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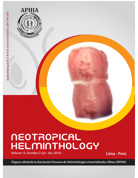

ORIGINAL ARTICLE / ARTÍCULO ORIGINAL

PARASITE COMMUNITY OF THE TADPOLE CODLING *SALILOTA AUSTRALIS* (GÜNTHER, 1878) (GADIFORMES: MORIDAE) FROM THE SOUTHERN CHILE AND ITS COMPARISON WITH ITS CLOSEST RELATIVES

COMUNIDAD DE PARÁSITOS DE LA BRÓTULA *SALILOTA AUSTRALIS* (GÜNTHER, 1878) (GADIFORMES: MORIDAE) DEL SUR DE CHILE COMPARADA CON LAS ESPECIES EMPARENTADAS MÁS CERCANAS

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ABSTRACT

Tadpole codling, *Salilota australis* (Günther, 1887), is a gadiform fish inhabiting the south of the South American coast. This fish has been overexploited in the past. However, nowadays, it has little economic importance. The biology of the tadpole codling is little known, and there are few records of parasite species in this fish. Thus, the aim of the present study is to analyze the parasite community of the tadpole codling and compare the same with the parasite communities of other gadiform fish. For the study, 23 specimens of tadpole codling were collected from the Strait of Magellan, Southern Chile, in summer between 2017–2019. The entire sample was parasitized, and 19 parasite taxa were recorded—two ectoparasites and 17 endoparasites. The most prevalent parasites were anisakid nematodes, *Contracaecum* sp., and *Pseudoterranova* sp., while the digenean *Pseudopecoeloides* sp. was the most abundant. The abundance and richness of parasite infracommunities decreased with the host body length. Several parasites of the tadpole codling have already been found in other gadiform fish. However, the maximum similitude, based on the presence–absence of parasites, was found to be 29% with *Merluccius australis* (Hutton, 1872). When using the average abundance of parasites, there was 51% similarity between the tadpole codling and *Micromesistius australis* Norman, 1937. The differences between the parasite communities among the fish analyzed can be attributed to the phylogenetic distances and the abundances of the tadpole codling and the other gadiform fish. In conclusion, the tadpole codling has a rich parasite community, considering that a small sample size was analyzed. Most of the parasite taxa were generalists, and two parasite species were specific to the tadpole codling.

Keywords: parasite composition – parasite infracommunities – Gadiformes – tadpole codling – Southern Chile

RESUMEN

La brótula o bacalao austral, *Salilota australis* (Günther, 1887), es un pez gadiforme que vive al sur de las costas sudamericanas. En décadas pasadas, esta especie de pez fue sobreexplotada, sin embargo, en la actualidad tiene escasa importancia económica. La biología de la brótula es poco conocida, y existen pocos registros de parásitos, es así que el objetivo de este estudio es contribuir al conocimiento parasitológico de este pez mediante el análisis de su comunidad de parásitos, comparada con las de otros peces gadiformes de la zona sur de américa. Durante el verano 2017-2019, se recolectaron 23 especímenes desde el Estrecho de Magallanes, sur de Chile. Todos los especímenes de brótula estaban parasitados, registrándose 19 taxa parasitarios; dos ectoparásitos y 17 endoparásitos. Los parásitos más prevalentes fueron nematodos anisákidos, *Contracaecum* sp. y *Pseudoterranova* sp., y la más abundante fue el digeneo *Pseudopecoeloides* sp. La abundancia y riqueza de las infracomunidades parasitarias disminuyó con la longitud total del pez. Varios de los parásitos de la brótula habían sido registrados en otros peces. Sin embargo, la similitud máxima, basado en la presencia- ausencia de parásitos, fue de 29% con *Merluccius australis* (Hutton, 1872), mientras que al considerar la abundancia promedio de parásitos, hubo un 51% de similitud entre la brótula y *Micromesistius australis* Norman, 1937. Las diferencias de las comunidades de parásitos entre los peces gadiformes considerados se debería a las distancias filogenéticas y abundancias entre la brótula y las otras especies. En conclusión, pese a la pequeña muestra de brótulas analizadas, se encontró una rica comunidad de parásitos. La mayoría de los taxa parasitarios eran generalistas, y solo dos serían específicos a la brótula.

Palabras clave: composición parasitaria – infracomunidad de parásitos – Gadiformes – brótula – sur de Chile

INTRODUCTION

Salilota australis (Günther, 1878), commonly known as tadpole codling in English and "brótula" or "bacalao austral" in Spanish, is a gadiform species from the family Moridae. It inhabits Patagonia, the Southern American cone, and is distributed at the Pacific and Atlantic coasts of America and Falkland Islands (earlier known as Malvinas Islands). It typically lives in 30–900 m depth, and it is frequently caught by bottom trawl nets (Reyes & Hüne, 2012).

Tadpole codlings had commercial significance in the past. Large catches were obtained during the 80s and 90s, with a fishing peak of ~8 tons for Chile in 1988 and ~16 tons for Argentina in 1996 (Cassia & Hanssen, 2005; Chong-Follert *et al*., 2017). However, a dramatic decrease in catches was observed in both countries, likely due to the biological characteristics of the tadpole codlings, such as medium longevity, early sexual maturity, and possible low growth, which make it a vulnerable species for industrial fishing (Chong-Follert *et al.,* 2017). However, this species is not considered as a threatened one (IUCN, 2019). Particularly in Chile, tadpole codlings have no commercial interest at present, and it is no longer a target species for the industry, which shows low fishing (~1 to 3 tons) in the last decade for by-catch only (SERNAPESCA, 2017).

Some biological aspects of the tadpole codling has been studied, such as its reproduction (Chong-Follert *et al*., 2017), and population structure (Wöhler *et al.,* 2001; Cassia & Hanssen, 2005). The biology of the tadpole codling is distinct from that of its closest relatives (Gadiformes such as austral hake, fish hoki, and southern blue whiting), which have been target species for fishing and have endured overexploitation for decades. Because gadiforms are important commercial resources, they are now protected by regulation fishing policies of Chile.

Parasitological studies on the tadpole codling have been conducted for Argentinian coasts and for some specific parasitic species only, such as taxonomic descriptions of a monogenean, *Tribuliphorus salilotae* (Mamaev & Paruchin, 1977; Suriano & Martorelli, 1984), a digenean *Ellytrophalloides oatesi* (Suriano & Sutton, 1981; Guagliardo *et al*., 2010), and the larval cestode *Grillotia patagonica* (Meronet & Ivanov, 2012). Only one record exists in Chile (Wilson, 1917), that of the parasitic copepod *Trifur tortuosus*. No study related to parasite communities in the tadpole codling has been conducted and, once again, this distinguished the species from its relatives that have been studied on the parasite community that are mostly focused on determining the stock populations of commercial gadiform fish (George-Nascimento & Arancibia, 1994; Oliva, 2001; MacKenzie & Longshaw, 1995; George–Nascimento *et al*., 2011; MacKenzie *et al*., 2013). Therefore, the aim of this study is to analyze the parasite community of the tadpole codling. Considering the lack of parasitological understanding of this fish, it would be useful for future studies to know how different parasite communities of the tadpole codling are with relative fish. Therefore, comparisons of the parasite communities of the tadpole codling with other gadiform fish species (*Merluccius australis* (Hutton, 1872)*, M. hubbsi* Marini, 1933*, Macruronus magellanicus* Lönnberg, 1907, and *Micromesistius australis* Norman, 1937) are also performed, using parasitological literature from the southern zone of South America at Pacific and Atlantic waters.

MATERIAL AND METHODS

A total of 23 specimens of *S. australis* were collected from the Strait of Magellan (53° 19' 44.0832" S70° 45' 30.6576" W) at Punta Arenas, Southern Chile, at a depth of 10-30 m. The spinel method was used onboard the artisanal boat during summers of 2017–2019. The tadpole codling specimens were the by-catch of austral hake fishing. The small size of the sample collected may be attributed to the fact that the tadpole codling inhabits deeper waters. Moreover, there is few fishermen in the zone, and there is no commercial interest in the tadpole codling, so that its discharge is legally authorized (SUBPESCA, 2017). The number of fish and the method of fishing were in accordance with the institutional guidelines for use of animals with scientific purposes, as stated in the Bioethics certificate # 058/2016 given by Universidad de Valparaiso (Chile).

All the fish specimens were frozen at -20° C and dissected posteriorly. The body length was recorded for each specimen. The metazoan parasites from each fish were collected and then fixed in either 10% formalin or 70% ethanol, according to the processes applied for identification. The parasites were identified and counted posteriorly. The parasites were then identified using taxonomic keys for parasite identification and descriptions of species (Suriano & Martorelli, 1984; Suiano & Sutton, 1981; Rocka, 2004; Guagliardo *et al*., 2010; Etchegoin *et al*., 2009; Meronet & Ivanov, 2012; Laskowski & Zdzitowiecki, 2017). Voucher specimens of each parasite species collected in his study were deposited in the Museo de Historia Natural de Chile (HNHNCL).

The abundance and prevalence of each parasite species were recorded and averaged for the entire fish sample, and the abundance and the species richness was calculated for each parasite infracommunity (Bush *et al*., 1997). Due to the small sample size (12 specimens in 2017, 8 in 2018, and 4 in 2019), it was not possible to consider the year sampling as a factor. Therefore, only suggestions were made about results and the potential influences of year sampling.

The parasite community of the tadpole codling was compared with the published literature on the parasites of the other four gadiform fish species from the southernmost zones of South America (51°S–56°S), specifically from Punta Arenas and Navarino Island (Pacific coast), and Falkland islands (Atlantic coasts). We referred to Oliva (2001) and Mackenzie *et al*. (2013) for *Macruronus magellanicus* (Macrouridae), George–Nascimento & Arancibia (1994) and Mackenzie & Longshaw (1995) for *Merluccius australis* and *M. hubbsi* (Merlucciidae), and George–Nascimento *et al*. (2011) for *Micromesistius australis* (Gadidae). The presence–absence and average abundances of the parasite species of each fish species were used for the comparisons.

Most data used in this study did not fit the normal distributions or display homoscedasticity of variances; therefore, several non-parametric analyses were applied in order to obtain reliable statistical results (Zar, 1996). The significance level was $P < 0.05$ for all the analyses applied, performed with the software PAST 3.13

(https://folk.uio.no/ohammer/past/index.html) (Hammer *et al.* 2001).

The abundance and species richness of parasite taxa were correlated with the host body length using the Spearman correlation analysis (Zar, 1996) in order to find out the importance of fish body length for parasite communities. Then, the parasite composition of the five fish species was represented through a cluster analysis using the Jaccard similarity coefficient, which ranges from 0 (no similarity) to 1 (complete similarity). This index was based on the presence–absence of parasite taxa in the five fish and then clustered through the single link method (Chao *et al*., 2006). Another similarity index with was calculated though the Bray–Curtis index, which ranges from 0 (no similarity) to 1 (complete similarity), and based on the average abundance of each parasite taxon. Then, a cluster analysis was performed with the Bray–Curtis similarity index, which parasite abundances were transformed to $\log_{10}$ (x+1). For this analysis, only the parasite species common in at least two host species were considered. The clustering analysis was applied using the single-link method (Clarke & Warwick, 1994). Bootstrapping, with 1000 resamplings, was applied in each cluster to find out the consistency of the groups that were similar to one another.

RESULTS

The body length of the tadpole codling differed over the sampling years ($H_{2, 23}$= 14.29; P< 0.001). The specimens collected in 2018 had the smallest body length (Table 1), and this was associated with the depth of the sampling, because the specimens were collected in shallow waters in this year (Table 1).

In the entire tadpole codling sample, 19 parasite taxa were recorded—two ectoparasites and 17 endoparasites (Table 1). All the specimens were parasitized with at least one parasite taxa. The 2018 sample included six parasite taxa that were not recorded in the other years, but all of them showed low parasite abundance and prevalence. However, the most common parasites (most abundant and prevalent) were present in the three-year sample. Acanthocephalans and nematodes had more species than the other parasitic groups (Table 1). The most prevalent parasites were anisakid nematodes, *Contracaecum* sp., and *Pseudoterranova* sp., while the digenean *Pseudopecoeloides* sp. were the most abundant (Table 1).

It was found that the abundance (n= 23, r_s= -0.503, *P*= 0.014) and richness (n= 23, r_s= -0.514, *P*= 0.011) of parasite infracommunities decreased with the tadpole codling body length. While the fish body length differed between the sampling years, the distribution of the infracommunity data (for abundance and richness) was in the same tendency (Fig. 1).

Several parasites of the tadpole codling have been found in other gadiform fish already. However, the maximum similitude index, based on the presence–absence of parasites, found with *Merluccius australis*, was 0.29 (29%) (Table 2). Considering the parasite abundance, the maximum similitude was 0.51 (51%) between the tadpole codling and *Micromesistius australis* (Table 2). Congruently, in the cluster diagram, the tadpole codling is positioned in a different branch than other gadiform fish, considering the presence–absence of parasite taxa and the average abundance of parasites (Fig. 2). However, the similarity between the pair of hosts was greater for the presence–absence of parasites than for the abundance of parasites shared among the fish species (Fig. 2). Although, the major similarity was between the same fish species from different sampling zones. In both cluster analyses, *S. australis* was less similar respect to the other four gadiform fish.

Table 1. Sampling size and body length of the tadpole codling, *Salilota australis*, per year.

Year	n	Range of LT	Mean ± SD	Depth of sampling
2017	12	42-63	46.2 ± 6.5	20-30 m
2018	8	32-46	35.1 ± 3.6	10-15 m
2019	3	43-45	43.5 ± 0.9	20-25 m

Table 2. Parasite taxa found specimens of the tadpole codling Salilota australis from Southern Chile collected from different site of infection (G: gills, BS: body surface, BC: body cavity, I: intestine, S: stomach). Presence of parasites per year samplings, and numerical descriptors for each parasite taxa in the whole sample; Prevalence (P, %), average abundance (X ABU) and its standard deviation (SD). Collection numbers of parasite specimens deposited in the MNHNCL are also shown.

			Presence of parasites			**Whole sample (n=23)**	
Parasite taxa	**Site**	**# MNHNCL**	**2017**	**2018**	**2019**	**P (%)**	**X ABU ± SD**
MONOGENEA							
Tribuliphorus salilotae Mamaev & Parukhin, 1977	G	PLAT-15009	x	x	x	56.5	4.87 ± 7.99
COPEPODA							
Trifur tortuosus Wilson, 1917	BS	COP-15128		x		4.3	0.04 ± 0.21
DIGENEA							
Azygiidae gen. sp.	I	PLAT-15011	x			8.7	0.09 ± 0.29
Elytrophalloides oatesi (Leiper & Atkinson, 1914)	I	PLAT- 15012	x			4.3	0.04 ± 0.21
Pseudopecoeloides sp.	I	PLAT- 15013	x	x	x	39.1	10.61 ± 19.95
CESTODA							
Grillotia sp.	BC	PLAT- 15010	x	x		13.0	0.17 ± 0.49
ACANTHOCEPHALA							
Aspersentis johni (Baylis, 1929)	I	ACAN-15000		x		17.4	2.17 ± 5.40
Corynosoma arctocephali Zdzitowiecki, 1984	BC	ACAN-15001	x	x		39.1	0.70 ± 1.11
Echinorhynchus petrotschenkoi Rodjuk, 1984	I	ACAN-15002	x	x	x	43.5	1.30 ± 2.12
Hypoechinorhynchus magellanicus Szidat, 1950	I	ACAN-15003		x		21.7	0.96 ± 3.15
*Metacanthocephalu*s sp.	I	ACAN-15004		x		17.4	1.91 ± 6.88
Rhadynorhynchidae gen. sp.	I	---	x			4.3	0.04 ± 0.21
NEMATODA							
Anisakis sp.	BC	NEM-15016	x	x	x	21.7	1.30 ± 3.27
Ascarophis sp.	I	NEM-15019	x	x		17.4	2.00 ± 6.26
Contracaecum sp.	S, I	NEM-15017	x	x	x	65.2	2.13 ± 2.60
Hysterothylacium sp.	I, BC	NEM-15020	x	x	x	30.4	0.52 ± 0.99
Pseudodelphis sp.	I	NEM-15021		x		13.0	0.26 ± 0.75
Pseudoterranova sp.	BC	NEM-15018	x	x	x	73.9	3.91 ± 5.21

Table 3. The similarity between the parasite communities of five gadiform fish species based on Jaccard index for presence–absence of parasites (over the grey line) and the Bray–Curtis index for parasite abundance (under the grey line). Also, the sampling zone fishing has been indicated (PA: Punta Arenas, NI, Navarino Island; FI: Falkland Islands) along with the bibliographic references.

Fish	Zone	Reference	S.aust	M.mage (1)	M.mage (2)	M.mage (3)	M.hubb	M.aust (1)	M.aust (2)	Mi.aust (1)	Mi.aust (2)
S.aust	PA	This study		0.115	0.174	0.182	0.120	0.292	0.250	0.280	0.208
M.mage (1)	PA	Oliva (2001)	0.016		0.250	0.357	0.235	0.263	0.278	0.250	0.222
M.mage (2)	PA	Mackenzie *et al.* (2013)	0.180	0.370		0.700	0.357	0.222	0.400	0.211	0.250
M.mage (3)	FI	Mackenzie *et al.* (2013)	0.171	0.801	0.389		0.286	0.235	0.333	0.222	0.267
M.hubb	FI	Mackenzie & Longshaw (1995)	0.142	0.556	0.639	0.344		0.353	0.375	0.263	0.313
M.aust (1)	PA	George-Nascimento & Arancibia (1994)	0.374	0.413	0.445	0.124	0.407		0.667	0.500	0.412
M.aust (2)	FI	George-Nascimento & Arancibia (1994)	0.265	0.671	0.592	0.206	0.540	0.541		0.368	0.438
Mi.aust (1)	IN	George-Nascimento *et al.* (2011)	0.510	0.441	0.486	0.063	0.363	0.592	0.505		0.786
Mi.aust (2)	FI	George-Nascimento *et al.* (2011)	0.271	0.507	0.540	0.086	0.467	0.572	0.588	0.602	

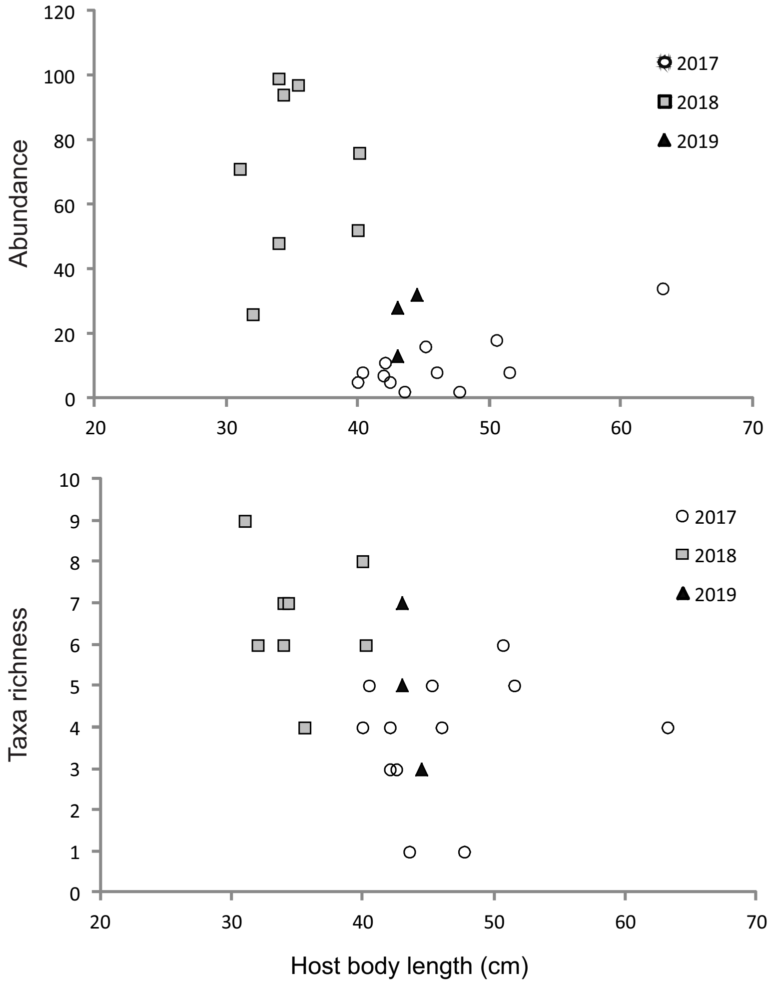

Figure 1. Correlation of the abundance and taxa richness of parasite infracommunities with the body length of tadpole codling *Salilota australis.*

DISCUSSION

Most of the parasites found in tadpole codling have been recorded previously, not only in other fish gadiform but also in other fish groups, such as Ophidiiformes and in several fish of Perciformes (Muñoz & Olmos, 2007, 2008). Only the monogenean *Tribuliphorus salilotae* was specific to tadpole codling. The *Pseudopecoeloides* sp. has neither been recorded in the other gadiform fish (Chávez *et al*., 2012) nor in Chile (Muñoz & Olmos, 2008), indicating that this parasite is not common in fish along the Chilean coast. However, it was highly abundant in the tadpole codling. Therefore, *Pseudopecoeloides* sp. can be considered specific to this fish.

The negative correlation between the abundance and richness of parasites and the host body length is unusual. Poulin (1999) found a negative correlation between the intensity of helminths and fish body mass. He argued that when the resources needed by the parasites are not related to the host body size, the positive correlation patterns between these variables breaks down. In addition, all animals, including fish, display physiological changes with age. For instance, the hormonal responses to stress change with the age of fish rather than their body size (Barcellos *et al.,* 2012),

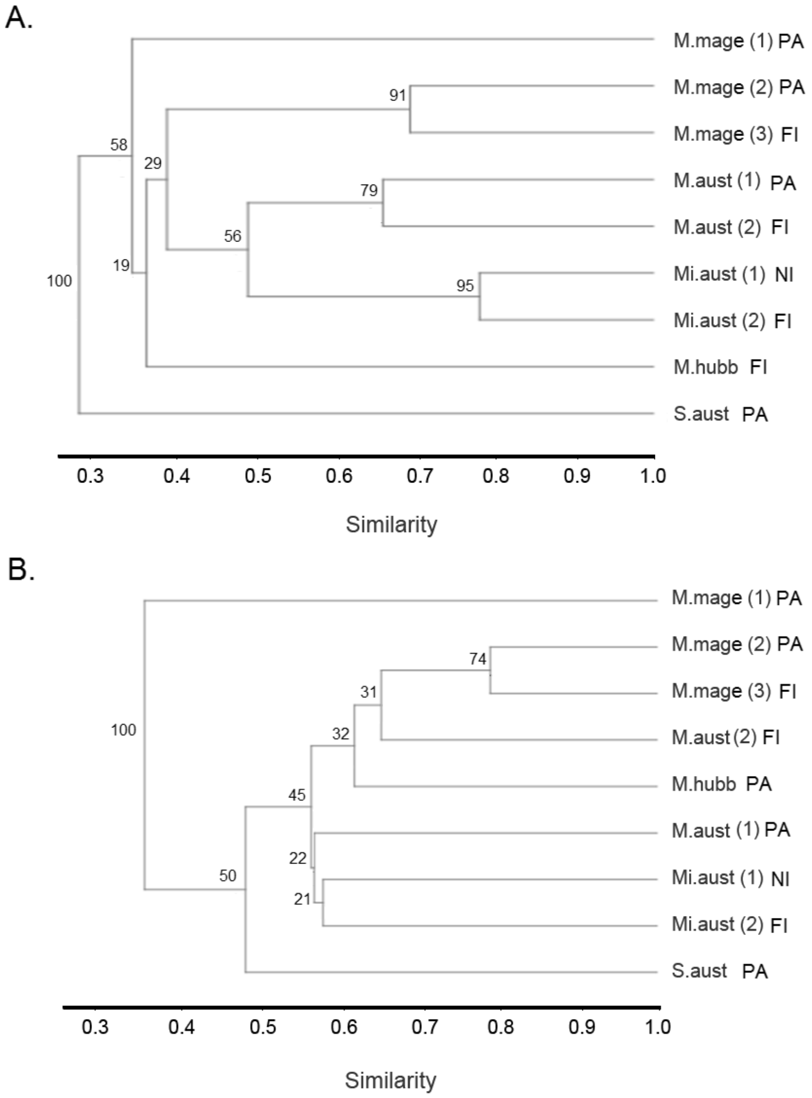

Figure 2. Cluster analyses for the parasite communities of *Salilota australis* (S.aust) with other four gadiform fish species based on the following: A) the presence–absence of all parasitic taxa present in the fish species and B) the average abundance of parasite taxa, considering only those species share in at least two fish species. Abbreviations of fish species and reference were: data of *M. magellanicus* are referred as M.mage (1) [Oliva (2001)], M.mage (2) and M.mage (3) [Mackenzie *et al.* (2013)]; data of *M. hubbsi* as M.hubb [Mackenzie & Longshaw (1995)]; data of *M. australis* as M.aust (1) and M.aust (2) [George-Nascimento & Arancibia (1994)]; *Micromesistius australis* as Mi.aust (1) and Mi.aust (2) [George-Nascimento *et al.* (2011)]. Sampling locality as: PA: Punta Arenas (Southern Pacific), FI: Folkland Island (Off Souther Atlantic), and NI, Navarino Island (Cabo de Hornos).

and this is applicable to many other physiochemical changes in the host body. Considering that parasites establish an intimate link with their hosts, it is highly possible that some parasites are lost when the host body undergoes change.

The cluster analyses and similarity indices demonstrated that fish species from different sampling zones had similar parasite species composition. Of the results obtained in this study, one exception was for *M. magellanicus*, specifically the sample called M.mage(1) (Fig. 2), which differed in parasites from the other conspecific samples. This result was due to two parasite taxa, *Cucullanus* sp. and Anisakidae gen. sp., both of which are found in high abundance in the sample (Oliva, 2001) but not in the other, i.e., M.mage(2) and M.mage(3) (Table 3, Fig. 2). Unfortunately, while anisakid species are common in coastal fish, few options can be applied to use this specific datum since the nematode genus was not specified. It might be considered as a different taxon (which would be wrong, since several anisakid species were present in the other samples) or deleted from the analysis. Regardless of the option chosen, the specific sample of M.mage(1) differed from the other primarily due to the level identification of the parasite. Therefore, for this kind of analysis, the identification of parasites should be at genus level at the very least.

In some studies, the host phylogeny has not been clearly associated to parasite composition, because the ecological aspects of the hosts, as well as the changes in the environment, affect each parasite species in different ways (Muñoz & Cribb, 2007; Chávez *et al*., 2012). However, the results of the present study are in accordance with phylogenetic groups of fish. As a result, the parasite community of the tadpole codling differs from the other gadiform fish, possibly due to the phylogenetic distances between the tadpole codling and the other fish. The tadpole codling is the only species of Moridae that lives on South American coasts. According to a morphological study on Gadiformes, the tadpole codling is phylogenetically distant from macrourids and merluccids (Hiromitsu, 2002). Moreover, ecological aspects also indicate important differences among gadiform fish; for instance, the amount of fishing has been historically lower in tadpole codling than other gadiform (492 tons of the tadpole codling were collected in 2016, which was 7–26 times less than the collection of other gadiform fish in the southern zone of Chile) (SERNAPESCA, 2017; SUBPESCA, 2017). Host abundance is one of the demographic parameters that directly relate to parasite infections and the sources of variability of parasite communities (Arneberg *et al*., 1998; Morand *et al*., 2000).

One of the limitations of this study is that the sampling years were not deeply analyzed in this study due to the small sample size of the tadpole codling. Moreover, the 2018 sample was collected in shallower waters as compared to the sampling of the other years. The tadpole codling typically lives in deep waters; however, there are some reports indicating that they can live at a depth of 8 m and that juveniles inhabit the fjords and channels in the south of Chile (Reyes & Hüne, 2012). The 2018 sampling was distinct, because the tadpole codling had several parasites (6 species) that were not present in the samples collected in the other years. Four of these parasites—*Hypoechynorhynchus magellanicus* Szidat, 1950*, Aspersentis johni* (Baylis, 1929)*, Dichelyne (Cucullanellus)* sp., and *Pseudodelphis* sp.—are common in fish from littoral, including the intertidal zone (Laskowski & Zdzitowiecki, 2004; Muñoz & Olmos, 2008, other personal data). It is possible that the tadpole codling share habitat and food items with littoral fish, thereby, acquiring other parasites (Reyes & Hüne, 2012). It is also known that the ecological behavior of the hosts has a strong impact on the similitude of the parasite communities, as demonstrated in other studies (Muñoz & Cribb, 2007; Chávez *et al*., 2012). It is important to note that in the cluster analysis based of abundance, those parasites that were not shared with other fish were not included. Thus the differences of the parasites tadpole codling with other fish were consistent, besides the differences in the sample size between years, and the particular composition of parasites found in the sample 2018.

The small sample size of the fish analysed in this study limited any further comparison related to habitat use, distribution or seasonal variation of fish and their parasites. Nevertheless, the present study has greatly contributed to find out the parasite composition of tadpole codling and understand the difference between this and other related species, which were unknown up to now. Most of the parasites present in this fish species are generalist, which are also present in several other fish. However, the composition of parasites and their abundance were distinguishable from other fish. There is still work to do on this species, specially on the variation of parasites, and other biological aspects, over time, due to the population changes that the tadpole codling have passed through.

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