species and other fishes can probably be explained by differences in the diet and environmental conditions. Furthermore, previous studies have suggested that parasites may be present in a locality when hosts are available, and when the specific abiotic conditions that allow the survival of the infective stages are present (Guidelli et al. 2003).

The parasite species richness in this rockfish was relatively low in comparison with other congeneric species. In *S. nebulosus* (from southeastern Pacific), a richness of 26 parasite species was reported and was mostly composed by digeneans (Holmes 1990). In *S. capensis* (from northern Chile) and *S. caurinus* (from the Atlantic and Pacific oceans), a richness of 16 and 50 parasite species was reported, respectively (Olsen 1952; González 1998). Also, in *S. serranoides* (a species that also distributes from Oregon, USA, to Baja California, Mexico), the species richness was of 36 species, which was positively related to the host age and size (Love et al. 1984). Although the parasite abundance in *S. miniatus* showed certain seasonality, it was not related to the weight and length of the fish or ocean water bottom temperature during our study period. Variations in abundance could be due to other factors such as prey availability over the year. The diet of *S. miniatus* includes a variety of species (fishes, skids, octopuses, shrimps, copepods, isopods, polychaetes, etc.), many of which are potential hosts for initial stages of cestodes (Rojas-Herrera et al. 2003). Similarly, adult stages of parasites also inhabit predators such as elasmobranches (Schmidt 1986) and sea lions (Lowry et al. 1991). In this respect, *S. miniatus* is a part of an intermediate food web permitting the parasites to reach their maturity in the final host (Love et al. 2002; Jensen 2001). Some parasites found in *S. miniatus* (digeneans, cestodes, nematodes, and acanthocephalans) are possibly transmitted via ingestion of larval forms or by the presence of free-living stages of larvae in the plankton, which often determines the parasitic fauna of the host (Dogiel 1964). Monogeneans and parasitic copepods can be acquired by being in contact with other intermediate hosts such as fish and crustaceans. Only the monogenean *Microcotyle sebastis* is specific in this fish group. All the parasite species found in this study, except nematodes, were found in adult stage, suggesting that fish are used as definitive host. Nematodes generally use marine mammals as definitive host (Aguayo and Maturana 1973).

The lack of correlation between the parasite abundance and the host size could also be because specimens of *S. miniatus* were limited to a size range (24–68 cm total length). Similar findings have been documented in other studies, where there is no significant relationship between the host body size and the abundance of parasites (Dogiel 1964; Rhode et al. 1994; Stromnes and Andersen 1998). For example, in *S. capensis* from Talcahuano, southern Chile, the lack of correlation was attributed to the small sample size ($n = 26$) and the narrow size range (16.5–35.5 cm total length) of fish collected in their study (Balboa and George-Nascimento 1998). A study in *S. capensis* from Coquimbo Bay, northern Chile, documented nine helminth species from 180 red rockfish captured (González and Acuña 2000). In that study, the abundances of *Pseudopecoelus* sp. and *Anisakis* sp. were significantly and positively correlated with the size of *S. capensis*, while *Corynosoma* sp. correlated negatively with host size (González and Acuña 2000). Moreover, in a parasitological study conducted on six species of *Sebastes* (*S. constellatus* 14–43 cm, $n = 63$; *S. elongates* 18–41 cm, $n = 42$; *S. rosaceus* 19–36 cm, $n = 33$; *S. umbrosus* 15–47 cm, $n = 41$; *S. helvomaculatus* 18–55 cm, $n = 26$; and *S. chlorostictus* 17–31 cm, $n = 15$) from the North-Occidental coast of Baja California, the authors found that the host size was not a relevant variable to explain variations in the intensity of infection (Alvarado-Villamar and Ruiz-Campos 1992). However, studies in *Sebastes fasciatus* (from the Scotia Shelf) revealed that the size of the host had little effect on parasite prevalence, except for *Anisakid* species, where smaller fish feed more heavily on the intermediate host of the parasite than do larger fish (Scott 1988). Thus, it is possible that other factors (e.g., the sexual maturity stage, changes in the diet, the ingest volume, or the contact possibilities with other intermediate hosts) may be involved in this lack of correlation (Muñoz and Cribb 2005).

Some parasite species of *S. miniatus* showed microhabitat specificity for intestine, stomach, and blind sacs. This could be because they find there a high availability of nutrients and low competition for resources (Stromnes and Andersen 1998). Thus, the specificity for certain microhabitats could also help determine the community structure of parasites in *S. miniatus* (Sasal et al. 1999). This specificity for organ host was similar to those reported in *S. capensis* (from the southeastern Pacific) (González and Acuña 1998).

Similar to other congeneric species, in the present study there was a predominance of certain groups of parasites of the genera *P. sagitticeps*, *Hysterothylacium, Anisakis, Microcotyle*, and *Corynosoma* (González and Acuña 1998). In *S. serranoides*, larval cestodes were predominant (Love et al. 1984). In other species from Baja California (*S. constellatus, S. elongatus, S. rosaceus, S. umbrosus, S. helvomaculatus*, and *S. chlorosticus*), the predominant group was the nematode *Anisakis* (65–90 % of prevalence), followed by digeneans (4.1–25 % of prevalence) (Alvarado-Villamar and Ruiz-Campos 1992).

The presence of larvae of *Anisakis* sp. and *Hysterothylacium* sp. was particularly important because in addition to being relatively abundant and causing diseases in the fish host, they may constitute a risk factor to human health (Anisakiasis). These parasites can infect humans by eating marinated raw fish, 'ceviche or cebiche' (Laffon-Leal et al. 2000), which is a popular seafood dish in the coastal regions of the Americas, especially Central and South America. Therefore, we recommend avoiding consumption of raw or inadequately cooked fish. Species of the genera *Anisakis* and *Pseudoterranova* are more commonly found causing Anisakiasis, but other species of the family Anisakidae (e.g., *Contracaecum*, *Hysterothylacium*, and *Raphidascaris*) do too (Chai et al. 1986).

In conclusion, the magnitude of infection (abundance, prevalence, and intensity) in this host supports previous findings that demersal fishes are rich in the number of individual parasites (Holmes 1990) and that they have a parasitic fauna represented mainly by helminths (cestodes, nematodes, and monogeneans). In this study, the importance of analyzing the parasitic fauna of commercially important fish species has been highlighted, in addition to contributing to the knowledge of marine biodiversity, because it reports parasite species that can represent a potential risk for human health.

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