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Current knowledge of trematodes (Platyhelminthes: Digenea, Aspidogastrea) in Chile

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Abstract: The aim of the present review was to evaluate the state of knowledge of trematodes (Platyhelminthes: Trematoda) in Chile, covering taxonomy, biology, geographic distribution, and a checklist of all taxa reported in the country. A total of 277 articles published between 1849 and December 2020, have been analyzed. A total of 215 taxa belonging to the subclasses Digenea and Aspidosgastrea have been reported from Chile, 119 of them identified to species level and only three species with completely described life cycles. Trematodes from Chile were found parasitizing both native and exotic species, however, no records from insects and most crustacean classes exist. Overall, 159 out of 3989 potential host native species were reported as hosts for trematodes. Molecular tools were used in more recent taxonomic studies. Although research on trematodes in Chile is on the rise, there is a clear need for more detailed taxonomic studies to include integrative taxonomy approach, deposition of helminths in collections and the training of new generation of parasitologists to better understand the diversity, ecology and evolutionary relationships of trematodes in the region.

Keywords: Trematoda, Digenea, Aspidogastrea, biodiversity, checklist.

INTRODUCTION

The class Trematoda is subdivided in two subclasses, Aspidogastrea and Digenea. The former group is small and comprises only four families, 12 genera and about 80 species (Roberts *et al*., 2013; Collins, 2017). On the other hand, digeneans are a very diverse group of parasites with more than 2500 genera and 18 000 nominal species (Kostadinova & Pérez-del-Olmo, 2014; Collins, 2017). However, there is a significant number of yet undescribed species, with some estimates suggesting that the total number of digenean species may exceed 44 000 (Carlson *et al*., 2020a).

Gay (1849) was the first to mention a trematode in Chile. It was a report of the liver fluke *Fasciola hepatica* (Fasciolidae) in cattle. Since then, trematodes have been reported from a variety of hosts across the country. Previously published checklists were restricted to particular groups of hosts or types of ecosystems (see Garín & González-Acuña, 2008; Muñoz & Olmos, 2008; Oyarzún-Ruiz & González-Acuña, 2021), while an overview covering the whole trematode fauna in the country is currently lacking. The aim of the present review was to analyze the data on trematodes in Chile and summarize of knowledge on their diversity, taxonomy, biology, and geographic distribution. We also outline the areas most urgently needing, attention and/or improvement in future research.

MATERIAL AND METHODS

Literature search

We performed an exhaustive bibliographic review of trematodes reported from domestic and wild animals, including humans, in Chile. Data from freshwater, marine and terrestrial environments, and all invertebrate and vertebrate hosts were included in this review. To achieve this objective, we analyzed 275 research articles, one book and one book chapter from physical libraries and electronic databases such as NCBI, ScholarGoogle, Scopus and Web of Science (WOS). The time cut-off for the published data was until December 2020. The present review did not consider "grey" literature (i.e. technical reports, conference proceedings, congress posters, theses) because they are not subjected to a peer review process.

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Taxonomy of hosts and parasites

The taxonomic classification for host species was stated as follows: AviBase (https://avibase.bsc-eoc.org/) for birds; FishBase (https://www.fishbase.in/search.php) for fishes; GBIF (https://www.gbif.org) and ITIS (Integrated Taxonomic Information System; https://www.itis.gov/), in this order of priority, for freshwater mollusks, reptiles, amphibians and mammals; and WoRMS (World Register of Marine Species; http://www.marinespecies.org/) and SeaLifeBase (https://www.sealifebase.ca/), in this order of priority, for marine mollusks and crustaceans. We followed Gibson *et al*. (2002), Jones *et al.* (2005), Bray *et al.* (2008), Roberts *et al* (2013), GBIF and WoRMS for the taxonomy of trematodes.

Hosts

The categorization of hosts as native, endemic, or exotic species followed Ministerio de Medio Ambiente (MMA, 2018a, b) and PNUD (2017). In addition, the diversity of native, endemic, and exotic animal species for every host group present in Chile was stated according to Valdovinos (1999), Martínez & González (2017), PNUD (2017) and Ministerio de Medio Ambiente (2018a, b; http://especies.mma.gob.cl).

Locations

The collection sites were attributed to Chilean regions represented by roman numbers and ordered according its geographical distribution from northern Chile to Chilean Patagonia following the Biblioteca del Congreso Nacional de Chile (BCN) (https://www.bcn.cl/siit/mapoteca/regiones) and Ministerio de Medio Ambiente (MMA) (2018a): (i) *Northern Chile*: XV= Arica y Parinacota region (18°22'4.8" S 70°13'1.199" W), I= Tarapacá region (20°9'49.202" S 69°32'46.841" W), II= Antofagasta region (23°36'14.873" S 69°5'3.401" W), III= Atacama region (27°33'25.842" S 70°0'56.477" W), IV= Coquimbo region (30°45'16.795" S 70°54'1.992" W); (ii) *Central Chile*: V= Valparaíso region (32°35'51.392" S 70°51'10.711" W), RM= Metropolitan region (33°30'13.172" S 70°45'44.692 W), VI= Libertador General Bernardo O'Higgins region (34°32'4.337" S 71°2'7.735" W), VII= Maule region (35°35'50.022" S 71°29'19.248" W); (iii) *Southern Chile*: XVI= Ñuble region (36°37'13.518" S 72°6'5.983" W), VIII= Biobío region (37°20'20.907" S 72°24'38.456" W), IX= Araucanía region (38°40'4.424" S 72°15'39.623" W), XIV= Los Ríos region (39°58'27.448" S 72°40'2.92" W), X= Los Lagos region (42°18'3.038" S 73°6'19.393" W); (iv) *Chilean Patagonia*: XI= Aysén del General Carlos Ibáñez del Campo region (46°28'16.16" S 73°31'14.417" W), XII= Magallanes y de la Antártica Chilena region (53°21'9.906" S 71°33'17.201" W).

RESULTS

Over the last 120 years, there is a clear tendency for the increase of number of publications reporting trematodes in Chile, with a first peak in the 1980s and a second peak in the 2010s (Fig. 1).

Trematodes

A total of 215 taxa of trematodes belonging to two subclasses, three orders, 47 families and 127 genera have been recorded in Chile. Of these, 119 (55.35 %; 119/215) taxa were identified to species level, with three species belonging to Aspidogastrea subclass and 116 to Digenea subclass (Table 1).

The most common digenean families mentioned for particular host groups were Fellodistomidae for mollusks, Microphallidae for crustaceans, Opecoelidae for fishes, Gorgoderidae for amphibians, Echinochasmidae and Echinostomatidae for birds, and Fasciolidae for mammals. Only family Opisthogonimidae was reported from reptiles.

Complete life cycles are known for only 3 out 119 species of trematodes reported in the country, namely *Fasciola hepatica*, *Proctoeces lintoni* (Fellodistomidae) and *Prosorhynchoides carvajali* (Bucephalidae).

Hosts

Trematodes were reported from 159 out of 3989 potential native animal species (including 14 out of 1081 endemic species) and 12 out of 92 exotic animal species known in Chile (Table 2). So far, there are no records of trematodes from insects or classes of crustaceans other than Malacostraca.

The highest diversity of trematodes was found in representatives of the following host orders: Mytilida (9 taxa) in mollusks, order Decapoda (3 taxa) in crustaceans, order Perciformes (75 taxa) in fishes, order Anseriformes (21 taxa) in birds, and orders Carnivora and Cetacea (7 taxa each) in mammals. One order of reptiles and one order of amphibians were reported as hosts.

Geographical distribution

Taxonomic diversity of trematodes at family level across different regions of Chile is presented in Figs 2-4. A total of 428 records were plotted for all trematode families. These records represent the sum of all taxa reported for every trematode family in every region of the country. Our analysis showed certain patterns in the distribution of several digenean families. For instance, families Allocreadidae, Brauninidae, Dicrocoeliidae,

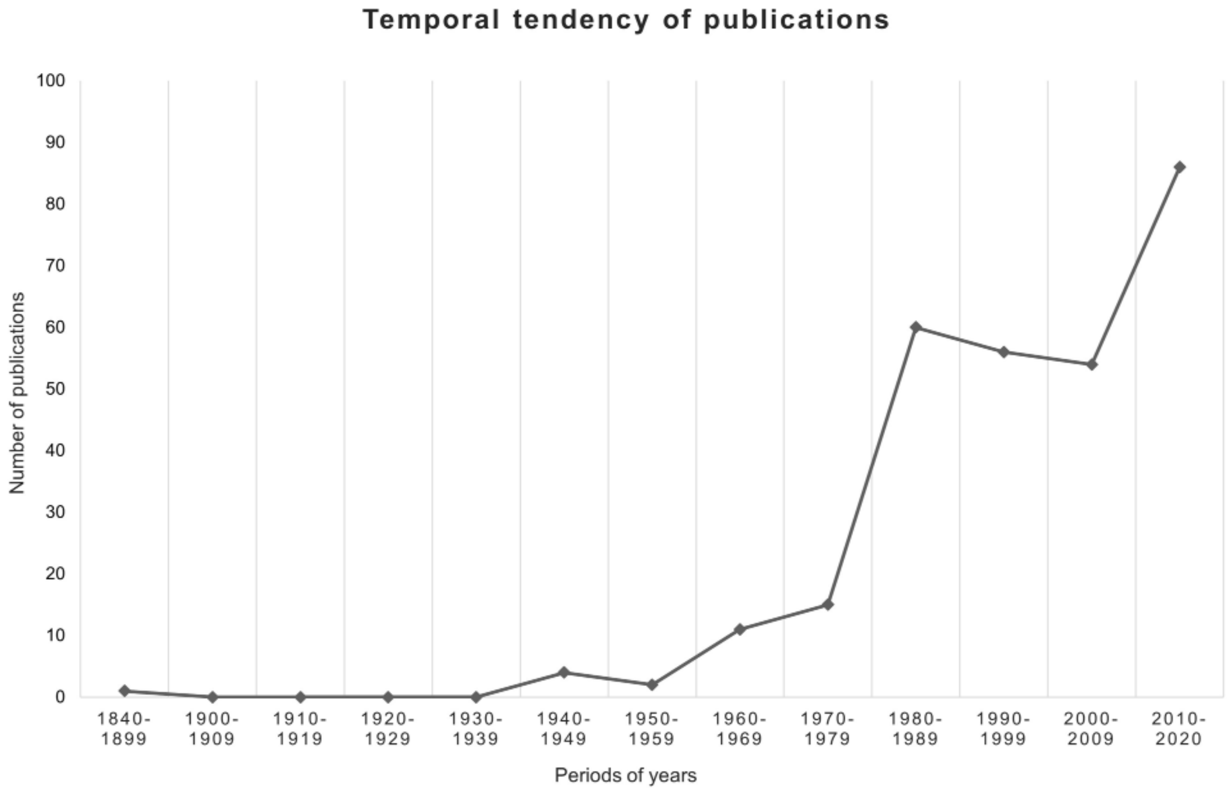

Fig. 1. Temporal tendendy in the number of publications related to trematodes in Chile.

Table 1. Parasitic taxa isolated from each host group.

	Moll‡	Crus	Fishes*	Am	Rep	Birds	Mam
Species	8	1	74	3	0	27	17
New species	3†	1†	22	3	0	0	3
Incompletely described	21	4	59	0	1	14	5
Genus sp.	7	0	49	0	1	11	4
Family gen. sp.	10	2	9	0	0	3	0
Subfamily gen. sp.	0	2	0	0	0	0	0
incertae sedis	4	0	1	0	0	0	1

Symbols and abbreviations: Moll= Mollusks; Crus= Crustaceans; Am= Amphibians; Rep= Reptiles; Mam= Mammals; ‡Including classes Gastropoda and Bivalvia; *including classes Actinopterygii, Holocephali and Elasmobranchii; †These species were also described from fishes.

Himasthlidae, Multicalycidae, Phaneropsolidae and Pleurogenidae have been recorded only in Southern Chile. Meanwhile, the Fasciolidae has been reported throughout the entire country.

The highest diversity of trematodes was recorded on Biobío region (VIII), Southern Chile, with 98 taxa belonging to 36 families, followed by Valparaíso region (V), Central Chile, with 62 taxa belonging to 20 families. On the other hand, the region with the lower diversity of trematodes was Libertador General Bernardo O'Higgins region (VI), Central Chile, with only 1 taxon (see Fig. 3).

Checklist

The checklist of the trematodes and their associated hosts is provided in the Appendix 1 [supplementary material S1]. The stage of development, parasitized organs, localities and references are also stated. An additional table provides a host-parasite list the Appendix 2 [supplementary material S1].

Table 2. Number of host species per host group in Chile (top 3 rows), and number and percentage, between parenthesis, of recorded species hosting trematodes in Chile (bottom 3 rows).

		Moll	Crus	Fishes	Am	Rep	Birds	Mam†	Total
Hosts biodiversity	Native species	1187	606	1401	57	135	443	160	3989
	Endemic species	886	21	35	34	82	10	13	1081
	Exotic species	35	0	26	1	2	9	19	92
Present Review	Native species	24 (2.02)	12 (1.98)	84 (6.00)	3 (5.26)	1 (0.74)	19 (4.29)	16 (10.00)	159 (3.99)
	Endemic species	0	0	9 (25.71)	2 (5.88)	1 (1.22)	0	2 (15.38)	14 (1.30)
	Exotic species	0	0	2 (7.69)	0	0	0	10 (52.63)	12 (13.04)

Abbreviations: Moll= Mollusks; Crus= Crustaceans; Am= Amphibians; Rep= Reptiles; Mam= Mammals; †= excluding human being.

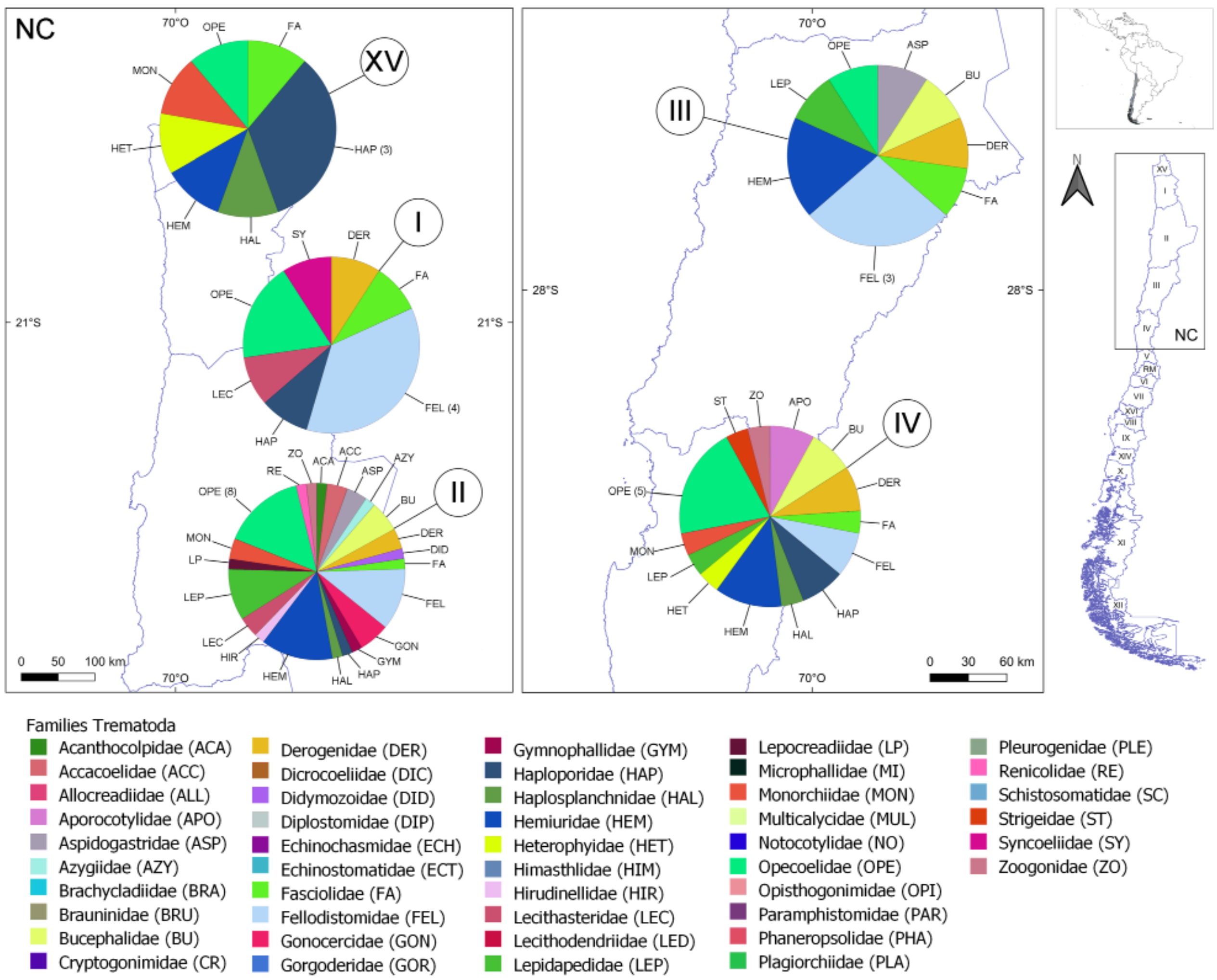

Fig. 2. Number of taxa per trematode family in Northern Chile (NC). Every color in the pie chart represents a particular family. The highest number of taxa for trematode families in every region is given between parentheses. The name of every region represented as a roman number is detailed in Material and Methods.

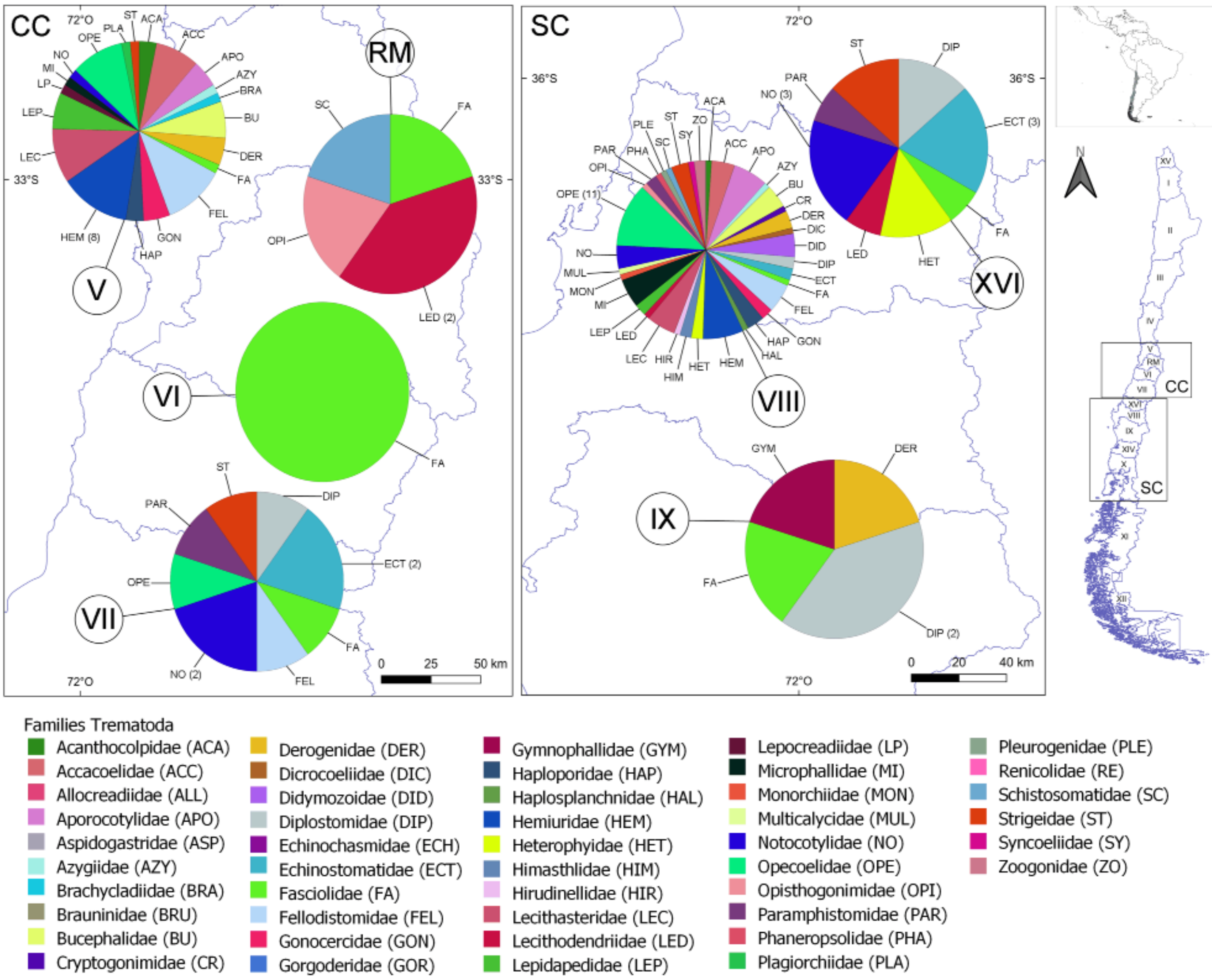

Fig. 3. Number of taxa per trematode family in Central Chile (CC) and Southern Chile (SC), regions XVI, VIII and IX. Every color in the pie chart represents a particular family. The highest number of taxa for trematode families in every region was stated between parentheses. The name of every region represented as a roman number is detailed in Material and Methods.

DISCUSSION

A significant trematode diversity has been recorded from Chile since the first publication by Gay (1849). However, the identification of a number of reported taxa is questionable, therefore, the collection of new quality specimens as well as the thorough re-examination of specimens deposited in museums are necessary. A number of species reported from Chile do not have descriptions or illustrations. For instance, *Proctoeces lintoni* (Fellodistomidae) (originally described from Europe) was reported in native fishes from Chile without adequate descriptions (Valdivia *et al*., 2010; Oliva *et al*., 2018). In the absence of DNA sequence data, comparisons with the two native species from Chile, *P. humboldti* and *P. sicyases*, is not possible (George-Nascimento & Quiroga, 1983; Valdivia *et al*., 2010; Oliva *et al*., 2018). Taking into account the uncertainty of the identification, the information on life cycle and presence of *P. lintoni* in Chile should be considered with caution (Valdivia *et al*., 2010; Oliva *et al*., 2018). The same is true for *Helicometrina nimia* (Opecoelidae), another European fluke reported in Chile, which needs additional analysis to establish its identity (Oliva *et al*., 2015).

Although complete life cycles are known for only 3 species of digeneans reported from Chile, larval stages of some other species have been reported. For instance, metacercariae of *Stephanoprora uruguayense* (Echinochasmidae), parasitic as an adult in seabirds, have been reported from two native fish species (Torres *et al*., 1982, 1983, 1991, 1992a, 1993a, 2017; Viozzi *et al*., 2008). Although in Chile the first intermediate host of this digenean remains unknown, aquatic snails of family Hydrobiidae have been recorded as its first intermediate host in Argentina (Ostrowski de Núñez, 2007). Members of family Hydrobiidae are distributed in Chile (Valdovinos, 1999), therefore, we anticipate that

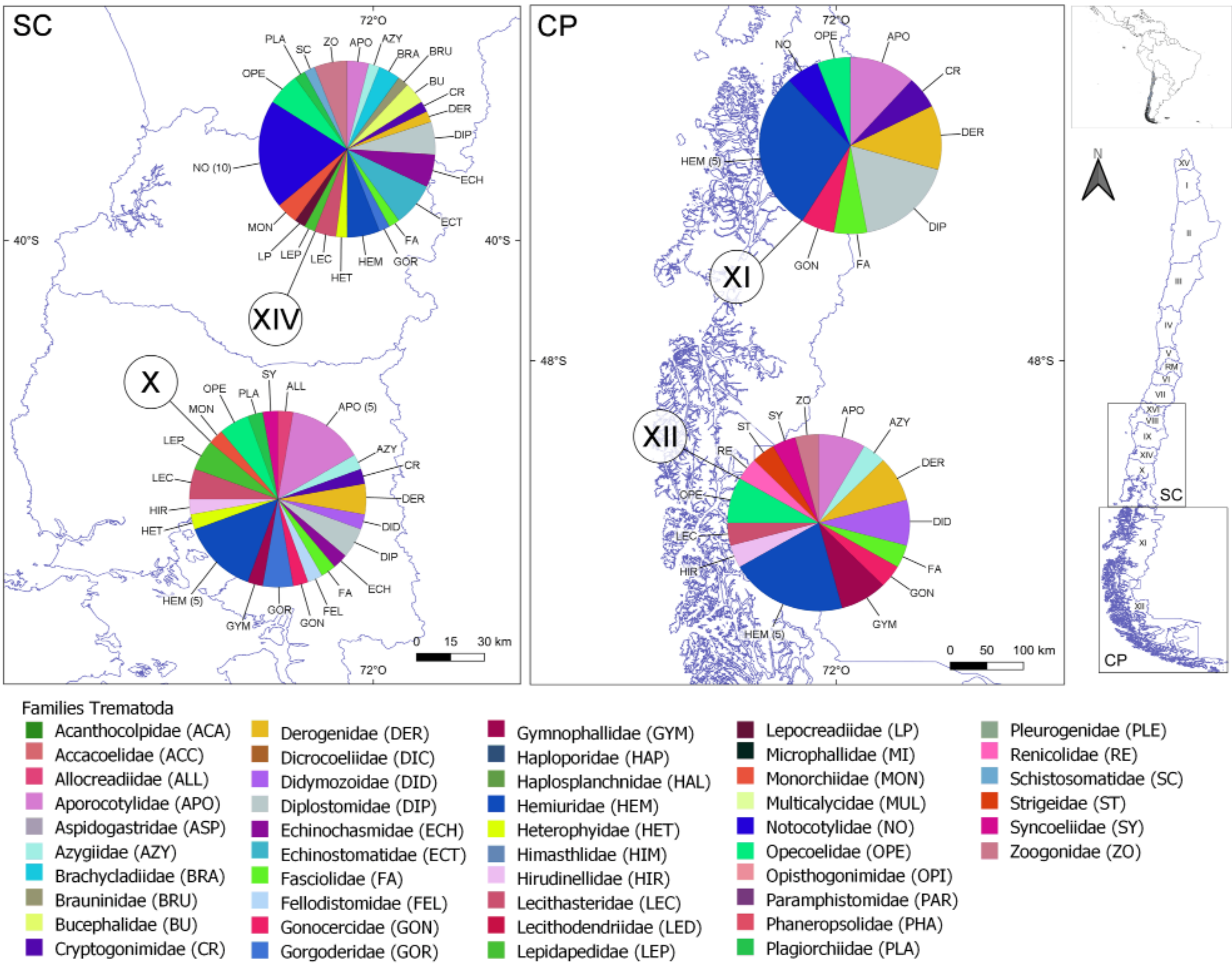

Fig. 4. Number of taxa per trematode family in Southern Chile (SC), regions XIV and X, and Chilean Patagonia (CP). Every color in the pie chart represents a particular family. The highest number of taxa for trematode families in every region was stated between parentheses. The name of every region represented as a roman number is detailed in Material and Methods.

future surveys may reveal the local transmission pathway of this trematode.

The insufficient coverage of host species diversity by parasitological studies in Chile (see Garín & González-Acuña, 2008; Muñoz & Olmos, 2008; Oyarzún-Ruiz & González-Acuña, 2021) might underestimate the complete richness of trematode species in the country. This echoes the situation of the coverage of South American fishes by parasitological studies with only 5 % of their total diversity examined for parasites so far (Choudhury *et al*., 2016).

Among introduced animals, cattle, and lagomorphs have been reported as hosts of *F. hepatica* (e.g. Alcaíno & Gorman, 1999; Courtin *et al*., 1975, 1979; Oyarzún-Ruiz *et al*., 2019b), and some salmonid fishes were reported as hosts of digeneans (Arata *et al*., 1977; Torres, 1995; Torres *et al*., 1992a). While publications on the helminth fauna of other exotic species such synanthropic rodents (*Rattus rattus*, *Rattus norvegicus,* and *Mus musculus*) do exist, there are no records of trematodes on these vertebrates (see Rojas *et al*., 1971; Landaeta-Aqueveque *et al*., 2014, 2018; Seguel *et al*., 2017).

Only a small proportion of studies on trematodes in Chile were performed using experimental infections (e.g. Tagle, 1944; Fernández, 1987b; Rebolledo *et al*., 2014; Muñoz *et al*., 2015). Thus, authors want to emphasize the need for performing this kind of studies, because these would help to a better understanding of the relationships between parasites and their hosts, mechanisms of transmission, pathological changes, behavioral manipulation, among others (Fried, 2000; Ostrowski de Núñe *et al*., 2004; Morley & Lewis, 2014; Blasco-Costa & Poulin, 2017; Karvonen *et al*., 2017).

The present review highlights the clear need for the broader use of molecular tools in the taxonomic studies of trematodes in Chile. Although the first study using DNA sequencing was published in 2010 (Valdivia *et al*., 2010), the number of works applying molecular techniques is still limited. The combined use of morphological and molecular approaches (aka integrative taxonomy) is the most promising approach to advance our knowledge of biodiversity, classification, diagnostics, and phylogenetic interrelationships of trematodes and other parasites (Kostadinova & Gibson, 2000; Kostadinova & Pérez-del-Olmo, 2014; Hoberg *et al*., 2015).

Another interesting and currently discussed topic is the conservation of parasites (Gómez & Nichols, 2013; Carlson *et al*., 2020b). Some trematodes reported in Chile have been found in endemic species, e.g. *Gorgoderina valdiviensis* (Gorgoderidae) in the helmeted water toad (*Calyptocephalella gayi*) (Puga, 1979, 1982) and *Rudolphitrema chilensis* (Plagiorchiidae) in the rosy ground frog (*Eupsophus roseus*) (Puga, 1986; Puga & Torres, 1999), with no additional reports in other hosts (see Fernandes & Kohn, 2014). In addition, hosts of these particular flukes are considered threatened species with declining populations (IUCN, 2020). Considering their host specificity, these parasites could be classified both as endemic and threatened species, and the concept of co-threatened species should be applied to these parasites (Gómez & Nichols, 2013). Likely, there are additional trematode species in not yet studied endemic hosts that would fall into the same category.

The deposition of parasites into publicly accessible museum collections is critically important. This is especially true for the descriptions of new species (Krell, 2016). As discussed above, an illustration of such need is the situation with *P. lintoni* and *H. nimia*, (Valdivia *et al*., 2010; Oliva *et al*., 2015, 2018). Thus, the authors strongly encourage researchers to deposit their specimens, both types and vouchers, in public collections. In Chile, the museums Museo Nacional de Historia Natural and Museo de Zoología at Universidad de Concepción, have helminthological collections receiving and curating specimens.

Although there has been an increase in the number of publications on trematodes in Chile in the past decades, there is a clear need for training parasitologists who would apply modern integrative approaches, and more broadly use experimental models. There is an obvious need for geographic and taxonomic expansion of trematodological research in the country in order to investigate not yet studied regions and host species.

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