

Is ectoparasite burden related to host density? Evidence from nearshore fish larvae off the coast of central Chile

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Abstract Variations in parasite populations may be temporal and/or spatial and can occur in relation to environmental factors. However, such changes may also occur due to differences in host population density, which is one of the main factors that affect the abundance of directly transmitted parasites. Fish larvae and their ectoparasites were collected via ichthyoplankton samplings during a 3-year survey near the coast of central Chile. To estimate the variations in ectoparasite abundance that occurred with fluctuations in host density, the prevalence and intensity of ectoparasites

(copepods and isopods) were calculated and compared with the density (i.e., the larval fish abundance standardized to $1,000\text{ m}^{-3}$) of six species of nearshore fish larvae that belonged to the families Gobiesocidae, Labrisomidae and Tripterygiidae. Copepods (Penellidae and Caligidae) and isopods (Cryptoniscidae) were found to be parasitizing the fish larvae. Pennellid copepods were the most prevalent ectoparasite, and the clingfish *Gobiesox marmoratus* (Gobiesocidae) was the most parasitized fish species (12.81 %). The individual burdens of pennellid, caligid and isopod ectoparasites failed to exhibit any correlation with the larval densities of four fish species (i.e., *Auchenionchus crinitus*, *Auchenionchus microcirrhis*, *Sicyases sanguineus* and *Helcogrammoides chilensis*). Nonetheless, the prevalence and intensity of the pennellid copepods exhibited

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a significant and positive correlation with the density of a gobiesocid species. In contrast, the prevalence of pennellid copepods (5.10 %) exhibited a significant but negative correlation with the density of tripterygid fish. Ectoparasite abundance is a result of a species-specific relationship with their hosts, but the evidence found suggests no correlation between ectoparasite burden and host density in larval fishes from coastal environments.

Keywords Host density · Tripterygiidae · Gobiesocidae · Prevalence · Pennellidae · Caligidae

Introduction

Variations in parasite populations and communities may be temporal or spatial (Kennedy 1975); in addition, such variations can be of high magnitude and occur without any stable pattern, varying both among and within fish species (Grutter 1994). Another cause of variability is the environment of the parasites, which differs from the environment of free-living organisms because it has two components: (1) the macroenvironment, which is the environment of the host, and (2) the microenvironment, which is the host body itself (Rohde 1984). Therefore, both environments play an important role in the ecology of parasite communities by controlling the interactions, abundance and diversity of parasites.

Macroenvironment variations can be associated with natural changes in climate, seasonal variations and other environmental conditions that influence parasites through direct and indirect pathways (Violante-González et al. 2008; Altman and Byers 2014). For example, the prevalence of metazoan ectoparasites of marine fishes is positively and strongly related to water temperature (Rohde et al. 1995; Castro and Santos 2013).

In addition, microenvironment variations, which include the reproductive periods, food availability, mortality rates (Negovetich and Esch 2007) and density (Fellis and Esch 2004) of the host, as well as any biological changes that occur in the host, can also affect the abundance of parasite populations (Anderson and May 1978; May and Anderson 1978; Muñoz and Randhawa 2011), leading to temporal variations in the dynamics of parasite populations and communities

(Muñoz and Randhawa 2011). Characteristics of the host, such as host size (Guegan et al. 2005) and host density (Simková et al. 2001), can be important for the acquisition and retention of parasites.

Host density typically plays a central role in determining the prevalence of directly transmitted parasites, explaining the species richness, distribution and abundance of parasite populations (Arneberg et al. 1998; Morand and Poulin 1998). Moreover, the probability of the transmission stage (e.g., eggs, larvae) contacting a host (Arneberg et al. 1998) increases with increasing host density, for example, the larval stages of *Caligus rogercresseyi* have a direct relationship with salmon density (Molinet et al. 2011), demonstrating that host density can be more important than oceanographic variables in certain circumstances. Consequently, those species of hosts occurring at high densities should harbor more parasitic species than species occurring at low abundances (Morand and Poulin 1998; Morand et al. 2000).

Most research concerning the ecology of marine fish ectoparasites was conducted using the adult and/or juvenile stages of fishes, but information related to ectoparasites on fish larvae is scarce. These developmental stages are more vulnerable to the effects of parasites than adult fish (Fogelman and Grutter 2008) due to their fragile nature (Herrera 1984, 1990) and because they are in the early stages of immunological and physiological development (Uribe et al. 2011).

Using a 3-year time series (2010–2012) of plankton sampling in nearshore waters (<500 m offshore) off the coast of central Chile, we tested the hypothesis that variations in host density (i.e., the density of fish larvae) influence the ectoparasite burden, as indicated by parasite prevalence and intensity, in different host species. This hypothesis was addressed using the larval stages of three fish families (i.e., Gobiesocidae, Labrisomidae and Tripterygiidae) that serve as hosts for the developmental stages of ectoparasites.

Materials and methods

Fieldwork

During the late winter and spring of 2010 (three cruises on 9/2, 9/9 and 10/4), 2011 (five cruises on 9/8, 9/15, 10/18, 11/18 and 11/23) and 2012 (five cruises on 11/8, 11/13, 11/27, 12/5 and 12/11), nearshore

(<500 m offshore) night surveys (1,900–2,300 h) were conducted in El Quisco Bay (33°24'S, 71°43'W) in central Chile on board an artisan vessel. Oblique hauls of a Bongo net (60 cm diameter, 300 µm mesh size) with one TSK flow meter (The Tsurumi-Seiki Co., Ltd., Tsurumi-ku, Yokohama, Japan) mounted in the frame of the net were performed for 10–15 min each from a depth of 20 m. The volume of seawater filtered by the net ranged from 13.1 to 437.4 m³ (mean ± one SD 141.8 ± 102.5 m³). All zooplankton samples ($n = 192$) were initially fixed with 5 % formalin buffered with sodium borate and preserved in 96 % ethanol after 12 h.

Unfortunately, macroenvironmental factors, such as seawater temperature, salinity, density and wind strength, could not be incorporated into the study because oceanographic and meteorological data were not available for every sampling period.

Laboratory work

All fish larvae were separated from general plankton samples, counted and classified into the lowest possible taxon following the descriptions of Pérez (1979, 1981) and Neira et al. (1998). Then, all fish larvae were observed under an Olympus ZS-61 stereomicroscope (Olympus Corporation, Shinjuku-ku, Tokyo, Japan) to separate and preserve each parasitized larva into individual containers for further analysis. Each ectoparasite was identified to the lowest possible taxon based on mouthparts and appendages (Castro and Baeza 1986, 1989; Muñoz et al. 2015).

Data analysis

The obtained fish larval abundance values were standardized as individuals 1,000 m⁻³ for each taxon. From the complete taxocenosis, only three families were selected due to their high prevalence in the samples: Labrisomidae, Gobiesocidae and Tripterygiidae. Each of these families was represented by two selected species: *A. crinitus* (Jenyns, 1841) and *A. microcirrhis* (Valenciennes, 1836), *G. marmoratus* Jenyns, 1842 and *S. sanguineus* Müller and Troschel, 1843, and *H. chilensis* (Cancino, 1960) and *Helcogrammoides cunninghami* (Smitt, 1898), respectively (Online Resource 1). These species were grouped into two categories [i.e., non-parasitized larvae (NPL) and parasitized larvae (PL)] to calculate the ectoparasite burden; the

prevalence and intensity were determined according to the method described by Bush et al. (1997).

The obtained host density, prevalence and intensity values for each parasite taxon were tested for their normality distribution using the Shapiro–Wilk test. As none of these variables presented a normal distribution (Shapiro–Wilk test $W > 0.8$; $P < 0.05$), Spearman's correlations were performed to evaluate the existence of a significant relationship between larval fish host abundance (ind. * 1,000 m⁻³) and ectoparasite burden. All of the statistical analyses were performed using the STATISTICA 7 package (Statsoft Inc., Tulsa, Oklahoma, USA).

Results

During the study period (i.e., 2010–2012), a total of 22,671 fish larvae from a total of 46 larval fish species were analyzed. The most parasitized larval fish families were kelpfish labrisomids [*Aucheniuunchus crinitus* (3.43 %) and *A. microcirrhis* (5.51 %)], clingfish [*G. marmoratus* (12.81 %) and *S. sanguineus* (0.52 %)] and triplefins [*H. chilensis* (5.46 %) and *H. cunninghami* (5.10 %)] (Fig. 1).

Three ectoparasitic taxa belonging to two taxonomic groups (i.e., Copepoda, from different chalimus stages, and Isopoda at the larval stage) were recognized in the samples: *Caligus* sp. (Copepoda: Caligidae), *Trifur* spp. (Copepoda: Pennellidae) and Cryptoniscidae (Isopoda) (Fig. 2). The most prevalent ectoparasites were pennellid copepods, with a variable intensity range (1–8 for pennellid copepods, 1–2 for caligids copepods and one isopod per parasitized fish). However, the prevalence and the intensity of the parasite species presented considerable differences in the recorded samples (Table 1).

The prevalence and intensity of ectoparasites were not correlated with the density of most fish larvae ($r_s < 0.7$; $P > 0.05$). However, significant correlations were found for two fish species. The prevalence (Spearman's correlation, $r_s = 0.72$; $P = 0.005$) and intensity of pennellid copepods (Spearman's correlation, $r_s = 0.83$; $P < 0.001$) exhibited a significant and positive correlation with the density of larval *G. marmoratus* (Fig. 3), whereas prevalence of pennellids exhibited a significant but negative correlation with the density of *H. cunninghami* (Spearman's correlation, $r_s = -0.76$; $P = 0.021$) (Fig. 3).

Fig. 1 Three major parasitized fish families. Labrisomidae: **a** *Auchenionchus microcirrhis*, **b** *Auchenionchus crinitus*; Gobiesocidae: **c** *Gobiesox marmoratus*, **d** *Sicyases sanguineus* and Trypterigiidae: **e** *Helcogrammoides chilensis*, **f** *Helcogrammoides cunninghami*. Scale bars 1 mm length

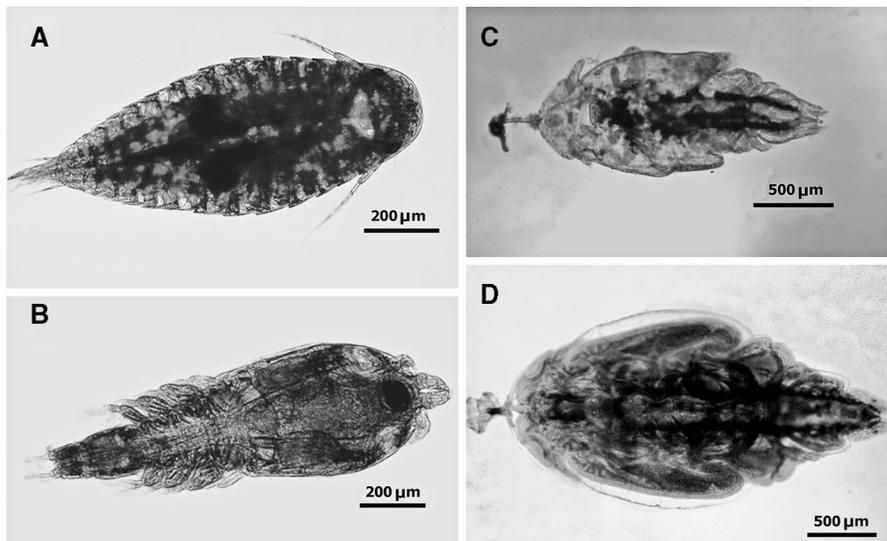
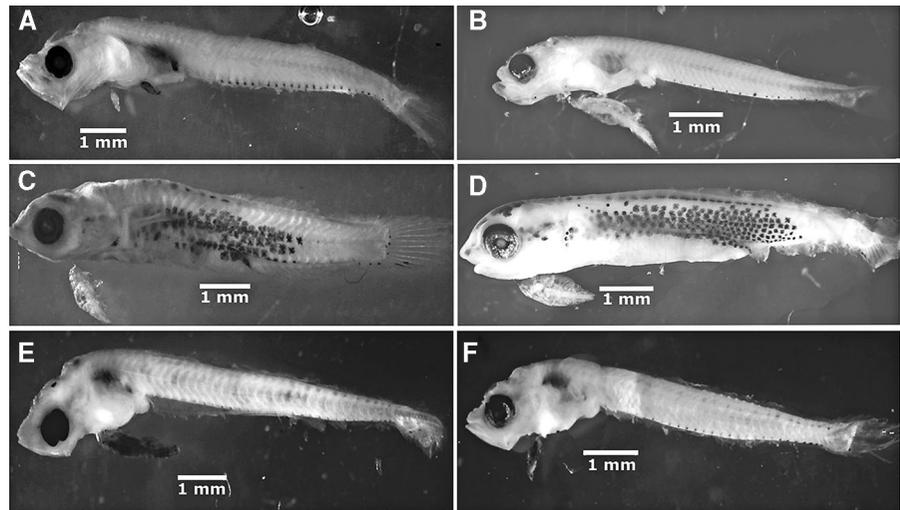


Fig. 2 Ectoparasites present during the study period. **a** Cryptoniscidae, **b** Pennellidae, **c**, **d** Caligidae

Discussion

All of the investigated species exhibited a low and variable ectoparasite prevalence between 0.52 and 12.81 %, which is not uncommon for fish larvae. Other studies that were performed using larval fish of different families described a low prevalence of ectoparasites in gobiids (4.4 %), *Anchoa* sp. (Engraulidae) (3.6 %), *Brevoortia* sp. (Clupeidae) (0.22 %) (Fellely et al. 1987), *Engraulis ringens* (Engraulidae) (prevalence ranged between 0.9 and

4.7 %), *Pomacentrus moluccensis* (Pomacentridae) (4 %) (Grutter et al. 2010) and Chilean triplefin *H. chilensis* (Tripterygiidae) (2.7–20.8 %) (Palacios-Fuentes et al. 2012).

The ectoparasite intensities were also low and variable, primarily between 1 and 3 parasites per host (the median value was one ectoparasite per fish larva), and higher values were rare (e.g., up to eight pennellid copepods in one specimen of clingfish *G. marmoratus*). These results concur with the descriptions given by Fellely et al. (1987), in which the majority of

Table 1 Prevalence and intensity range of the three parasite families found on six different larval fish species from nearshore waters off the coast of central Chile

Taxa	Sample size (n)	Total density (ind * 1,000 m ⁻³)	Pennellidae		Caligidae		Cryptomiscidae		Total	
			Prevalence	Intensity	Prevalence	Intensity	Prevalence	Intensity	Prevalence	Intensity
<i>Auchenionchus microcirrhus</i>	936	7877.698	4.515	[1–2]	0.948	[1–2]	0.043	[1]	5.506	[1–2]
<i>Auchenionchus crinitus</i>	770	5930.722	1.197	[2]	1.642	[1]	0.592	[1]	3.43	[1–2]
<i>Gobiesox marmoratus</i>	1349	13785.591	12.161	[1–8]	0.648	[2]			12.81	[1–8]
<i>Sicyases sanguineus</i>	619	6867.016	0.435	[1]	0.081	[1]			0.52	[1]
<i>Helcogrammoides chilensis</i>	1846	15071.746	5.269	[1–5]	0.126	[1]	0.067	[1]	5.46	[1–5]
<i>Helcogrammoides cunninghami</i>	1124	11927.750	4.109	[1–2]	0.993	[1]			5.10	[1–2]

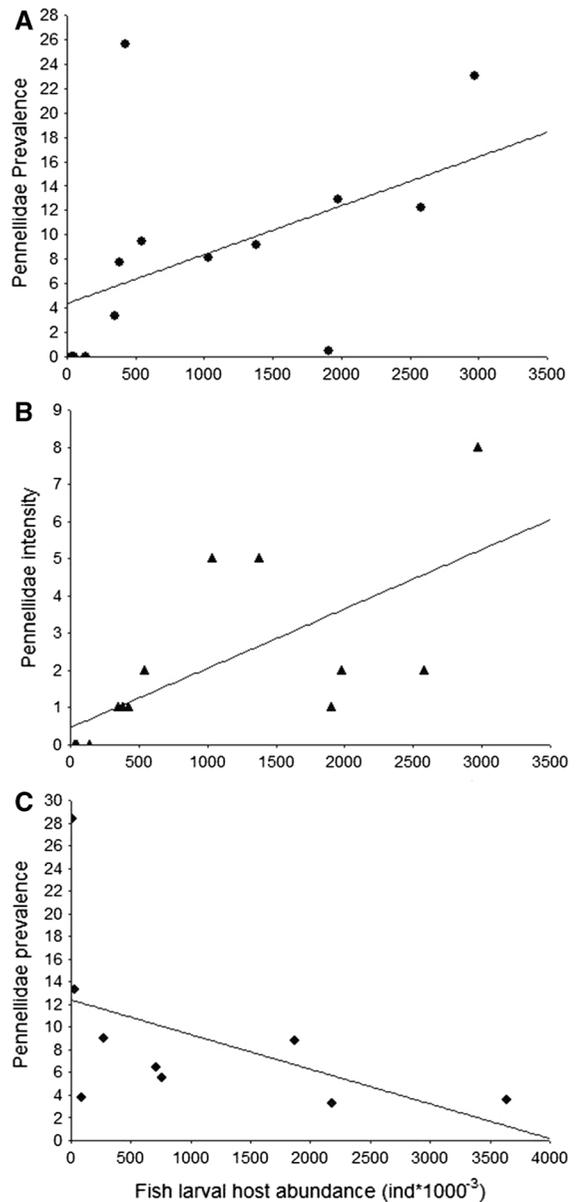


Fig. 3 Correlations between: **a** *G. marmoratus* abundance and prevalence, **b** *G. marmoratus* abundance and intensity and **c** *H. cunninghami* abundance and prevalence

parasitized fish larvae in an estuary had a single copepod attached and only four fish larvae (*Gobiids* 0.028 %, *Anchoa* sp. 0.011 % and *Brevoortia* sp. 0.0077 %) had two or three parasites.

This study represents an initial attempt to identify a relationship between ectoparasite burden and larval fish density. The difficulty of estimating host densities in coastal areas limits the probability of determining

significant correlations for the parasite–host relationship in marine fishes. We were unable to find significant correlations between ectoparasite burden and host density for most of the fish species considered in this study. The lack of a detectable correlation may be caused by random environmental processes near the coast, such as tides, coastal water advection, lunar cycles, wind-driven turbulence and/or seasonal variability (Narváez et al. 2004). Therefore, macroenvironmental factors can affect the transmission of parasites to their hosts in different ways; this effect should be considered in future analyses.

G. marmoratus was the only host species that exhibited positive correlations with pennellid copepod burdens (i.e., prevalence and intensity). This fish species was not the most abundant species, but it had the highest prevalence and intensity of pennellids, suggesting that these parasitic taxa might prefer this host species. This relationship may be explained by the life cycle of this host, which includes planktonic larval stages that spend approximately 1 month in the water column (Contreras et al. 2013); thereafter, they locate near the sea floor where the probability of infection by pennellidae may increase, because many parasites develop their life cycles near the benthos where invertebrates that are intermediate hosts for them (Chambers and Dick 2005; Klimpel et al. 2006).

Most parasites are host specific as a strategy for improving fitness because each host species provides different microenvironments for parasites (i.e., some host species are more suited for a successful life for a parasite than other hosts) (Muñoz and Cortés 2009). A similar result was found for the copepod *C. rogercresseyi*, for which a positive correlation was observed between larval abundance and the density of salmon hosts (Molinet et al. 2011). This link was generated not only because host density positively affects parasite transmission rates but also because *C. rogercresseyi* prefers salmon hosts to native hosts.

In contrast, the prevalence of pennellid copepods exhibited a negative correlation with the larval density of triplefin *H. cunninghami*. The pelagic larval stage of triplefin lasts approximately 4 months (Plaza et al. 2013; Mansur et al. 2014; Palacios-Fuentes et al. 2014); during these months, the larvae aggregate as dense schools near surface waters (Palacios-Fuentes pers. obs.). Fishes with schooling behavior may exhibit a lower rate of parasitism depending on their position in the group (Krause 1994) and exhibit significantly

greater distances from their neighbors than uninfected shoal members (Barber and Huntingford 1996). These findings might explain why only a few specimens of larval *H. cunninghami* were infected, despite the large densities found in the study.

Characteristics of host biology that increase self-recruitment may promote the completion of the life cycle of ectoparasite copepods by increasing the probability that the parasites will find a definite host; thus, such characteristics favor the dispersal of pennellid ectoparasites (Cribb et al. 2000). Therefore, pennellid and caligid copepods may be utilizing meroplanktonic fish larvae as intermediate hosts (Palacios-Fuentes et al. 2012; Muñoz et al. 2015) and detaching before the fish move to the intertidal zone. This theory suggests that the definitive host for the pennellids and caligids found in the larval fish considered in this study would be adult fish from the demersal and subtidal zones (e.g., *Bovichtys chilensis*, *Merluccius gayi* and *Sebastes oculatus*) (Muñoz et al. 2002; George-Nascimento 1996; Oliva and González 2004).

This study represents an initial approach to improving our understanding of how the developmental stages of ectoparasites are related to the early life stages of coastal fishes. Consequently, several questions should be addressed, and it is important for studies of larval fish ecology to consider the effects of ectoparasites on the feeding habits, growth, condition and survival rates of fish larvae.

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