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PARASITIC COPEPODS OF THE VERMILION ROCKFISH *SEBASTES MINIATUS* (PISCES: SCORPAENIDAE) FROM INSHORE WATERS OF BAJA CALIFORNIA (EASTERN PACIFIC)

COPÉPODOS PARÁSITOS DEL PEZ VERMILLON *SEBASTES MINIATUS* (PISCES: SCORPAENIDAE) EN LAS COSTAS DE BAJA CALIFORNIA (PACÍFICO NORESTE)

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ABSTRACT

A qualitative and quantitative survey of the parasitic copepod fauna of the rockfish *Sebastes miniatus* from the Pacific coasts of Baja California, Mexico, is presented. The species composition, temporal changes in abundance, prevalence and intensity of infection of parasitic copepods were assessed over an annual cycle (2005). Three copepods species were found, *Clavellotis sebastidis* and *Naobranchia scorpaenae* were identified from gill rakers, whereas *Lepeophtheirus rotundipes* showed preference for gill arches. *Clavellotis sebastidis* and *L. rotundipes* were the most abundant and most prevalent species. The intensity of infection was higher for *L. rotundipes* than for the other species. The average abundance, prevalence and intensity of infection showed significant variation over the year ($p < 0.05$). The overall mean abundance of copepods was highest in summer (August), whereas maximum values of prevalence were detected in the autumn-winter and the intensity of infection was highest in the spring. The occurrence of these copepod species on *S. miniatus* constitutes a new host record and extends their known geographical distribution. This study is important as it provides new information and ecological data from copepods parasites whose ecology is poorly studied worldwide.

Keywords: Baja California - *Clavellotis sebastidis* - *Lepeophtheirus rotundipes* – Mexico - *Neobranchia scorpaenae* - parasitic copepods - *Sebastes miniatus.*

RESUMEN

En este trabajo se presenta un estudio cualitativo y cuantitativo de la fauna de copépodos parásitos del pez vermillon o rockotrojo *Sebastes miniatus* de las costas del Pacífico de Baja California, México. Se evaluó la composición de las especies de copépodos parásitos así como la abundancia, prevalencia e intensidad de infección durante un ciclo anual (2005). Las especies de copépodos identificados fueron: *Lepeophtheirus rotundipes*, *Naobranchia scorpaenae* y *Clavellotis sebastidis*. De los cuales *N. scorpaenae* y *C. sebastidis* mostraron preferencia por las branquiespinas, mientras que *L. rotundipes* mostró preferencia por los arcos branquiales. La especie más abundante fue *C. sebastidis*, mientras que la prevalencia fue mayor en *L. rotundipes*. La intensidad de infección fue relativamente mayor en *L. rotundipes*. La abundancia media, prevalencia e intensidad de infección mostraron variaciones significativas durante el año ($p < 0.05$). La abundancia promedio total de copépodos fue mayor en el verano (agosto), mientras que los valores máximos de prevalencia fueron detectados en el periodo otoño-invierno. Por otra parte, la intensidad de la infección fue mayor en primavera. El registro de estas tres especies de copépodos en *S. miniatus* presentadas en este estudio constituye un nuevo registro de hospedero y amplían su distribución geográfica conocida.

Palabras clave: Baja California - *Clavellotis sebastidis* - copépodos parásitos - *Lepeophtheirus rotundipes* - Mexico - *Neobranchia scorpaenae* - *Sebastes miniatus.*

INTRODUCTION

The genus *Sebastes* from the Pacific coast of North America is composed of 65 species, and the greatest diversity (56 species) is found within the Southern California Bight (Love *et al.*, 2002). Rockfishes are economically important for the coastal fisheries of Baja California (Mexico) (Rodriguez-Medrano, 1993; Hernández-Hernández, 2002; Rosales-Casián & Gonzalez-Camacho, 2003) and California (USA) (Eschmeyer *et al.*, 1983; Love *et al*., 2003; Stephens *et al.*, 2006). The vermilion rockfish, *Sebastes miniatus* (Jordan & Gilbert 1880), is a common target fish species in the recreational and commercial fisheries of Baja California (Rodríguez-Santiago & Rosales-Casián, 2008), as well as a highly prized fish for party and private vessel anglers throughout California, with the majority of catches occurring at south of Monterey Bay (Love *et al.*, 2002). This rockfish distributes from Prince William Sound, south Alaska to central Baja California, and inhabits rocky reefs, kelp forests and canyons at depths of 15–467 m, but is most commonly found at depths of 50-150 m (O'Connell *et al.*, 1992; Love *et al*., 2002).

Given its wide latitudinal distribution, this species represents a potential intermediate host for many parasites, and can be prey of final hosts such as the California sea lion (Lowry *et al.*, 1991). Parasitic copepods are commonly found on cultured and wild marine finfish. The attachment and feeding activities on mucous, tissues, and blood of these types of parasites may cause diseases and mortality (Lin *et al.*, 1994; Pike & Wadsworth, 1999; Ho *et al.*, 2001). Therefore, knowledge of their occurrence and abundance on cultured fishes is of great importance as they may have the potential to affect growth, fecundity and survival (Krkosek *et al*., 2006; Costello, 2006; Morales-Serna *et al.*, 2011) and in wild population (Iannacone *et al.*, 2010; Iannacone *et al.*, 2011; Acacio *et al.*, 2012; Mendoza-Cruz *et al.*,2013).

Currently, few parasite studies in commercial marine fishes from the Mexican Pacific coasts, especially from Baja California, are available (Rodríguez-Santiago & Rosales-Casián, 2008; Rodriguez-Santiago *et al.*, 2014). Considering the number of coastal systems along the Mexican coasts, particularly along the Baja California peninsula, and the economic importance of rockfish species, this lack of parasitological studies is noteworthy. Reports on the copepod parasitic fauna of fishes from Mexican coastal systems is scarce and are either published only sporadically or deal with the occurrence of certain copepod species or description of new taxa (Morales-Serna *et al.*, 2012). Therefore, the aim of the present study is to assess the intra-annual variability in the abundance, prevalence and intensity of infection of parasitic copepods of *S. miniatus* from the Pacific coast of Baja California (Mexico), previous studies (Rodríguez-Santiago & Rosales-Casián, 2008; Rodriguez-Santiago *et al.*, 2014) have identified this area which has potential value for a wide range of commercial fish, as well as to analyze the relationship between copepod abundance and the size and condition factor of the host and water temperature.

MATERIALS AND METHODS

Samples of the red rockfish, *Sebastes miniatus* were obtained bimonthly from catches of recreational fishing at San Quintín, Baja California, México (30°33'37" N; 115°56'33" W) (Figure 1). A total of 210 individuals (210-610 mm total length) were sampled. Surface water temperatures (°C) and at a depth range of 50–140 m depth were obtained during 2005 from station 107.32 during the IMECOCAL cruises (30°27'17.3''N, 116°09'41.8''W), located close to Isla San Martin (García-Córdova *et al.*, 2005).

Fish samples were transported in individual plastic bags to the laboratory in a cool box. Each fish was examined for the presence of parasitic copepods on skin, fins, gills and gill rakers. External examination of copepods on the body surface of the hosts was performed under good illumination, and gill arches were removed from each fish and carefully inspected in a Petri dish using a stereomicroscope (LEICA MZ9.5). The plastic bag contents were also examined for the presence of detached copepods.

Parasites found on each fish were preserved in labeled vials with 70% ethanol. Copepods identification was performed following Castro-Gonzalez (2005), Dojiri (1981) and Dojiri (1979). Voucher specimens were deposited in the fish collection of the Laboratorio de Ecología Pesquera, of the Centro de Investigación Científica y de Educación Superior de Ensenada CICESE, Ensenada, Baja California, México. The Fulton's Condition Factor (KLP) was calculated for each fish as $K = [W/TL^3]\ 10{,}000$; where: W = weight (g) and TL = total length (mm) (Ricker, 1975). This factor is used to describe the physiological condition of the individual fish. Weight (g) of specimens was measured with an analogic balance and the total length (cm) with an ictiometer.

Prevalence (percent of infected hosts among all hosts examined), abundance (number of parasites per host) and intensity (number of parasites per infected hosts) of parasites were determined according to Margolis *et al.* (1982). To assess significant variations in copepod abundance, prevalence and intensity of infection over the year, non-parametric analyses of variance of Kruskall-Wallis (KW) were performed (Steel & Torrie, 1986). Spearman rank correlations were used to assess relationships between the parasite abundance and the host size (mm) and weight (g), Fulton's condition, and seawater temperature (°C).

RESULTS

Water temperature

During 2005, the surface water temperature in the fishing area showed a mean (± SE) of 16.0 ± 0.3°C. The highest mean temperature was observed in August (18.2 ± 0.5°C), and the lowest in February (14.9 ± 0.3°C). At the fishing depth (50-140 m), the water temperature did not show considerable variation; the average annual temperature was 10.9 ± 0.09°C with maximum values in October (11.5 ± 0.20°C) and lowest values in June (10.2 ± 0.08°C).

Abundance, prevalence and intensity of parasitic copepods

Three parasitic copepod species *Lepeophtheirus rotundipes* Dojiri, 1979, *Naobranchia scorpaenae* Dojiri, 1981 and *Clavellotis sebastidis* Castro & González, 2005 were identified on from individuals of *S. miniatus* the skin, gills and rakers. Specimens of *L. rotundipes* were found on the skin and gill filaments whereas those of *N. scorpaenae* and *C. sebastidis* were found attached to gill filaments and gill rakers.

The overall mean abundance of parasitic copepods was of 0.5 ± 0.2 ind/host with maximum values in August and lowest values in February (Table. 1). The most abundant species was *C. sebastidis* (annual mean abundance = 0.6 ± 0.2 ind/host), whereas *N. scorpaenae* was the least abundant species (annual mean abundance = 0.3 ± 0.2 ind/host).

In general, the highest proportion of infected hosts was recorded in October (mean prevalence = 30 ± 12.3%) and the lowest in February (4.4 ± 5.4%). The prevalence was relatively higher in *L. rotundipes* (16.2 ± 2.8%) than in *C. sebastidis* and *N. scorpaenae* (14.9 ± 7.6 and 14.5 ± 5.6%, respectively) (Fig. 2b). The intensity of infection showed an annual average value of 1.97 ± 0.4 and did not show significant variations over the year. The higher average value of intensity was in October (3.3 ± 1.0). The mean abundance of *N. scorpaenae* showed significant changes (Kruskall-Wallis, H = 11.05, $p < 0.05$) over time.

The Spearman rank correlation analyses showed that there were no significant relationships between abundance and

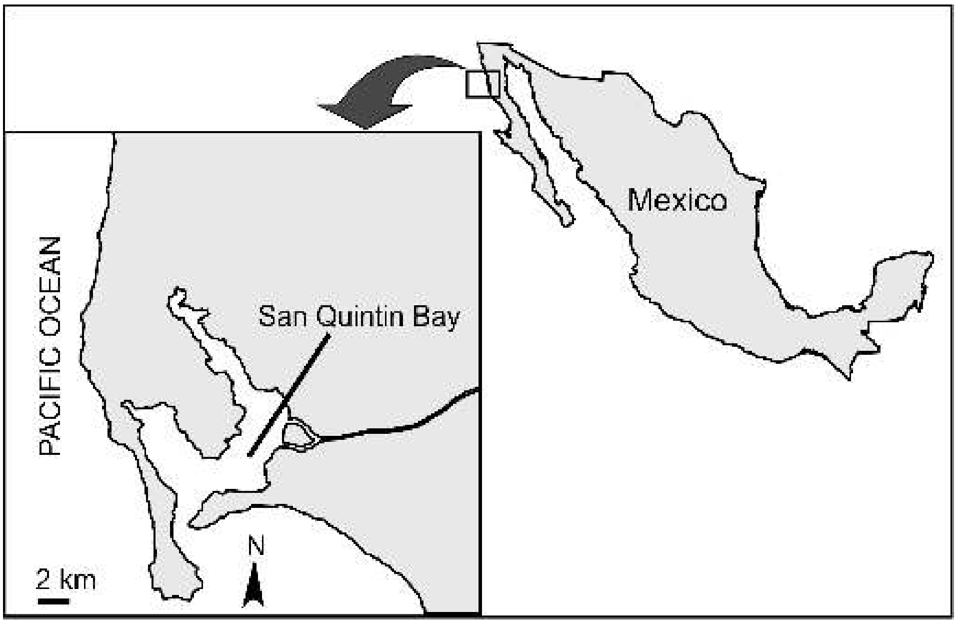

Figure. 1. Location of the study area at San Quintín Bay, Baja California, Mexico.

prevalence of parasitic copepods with the size (r = 0.10, $p > 0.05$) and weight (r = 0.19, $p >$ 0.05) of the hosts, surface water temperature (r = -0.10, $p > 0.05$), bottom temperature (r = 0.19, $p > 0.05$) and condition of fish (r = -0.01, $p > 0.05$). However, the highest (August) and lowest (February) recorded abundance of parasitic copepods coincided when surface water temperatures reached their highest and lowest values respectively (Figure 5).

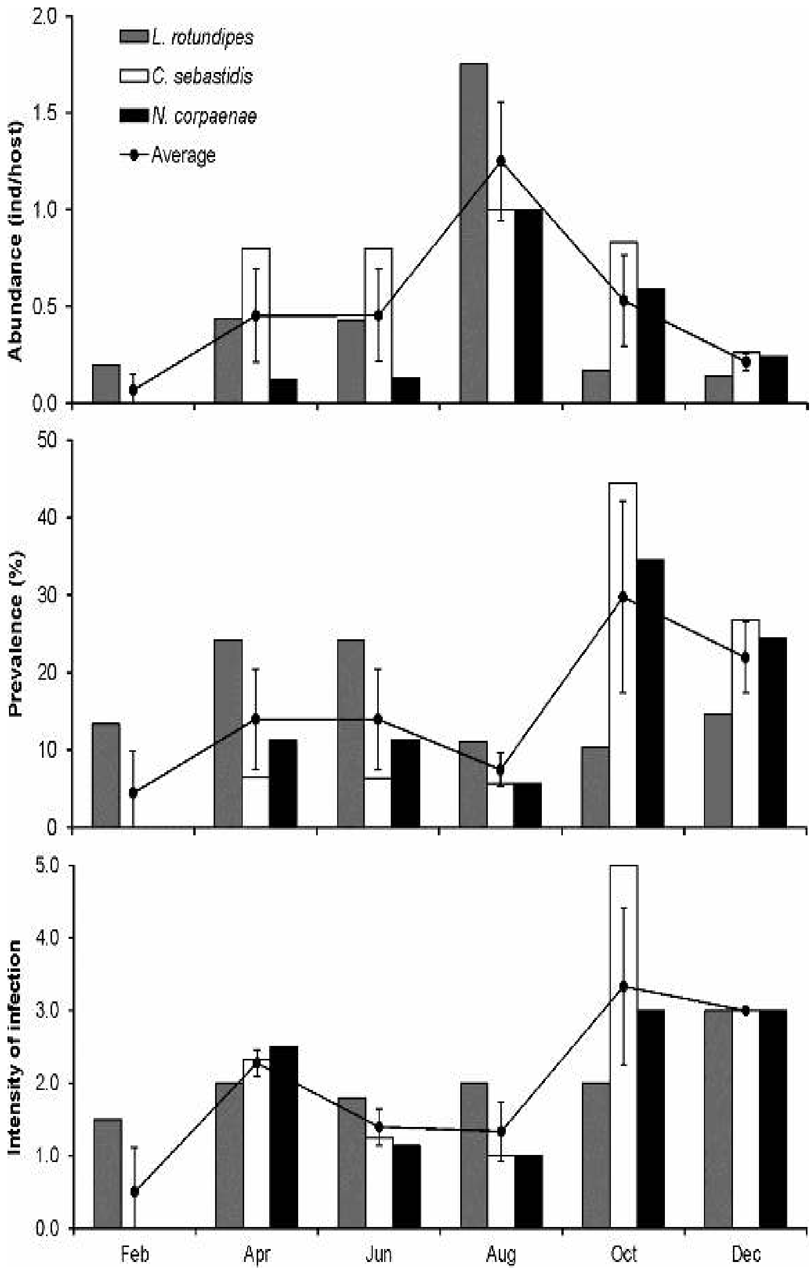

Figure. 2. Mean abundance, prevalence and intensity of infection of copepods parasites in S*ebastes miniatus* collected at San Quintin, Baja California, during an annual cycle, 2005.

Table. 1. Characterization of copepods parasitic infections of *Sebastes miniatus* (n = 210) from the coasts of San Quintin, Baja California, Mexico. Number of examined fish (NF), number of copepod species (NS), prevalence (MP%), mean abundance (MA), mean intensity (MI), mean bottom temperature (BT), mean surface water temperature (ST), mean condition factor (K), total length in cm (TL), weight in g (W).

Sampling month	NF	NS	NP	MP %	MA	MI	BT	ST	K	TL	W
February	15	1	3	4.4±5.44	0.1±0.08	0.5±0.61	12.4	14.4	0.11	400	1081.6
April	28	3	26	14.0±6.48	0.5±0.24	2.27±0.17	10.6	13.9	0.15	615	629.5
June	62	3	40	14.0±6.49	0.5±0.23	1.39±0.25	10.8	15.0	0.13	520	1448.5
August	35	3	11	7.5±2.16	1.3±0.30	1.33±0.40	10.6	21.8	0.13	485	1128.6
October	29	3	46	29.7±12.3	0.5±0.23	3.33±1.08	12.4	15.2	0.13	550	823.7
December	45	3	54	22.0±4.56	0.2±0.04	3.0±0.0	12.2	15.6	0.14	680	1285.7

DISCUSSION

Despite the economic importance of the rockfish *Sebastes miniatus* in the Pacific coasts of North America (Rosales-Casian & González-Camacho, 2003) little is known about the ecology of its parasitic fauna, particularly of the three parasitic copepods found in this study (*L.rotundipes*, *N. scorpaenae* and *C. sebastidis*). The genus *Lepeophtheirus* Normann, 1832, has about 133 valid species (Ho & Lin, 2000) from which only *L. longipes* Wilson C.B., 1905, *L. parviventris* Wilson C.B., 1905, *L. paulus* Cressey, 1969 and *L. oblitus* Kabata, 1973 have been reported in 12 of the 65 *Sebastes* species recorded in this region (Love *et al.*, 2002). It is important to mention that species of genus *Lepeophtheirus* have also been reported in other fish hosts and are very common in cultured fish (Johnson *et al.*, 2004).

Other species of the genus *Naobranchia* (i.e., *N. robusta* [Kabata, 1970] and *N. occidentalis* Wilson C.B., 1915 [Sekerak & Arai, 1977]) are known to parasitise other *Sebastes* species (Love *et al.*, 1984), such as *S. alutus* (Gilbert 1890), *S. bobcocki* (Thompson, 1915), *S. borealis* Barsukov 1970, *S. brevispinis* (Bean,1884), *S. caurinus* Richardson, 1844, *S. diploproa* (Gilbert, 1890), *S. maliger* (Jordan & Gilbert, 1880), *S. nigrocinctus* Ayres, 1859, *S. paucispinus* Ayres, 1854, *S. pinniger* (Gill, 1864) and *S. proriger* (Jordan & Gilbert, 1880), in the Northwest Pacific (Sekerak & Arai, 1977; Kabata, 1988). Love *et al.* (1984) also reported *Naobranchia occidentalis* C.B. Wilson, 1915 in *Sebastes serranoides* (Eigenmann & Eigenmann, 1890) in central California. Prior to this study, *C. sebastidis* had not been recorded in Mexican waters. The genus *Clavellotis* includes nine species (Kroyer, 1863), seven of which were transferred from the genus *Clavellopsis* (Wilson, 1915) by Kabata (1990) and recently *C. sebastidis* female and male were described for the fish *Sebastes oculatus* by Castro & Gonzalez (2005). *Clavella parva* C. B. Wilson, 1912 has been found in *Sebastes aleutinus* (Jordan & Evermann, 1898), *S. elongatus* Ayres, 1859, *S. bobcocki* (Thompson, 1915) and *S. caurinus* Richardson, 1844 in the North Pacific (Sekerak & Arai, 1977), *S. alutus* (Gilbert, 1890) and *S. auriculatus* Girard, 1854 in British Columbia (Wilson, 1915; Sekerak & Arai, 1977), *S. serranoides* (Eigenmann & Eigenmann, 1890) in central California (Love *et al.*, 1984), *S. diploproa* in British Columbia (Kabata, 1970), *S. maliger* in the North Pacific (Kabata, 1988) and *S. melanops* Girard, 1856 in Alaska (Wilson, 1915). In this work, the genus *Clavellotis* is reported for the fist time parasitising *S. miniatus*, and San Quintin Baja California in the Mexican Pacific coast is reported as a new geographic distribution area. The present report of *L. rotundipes*, *N. scorpaenae* and *C. sebastidis* in *S. miniatus* constitutes a new host record in the Pacific coasts of Baja California and a new geographical record. The low overall prevalence was probably due to loss of parasites, while accidental transfer among hosts may also have occurred in this study. In addition, ecological and environmental conditions have been shown to influence the prevalence of ectoparasites (Williams & MacKenzie, 2003). Copepods embedded in the tissues of the host were rejected by an immune reaction of the host tissues (Jonhson & Albright, 1992; Tsotetsi, 2005) apparently resulting from the integument's response to penetration by the parasite. *N. scorpaenae* and *C. sebastidis* showed relatively high abundances from spring to autumn, whereas its prevalence and intensity of infection were highest in spring. Only *L. rotundipes* showed a seasonal pattern throughout the year. Similarly, the prevalence and mean intensity of *N. scorpaenae* and *C. sebastidis* was significantly higher in October and December compared to the rest of the year. The prevalence and mean intensity of *L. rotundipes* was significantly higher in April and June (with the highest water temperature) than in other months. Seasonality has also been documented in two other species of *Lepeophtheirus* (*L. salmonis* and *L. pectoralis*) from higher latitudes; both of which reached high infection levels in spring (Schram *et al.*, 1998; Cavaleiro & Santos, 2009).

The prevalence of *L. rotundipes* varied significantly between sampling months, but did not show a regular pattern. This suggests that the occurrence of *L. rotundipes* on *S. miniatus* is not affected by water temperature. However, the mean intensity of this species was almost constant throughout the one year period of study, except for a significantly lower value observed in February. Nagasawa *et al.* (1993) found increasing infection levels of the copepod *Lepeophtheirus salmonis* (Krøyer, 1837) with host age and size, while Morand *et al.* (1999) found that parasite species and parasite abundance correlated positively with host body length, and Boxshall (1974) found that the age of the host influenced the frequency distribution of the parasitic copepod *Bomolochus confusus* Stock, 1953. The difference between the frequency distributions of the parasite on the different size classes of hosts suggests that there is a gradual accumulation of parasites with increasing size, and therefore age, of host fishes. Iannacone *et al.* (2011) found that the total fish length was not related to the prevalence and abundance of helminth infection, except for a negative relationship with the prevalence of the copepod *Ommatokoita elongata* Grant, 1827 in the Pacific Guitar fish *Rhinobatos planiceps* (Garman, 1880) in Peru. Subsequent, Iannacone & Alvariño (2013) reported the total length and weight of the fish *Brama japonica* Hilgendorf, 1878 showed a close relation between fish sex and the average volumetric abundance of the copepod parasite *Hatschekia conifera* Yamaguti, 1939.

The prevalence of all three parasitic copepod species (*L. rotundipes*, *N. scorpaenae* and *C. sebastidis*) was more variable than their mean intensity. This supports the hypothesis that intensity of infection is a species characteristic and that the biological features of parasitic species can potentially override local environmental conditions in driving parasite population dynamics. According to Poulin (2006), this is possible because prevalence is determined by encounter rates between parasites and hosts, which are influenced by processes external to the fish (e.g., survival of free-living parasite stages), probably determined by local factors, whereas intensity of infection is determined to a large extent by processes acting within the fish. No significant association was detected in this study between the burden of parasitic copepods and fish condition factor K. Similarly, other studies failed to indicate that parasites affect the fish condition in natural systems (Mo & Heuch, 1998; Olivero-Vervel *et al.*, 2005; Jones *et al.*, 2006). In contrast, Lemly & Esch (1984) provided a clear example of mortality due to the direct effects of parasitism in a natural population of fish. Evidence of damage produced by parasitic copepods is better documented from aquaculture studies. In a farm of the southern bluefin tuna *Thunnus maccoyii* (Castelnau, 1872), Hayward *et al.* (2009) found that the sea louse *Caligus chiatos* Lin & Ho, 2003 was strongly associated with both fish condition and severity of eye damage. It is possible that the health of *S. miniatus* was already reduced by copepod infection because these crustaceans damage their hosts directly through their attachment mechanisms and feeding activities. However, the severity of damage reported by Hayward *et al.* (2009) was likely subtle, and the methods used here waere unable to detect any significant effect of copepod parasitism on *S. miniatus*. The presence of *L. rotundipes* (n=67), *N. scorpenae* (n=60) and *C. sebastidis* (n=53), are described for the first time parasitising the vermilion rockfish, *S. miniatus*, in Baja California. It is evident that both taxonomic and ecological aspects of fish copedods parasite research are greatly needed and the knowledge concerning the biodiversity of parasitic copepods in Mexico (Morales Serna *et al.*, 2012). Although *C. sebastidis* has been previosly reported in Argentina (Castro & Gonzalez, 2005). Although some work has been perfomed, still a lack of knowledge which impede our understanding of the evolutionary and biogeographical history of the host-parasite associations. The ecological studies of parasitic copepods in commercially important fish species like the vermilion rockfish *S. miniatus* are important due to a high market value. Also, this fish species is highly appreciated by its white meat, texture and flavor. This fish species is abundant in the commercial fishing and sport-fishing from Baja California (México) and California (USA) and is a common target for recreational and commercial fisheries of Baja California (Rodríguez-Santiago & Rosales-Casián, 2008; Rodriguez-Santiago *et al.*, 2014). In conclusion, in this study the magnitude of infection is very well represented, also the importance of analysing the copepod parasitic fauna of commercially important fish species has been highlighted and shed some light on the knowledge of biodiversity and biology of parasitic copepods. New geographical host records are important, for the reason that you can detect distribution patterns, and may employ other fish to colonise, etc. Studies on copepod parasitizing other commercial fish hosts, particularly in Mexico and Baja California, and the completion of their life cycle warrant further investigation.

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