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Helminth parasites of finfish commercial aquaculture in Latin America

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Abstract

Latin America has tripled production by aquaculture up to 78 million tonnes in the past 20 years. However, one of the problems that aquaculture is facing is the presence of helminth parasites and the diseases caused by them in the region. In this review we have collected all the available information on helminths affecting commercial aquaculture in Latin America and the Caribbean (LAC), emphasizing those causing serious economic losses. Monogeneans are by far the most common and aggressive parasites affecting farmed fish in LAC. They have been recognized as serious pathogens in intensive fish culture because they reach high levels of infection rapidly, and can infect other phylogenetically related fish species. The next most important group comprises the larval stages of digeneans (metacercariae) such as *Diplostomum* sp. and *Centrocestus formosanus*, which cause serious damage to farmed fish. Since LAC aquaculture has been based mainly on exotic species (tilapia, salmon, trout and carp), most of their parasites have been brought into the region together with the fish for aquaculture. Recently, one of us (A.I.P.-T.) has suggested that monogeneans, which have generally been considered to be harmless, can produce serious effects on the growth of cultured Nile tilapia. Therefore, the introduction of fish together with their 'harmless' parasites into new sites, regions or countries in LAC should be considered a breakdown of biosecurity in those countries involved. Therefore, the application of quarantine procedures and preventive therapeutic treatments should be considered before allowing these introductions into a country.

Introduction

Aquaculture has been experiencing continuous expansion in many countries worldwide and provides a livelihood for 8% of the world's population (540 million people) (FAO, 2014). It is estimated that world aquaculture production doubled from 32.4 million tonnes in 2000 to 66.6 million tonnes in 2012 (FAO, 2014). The fastest annual growth rate in production was observed in Africa (11.7%) and Latin America and the Caribbean (LAC) (10%). For LAC, the economic contribution of aquaculture has grown substantially in the past 10 years, with employment of more than 200,000 people directly, and about 500,000 indirectly (FIS México, 2016). While Chile, Brazil, Ecuador and Mexico account for more than 80% of the regional aquaculture volume, this activity occurs on different scales in almost every country of Latin America. With the exception of *Penaeus vannamei* in Mexico, most of the species under aquaculture conditions in LAC are exotic: salmonids (trout and salmon) in nine countries of the region, marine shrimp in 18 countries and tilapia in 20 countries (FAO, 2014).

An important limitation to the development of commercial aquaculture in LAC in recent decades has been

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the emergence of infectious diseases. Diseases of bacterial (*Streptococcus iniae*, *Pseudomonas* sp., *Aeromonas* sp.) and viral (Iridoviridae, Orthomixoviridae, Rhabdoviridae, Alloherpesviridae) origin are widely distributed and cause high mortalities, producing serious economic losses in aquaculture (Conroy, 2004; OIE, 2015). For example, the bacterium *Francisella* sp. in cultured tilapia has caused losses of US$2.5 million in Costa Rica and is currently present in Mexico, Brazil and Guatemala, with mortality of up to 85% in juveniles (Conroy, 2004). Likewise, parasites are often associated with important economic losses in aquaculture. For example, *Bothriocephalus acheilognathi* is a pathogenic helminth that causes serious mortalities among juvenile fish in culture conditions and in wild populations (Salgado-Maldonado *et al.*, 1986; Salgado-Maldonado & Pineda-López, 2003); in fact, due to its pathogenicity it is considered a threat to endemic fish in Mexico (Velázquez-Velázquez *et al.*, 2011).

Helminths are frequently neglected as causative agents of fish diseases. Indeed, several fish farmers frequently believed that these parasites are harmless (Paredes-Trujillo *et al.*, 2016a). However, under aquaculture conditions such as low water quality, high fish density and extreme environmental variables (e.g. high ammonia concentration, high temperature) these parasites can cause disease (e.g. Gonzáles-Fernández, 2012a; Paredes-Trujillo *et al.*, 2016a). The spread and establishment of parasitic helminths may have detrimental health consequences when present in high numbers within a cultured population with deficient management practices and a lack of biosecurity plans. Therefore, knowledge of the potential risks that helminths represent to farmed fish can be useful for designing appropriate contingency plans and management strategies (Bondad-Reantaso *et al.*, 2005).

In this review, our main objective has been to present the extant information on helminths producing negative effects (e.g. histological or physiological) in finfish under aquaculture conditions. However, we have also included helminths that are apparently harmless, but that we consider potentially dangerous in view of the intensive aquaculture conditions that will be developed in the near future in LAC. For this purpose, this article is divided into five groups of cultured fish arranged according to their economic importance in LAC (salmonids, tilapia, carp, native fish and ornamental fish).

Salmonids

In Latin America, salmonid production is one of the most important aquaculture activities, with a sustained economic growth (586,289 tonnes in 2004) and is highly profitable (Rojas & Wadsworth, 2005). Studies on parasites of salmonids have focused primarily on those that produce diseases in commercial fish. Most of the diseases in salmonids have a viral origin in Latin America (www.oie.int/es/). Consequently, it is difficult to determine the relative impact of helminth infections on salmonid farming (Shinn *et al.*, 2015). Probable reasons for the scarcity of information on helminths include the difficulties in identifying parasites accurately at the farm level and poor record keeping. Table 1 shows the helminth species recorded from salmonid species farmed in Latin America.

Monogeneans

There are records of *Gyrodactylus* sp. in *Oncorhynchus mykiss* for Mexico and Colombia with relatively high infection parameters (mean abundance 100 ± 87 parasites/host) (Salas-Benavides *et al.*, 2015). The clinical signs of *Gyrodactylus* sp. included irritation, bleeding and erosion of the gill tissue. These reports correspond to isolated findings and were not associated with mortality of farmed fish. However, further research is required to understand the presence of these metazoan parasites in farmed salmonids. *Gyrodactylus salmonis* was reported by Rubio-Godoy *et al.* (2012a) from *O. mykiss* in Veracruz, Mexico. However, there are no reports of fish morbidity or mortality associated with gyrodactylid infection in rainbow trout farms in Veracruz, which would suggest a stable host–parasite interaction (Rubio-Godoy *et al.*, 2012a).

Digeneans

Larval forms of diplostomids affecting the brain (*Austrodiplostomum mordax*) and eyes (*Diplostomum* sp.) have been reported in salmonids in LAC. Records in Argentina and Colombia indicate that diplostomiasis is widely distributed in natural environments (Semenas, 1998; Salas-Benavides *et al.*, 2015). The larval genus *Diplostomum* includes metacercariae in the tegument, which generates black spots on the skin, but the most common infections are caused by mesocercariae in the lens, causing oedema, congestion, leucocyte infiltration and bleeding. This damage affects the choroid and iris, causing muscular and retinal necrosis, and finally partial or total blindness of the eye, which forces fish to swim near the surface, making them easy prey for predatory birds.

Nematodes

Hysterothylacium is a nematode genus that has been suggested to affect the health of salmonids in production systems. This genus was first reported in marine cage farms of Chilean salmonids by Carvajal & González (1990). This anisakid nematode was present in the digestive tract of several native fishes (Fernández, 1985) and has been transmitted to the salmonids introduced in Chile for commercial aquaculture. Larvae and adults of *Hysterothylacium aduncum* have been recorded in *Oncorhynchus kisutch*, *O. mykiss*, *Salmo salar* and *Oncorhynchus tshawytscha* reared in floating cages in Chile and Argentina (Carvajal & Gonzalez, 1995) and in *S. salar* from localities close to Puerto Montt (Sepulveda *et al.*, 2004). The effect of *Hysterothylacium* spp. on salmonids has been poorly investigated, but published records indicate that *H. aduncum* causes mortality in juvenile fish (Balbuena *et al.*, 2000) and heavy *Hysterothylacium bidentatum* infections induce digestive tract obstruction (Molnár *et al.*, 2006). It has also been reported that *H. aduncum* represents a zoonotic risk, due to reports of human infection in Japan (Yagi *et al.*, 1996).

Cestodes

Diphyllobothrium sp. plerocercoids have been isolated from the viscera of one specimen of *O. mykiss* reared in

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Table 1. Helminth species recorded from salmonid species farmed in Latin America.

Helminth	Host	Locality	Reference
Monogenea			
Gyrodactylus salmonis	*Oncorhynchus mykiss*	México	Rubio-Godoy *et al.*, 2012a; Salgado-Maldonado & Rubio-Godoy, 2014
Gyrodactylus sp.	*O. mykiss*	México	Rubio-Godoy *et al.*, 2012a; Salas-Benavides *et al.*, 2015
Digenea			
Austrodiplostomum mordax	*O. mykiss*	Argentina	Ortubay *et al.*, 1994; Semenas, 1998
Diplostomum compactum	*O. kisutch*	Venezuela	Conroy &Vásquez, 1975
D. spathaceum	*O. kisutch*	Argentina	Ortubay *et al.*, 1994; Semenas, 1998
Diplostomum sp.	*O. mykiss*, *O. kisutch*	Argentina	Ortubay *et al.*, 1994; Semenas, 1998; Tanzola *et al.*, 2009
Nematoda			
Camallanus corderoi	*O. mykiss*	Argentina	Ortubay *et al.*, 1994; Tanzola *et al.*, 2009
	O. mykiss	Chile	Torres, 1995
Camallanus sp.	*Salmo salar*	Chile	Torres, 1995
Contracaecum sp.	*S. salar*	Chile	Torres *et al.*, 1991a; Torres, 1995
Goezia sp.	*S. salar*	Chile	Torres *et al.*, 1991a; Torres, 1995
Hysterothylacium aduncum	*O. mykiss*	Chile	Torres, 1995
Hysterothylacium sp.	*O. kisutch*	Chile	Carvajal & González, 1990
	S. salar	Argentina	Torres *et al.*, 1993; Ortubay *et al.*, 1994; Sepulveda *et al.*, 2004
Rhabdochona sp.	*O. kisutch*	Argentina	Torres *et al.*, 1993
	O. kisutch	Chile	Ortubay *et al.*, 1994; Sepulveda *et al.*, 2004
Cestoda			
Diphyllobothrium dendriticum	*O. kisutch*	Chile	Torres *et al.*, 1991a, b; Torres *et al.*, 1998; Rozas-Serri, 2006; Rozas-Serri *et al.*, 2012
Diphyllobothrium sp.	*O. mykiss*	Chile	González *et al.*, 1978; Torres *et al.*, 1991a, b; Torres *et al.*, 2002a; Rozas-Serri *et al.*, 2012
Hepatoxylon trichiuri	*Salmo trutta*	Chile	Torres *et al.*, 2000
Phyllobothriidae gen. sp.	*O. kisutch*	Chile	Torres *et al.*, 2000
Acanthocephala			
Acanthocephalus tumescens	*S. trutta*	Chile	Cardemil-Rebolledo, 2012
Acanthocephalus sp.	*S. trutta*	Chile	Cardemil-Rebolledo, 2012
	O. mykiss	Chile	Cardemil-Rebolledo, 2012

the south of Chile (Torres *et al.*, 1998). Since most salmonid production is undertaken in floating cages, some of these parasites are particularly important helminth species because of their zoonotic risk. Additionally, since these parasites complete their life cycles in natural environments, it would be expected that under aquaculture conditions, due to the high fish density in floating cages, the prevalence and abundance of this parasite would be higher. The tapeworm *Diphyllobothrium denditricum* has been detected in wild salmonids (*Salmon coho* and *O. kisutch*) introduced into Chile (Torres *et al.*, 1998). Previous research suggests that diphyllobothriasis and other parasitic infestations in wild fish are potential risks to salmon farming in Chile (Torres *et al.*, 1998), as proven in the northern hemisphere (Rahkonen *et al.*, 1996; Karasev *et al.*, 1997). Furthermore, the larval stages of the tapeworm *D. dendriticum* and the nematode *Contracaecum* sp. are considered to be of zoonotic importance, since the consumption of salmon meat is the entry route to humans (Von Bonsdorff, 1977).

Tilapia

The state of development of aquaculture in LAC suggests that several countries (Brazil, Colombia, Costa Rica, Ecuador and Mexico) predominate in the aquaculture of these African cichlids (FAO, 2014), with Jamaica being one of the largest producers of high-quality red tilapia (FAO, 2014). In many Latin American countries, tilapia was introduced during the 1960s, but this biotechnology was not developed as a commercial activity until the 1980s. Commercial production began in Jamaica in 1983, spread to Colombia, and shortly after to Costa Rica, Brazil, Ecuador, Honduras, Nicaragua and Venezuela (Castillo-Campo, 2006). Currently, tilapia is cultured in 20 out of 26 Latin America countries. With the intensification of tilapia farming, parasitic diseases began to appear, posing important limitations to the development of aquaculture in LAC. Table 2 shows the helminth species recorded from tilapia species farmed in LAC.

Monogeneans

Members of the families Gyrodactylidae and Dactylogyridae are the most important parasites in tilapia aquaculture. Species of the family Capsalidae are also important parasites on tilapia cultured in seawater (Conroy & Conroy, 2008; Rubio-Godoy *et al.* 2011; Shinn *et al.*, 2015). Several authors have shown that the main helminth species affecting fish health in intensive closed-system culture are monogeneans. These helminths are often present in the sex-reversal process, where their infestation is favoured by their direct life cycle at high fish densities (Conroy, 2001). For example, in Brazil, Martins *et al.* (2006) suggested that monogeneans are the ectoparasites

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Table 2. Helminth species recorded from farmed tilapia species in Latin America.

Helminth	Host	Locality	Reference
Monogenea			
Anacanthorus colombianus	*O. mossambicus*	Colombia	Dossman, 1976; Thatcher, 1993
Ancyrocephalus sp.	*O. niloticus*	Brazil	Martins *et al.*, 2002
	O. mossambicus, O. urolepis	México	Salgado-Maldonado & Rubio-Godoy, 2014
Cichlidogyrus dossoui	*O. aureus, O. mossambicus, O. niloticus*	México	Jiménez-García *et al.*, 2001; Flores-Crespo & Flores-Crespo, 2003; Salgado-Maldonado & Rubio-Godoy, 2014; Aguirre-Fey *et al.*, 2015; Paredes-Trujillo *et al.*, 2016a
	O. niloticus	Panamá	Roche *et al.*, 2010
C. halli	*O. niloticus*	Brazil	Jeronimo, 2009, Jeronimo *et al.*, 2011; Lacerda *et al.*, 2013; Zago *et al.*, 2014
	O. niloticus	México	Paredes-Trujillo *et al.*, 2016a
C. haplochromii	*O. aureus, O. niloticus*	México	Jiménez-García *et al.*, 2001; Flores-Crespo & Flores-Crespo, 2003; Salgado-Maldonado & Rubio-Godoy, 2014
C. longicornis	*O. aureus. O. niloticus*	México	Jiménez-García *et al.*, 2001; Flores-Crespo & Flores-Crespo, 2003; Salgado-Maldonado & Rubio-Godoy, 2014; Paredes-Trujillo *et al.*, 2016a
C. quaestio	*O. niloticus*	México	Paredes-Trujillo *et al.*, 2016a
C. sclerosus	*O. niloticus, O. mossambicus, O. aureus*	Brazil	Azevedo, 2004; Ghiraldelli *et al.*, 2006; Lizama *et al.*, 2007a; Jeronimo, 2009; Jeronimo *et al.*, 2011; Lacerda *et al.*, 2013; Dossman, 1976; Thatcher, 1993
	O. urolepis	Colombia	Trujillo, 1987
	O. urolepis	Cuba, México	López-Jiménez, 2001; Jiménez-García *et al.*, 2001; Flores-Crespo & Flores-Crespo, 2003; Salgado-Maldonado, 2006; Salgado-Maldonado & Rubio-Godoy, 2014; Aguirre-Fey *et al.*, 2015; Paredes-Trujillo *et al.*, 2016a
	O. urolepis	Nicaragua	Santamaría & Medina, 2000
C. thurstonae	*O. niloticus*	Brazil	Jeronimo, 2009; Jeronimo *et al.*, 2011; Lacerda *et al.*, 2013; Zago *et al.*, 2014
C. tilapiae	*O. niloticus, O. aureus*	Brazil	Pantoja *et al.*, 2012; Lacerda *et al.*, 2013; Bittencourt *et al.*, 2014
	O. niloticus, O. aureus	Colombia	Dossman, 1976; Thatcher, 1993
	O. niloticus, O. aureus	Cuba	Prieto *et al.*, 1985; Trujillo, 1987
	O. niloticus, O. aureus	México	López-Jiménez, 2001; Jiménez-García *et al.*, 2001; Flores-Crespo & Flores-Crespo, 2003; Salgado-Maldonado & Rubio-Godoy, 2014; Paredes-Trujillo *et al.*, 2016a
	O. niloticus, O. aureus	Puerto Rico	Bunkley-Williams & Williams, 1994
Cichlidogyrus spp.	*O. niloticus*	Brazil	Ranzani-Paiva *et al.*, 2005; Ghiraldelli *et al.*, 2006; Lizama *et al.*, 2007a; Zago *et al.*, 2014
	O. niloticus	Colombia	Sánchez-Ramirez *et al.*, 2007
	O. niloticus	Costa Rica	Muñoz, 2001; Kubitza, 2005
	O. niloticus	Cuba	Sánchez-Ramirez *et al.*, 2007
	O. niloticus	Ecuador	Jiménez, 2007
	O. niloticus	México	Paredes-Trujillo *et al.*, 2016a
	O. niloticus	Venezuela	Aragort *et al.*, 1997
Cleidodiscus sp.	*O. niloticus*	Brazil	Kubitza & Kubitza, 2000
Dactylogyrus vastator	*O. niloticus*	Brazil	Figueira & Ceccarelli, 1991; Zanolo *et al.*, 2009
Dactylogyrus sp.	*O. niloticus, Oreochromis* spp.	Colombia	López-González, 1987; Sanabria-Tamayo & Useche-López, 1995
	O. niloticus, Oreochromis spp.	Costa Rica	Muñoz, 2001; Kubitza, 2005
	O. niloticus, Oreochromis spp.	Brazil	Marengoni *et al.*, 2009; Leonardo *et al.*, 2006; Zanolo & Yamamura, 2006
	O. niloticus, Oreochromis spp.	Uruguay	Vogelsang, 1929
	O. niloticus, Oreochromis spp.	México	Flores-Crespo *et al.*, 1992; Flores-Crespo & Flores-Crespo, 2003

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Table 2. (*Cont.*)

Helminth	Host	Locality	Reference
Enterogyrus cichlidarum	*O. niloticus*	Brazil	Lacerda *et al.*, 2013
E. malmbergi	*O. aureus, O. niloticus*	México	Jiménez-García *et al.*, 2001; Flores-Crespo & Flores-Crespo, 2003; Salgado-Maldonado & Rubio-Godoy, 2014; Paredes-Trujillo *et al.*, 2016
E. niloticus	*O. niloticus*	México	López-Jiménez, 2001; Salgado-Maldonado & Rubio-Godoy, 2014
Enterogyrus sp.	*O. niloticus*, *O. mossambicus*	Costa Rica, México	Muñoz, 2001; Salgado-Maldonado & Rubio-Godoy, 2014; Flores-Crespo & Flores-Crespo, 2003
	O. niloticus, *O. mossambicus*	Venezuela	Conroy & Conroy, 2008
Gyrodactylus yacatli	*Oreochromis niloticus niloticus*, *O. niloticus*	México	García-Vásquez *et al.*, 2011; Rubio-Godoy *et al.*, 2012b; Salgado-Maldonado & Rubio-Godoy, 2014
G. cichlidarum	*O. niloticus*	Brazil	Lacerda *et al.*, 2013
	O. mossambicus	Ecuador	Jiménez, 2007
	O. mossambicus	México	García-Vásquez *et al.*, 2010, 2011; Rubio-Godoy *et al.*, 2012b; Salgado-Maldonado & Rubio-Godoy, 2014
	Oreochromis spp.	Puerto Rico	Bunkley-Williams & Williams, 1994
G. niloticus	*O. aureus*, *O. mossambicus*, *O. niloticus*	México	Hernández-Martínez, 1992; López-Jiménez, 2001; Salgado-Maldonado *et al.*, 2005; Rubio-Godoy *et al.*, 2012b; Salgado-Maldonado & Rubio-Godoy, 2014
Gyrodactylus sp.	*O. niloticus, O. aureus*	Brazil	Martins *et al.*, 2002; Ghiraldelli *et al.*, 2006; Leonardo *et al.*, 2006; Zago *et al.*, 2014
	O. mossambicus	Colombia	Sanabria-Tamayo & Useche-López, 1995
	Oreochromis spp.	Costa Rica	Muñoz, 2001; Kubitza, 2005
	Oreochromis spp.	Ecuador	Jiménez, 2007
	Oreochromis spp.	México	Salgado-Maldonado & Rubio-Godoy, 2014
	Oreochromis spp.	Perú	Gonzáles-Fernández, 2012a
	Oreochromis spp.	Uruguay	Vogelsang, 1929
Neobenedenia melleni	*O. mossambicus* x *O. aureus*	Jamaica	Khalil *et al.*, 1988
	O. aureus	Costa Rica	Kubitza, 2005
	O. mossambicus	Puerto Rico	Robinson *et al.*, 1992; Bunkley-Williams & Williams, 1994
	O. mossambicus x *O. urolepis*	Bahamas	Bunkley-Williams & Williams, 1995
	O. niloticus	Venezuela	Conroy, 2001
Neobenedenia sp.	*O. niloticus*	México	Rubio-Godoy *et al.* 2011
Sciadicleithrum bravohollisae	*O. aureus*	México	Jiménez-García *et al.*, 2001; Flores-Crespo & Flores-Crespo, 2003; Salgado-Maldonado & Rubio-Godoy, 2014
Scutogyrus longicornis	*O. niloticus*	Brazil	Jeronimo, 2009; Jeronimo *et al.*, 2011; Lacerda *et al.*, 2013; Zago *et al.*, 2014
	O. niloticus	México	López-Jiménez, 2001; Salgado-Maldonado & Rubio-Godoy, 2014
Scutogyrus sp.	*O. mossambicus*, *O. niloticus*	México	Salgado-Maldonado & Rubio-Godoy, 2014; Aguirre-Fey *et al.*, 2015
Tetraonchus sp.	*O. mossambicus*, *O. urolepis*	México	Flores-Crespo & Flores-Crespo, 2003; Salgado-Maldonado & Rubio-Godoy, 2014
Digenea			
Atrophacaecum astorquii	*O. niloticus*	Panama	Roche *et al.*, 2010
Centrocestus formosanus	*O. urolepis*	Brazil	Pinto *et al.*, 2014
	O. niloticus	Costa Rica	Arguedas-Cortés *et al.*, 2010
	O. aureus, *O. mossambicus*	México	Scholz & Salgado-Maldonado, 2000; Salgado-Maldonado, 2006; Salgado-Maldonado & Rubio-Godoy, 2014
Clinostomum complanatum	*O. niloticus*	Brazil	Silva *et al.*, 2008; Lacerda *et al.*, 2013
	O. niloticus	México	García *et al.*, 1993
Culuwiya cichlidorum	*O. niloticus*	Panama	Roche *et al.*, 2010

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Table 2. (*Cont.*)

Helminth	Host	Locality	Reference
Diplostomum compactum	*O. aureus*	Brazil	Pinto *et al.*, 2014
	O. mossambicus, *Oreochromis* spp.	México	Pineda-López, 1985; García *et al.*, 1993; Vidal-Martínez, 1995; Violante-González *et al.*, 2009
	O. mossambicus, *Oreochromis* spp.	Panamá	Roche *et al.*, 2010
	O. mossambicus, *Oreochromis* spp.	Venezuela	González & González, 1981; Ostrowski de Núñez, 1982; Aragort *et al.*, 1997; Conroy, 2001; Conroy & Conroy, 2008
D. spathaceum	*O. niloticus*	Costa Rica	Muñoz, 2001
Diplostomum sp.	*O. niloticus*, *O. mossambicus*	Brazil	Onaka, 2009
	O. niloticus, *O. mossambicus*	Colombia	Castro-Castillo, 1980; Rodríguez-Gómez, 1981
	O. niloticus, *O. mossambicus*	Cuba	Prieto *et al.*, 1991
Drepanocephalus sp.	*O. niloticus*	Brazil	Pinto *et al.*, 2014
Echinochasmus sp.	*O. niloticus*	Ecuador	Jiménez, 2007
Pelaezia loosi	*O. niloticus*	Panama	Roche *et al.*, 2010
Ribeiroia sp.	*O. niloticus*	Brazil	Pinto *et al.*, 2014
Saccocoelioides sp.	*O. aureus*	México	García *et al.*, 1993
Nematoda			
Brevimulticaecum sp.	*O. niloticus*	Panama	Roche *et al.*, 2010
Falcaustra sp.	*O. niloticus*	Panama	Roche *et al.*, 2010
Raphidascaris sp.	*Oreochromis* spp.	Colombia	Sánchez-Páez, 1993
Spiroxys sp.	*O. niloticus*	Panama	Roche *et al.*, 2010
Cestoda			
Bothriocephalus acheilognathi	*O. mossambicus*	Cuba	Prieto *et al.*, 1991, Bunkley-Williams & Williams, 1995
	O. niloticus	México	Pineda-López & Gonzalez-Enriquez, 1997; Gutiérrez-Cabrera *et al.*, 2005; Salgado-Maldonado, 2006; Pérez-Ponce de León *et al.*, 2009; Salgado-Maldonado & Rubio-Godoy, 2014
Onchobothrium sp.	*Oreochromis* spp.	Colombia	Rey-Castaño, 1999; Rey-Castaño *et al.*, 2002
Ophiovalipora minuta	*O. mossambicus*	Puerto Rico	Bunkley-Williams & Williams, 1994
Ophiotaenia sp.	*O. mossambicus*	Puerto Rico	Bunkley-Williams & Williams, 1994

responsible for the most important parasitic disease among farmed tilapia.

Overall, gyrodactylids are known to be very aggressive, tending to be extremely pathogenic to tilapia, especially to larvae and small fish at high population densities and intensive culture conditions. Infestations occur mainly on the body, rarely on the gills, and produce excessive secretion of mucus and epithelial cell proliferation. This leads to erosion of the skin surface and the possibility of secondary infections caused by bacteria and fungi. Due to their viviparous reproductive strategy, gyrodactylids are able to achieve high infestation levels in very short periods of time (Flores-Crespo & Flores-Crespo, 2003; Conroy & Conroy, 2008). *Gyrodactylus cichlidarum* is widely distributed in Latin America (Brazil, Colombia, Ecuador, Honduras, Mexico, Puerto Rico) and has been detected in Nile tilapia (*Oreochromis niloticus*), blue tilapia (*O. aureus*), Mozambique tilapia (*O. mossambicus*) and hybrid red tilapia (*O. mossambicus* × *O. urolepis*) (Bunkley-Williams & Williams, 1994; Conroy, 2001; Jiménez, 2007; García-Vásquez *et al.*, 2011; Lacerda *et al.*, 2013; Salgado-Maldonado & Rubio-Godoy, 2014; Paredes-Trujillo *et al.*, 2016a). *Gyrodactylus cichlidarum* is especially harmful to tilapia kept in ponds, attacking mainly the skin and fins (García-Vázquez *et al.*, 2011; Paredes-Trujillo *et al.*, 2016a). *Gyrodactylus niloticus* has been recorded from Mexico on *O. aureus, O. mossambicus* and *O. niloticus* (Hernández-Martínez, 1992; López-Jiménez, 2001; Salgado-Maldonado *et al.*, 2005). However, García-Vásquez *et al.* (2010) considered *G. niloticus* to be synonymous with *G. cichlidarum*. *Gyrodactylus yacatli* was originally described by García-Vásquez *et al.* (2011) from *O. niloticus* and, for LAC, this species has only been reported from Mexico (García-Vásquez *et al.*, 2011; Salgado-Maldonado & Rubio-Godoy, 2014).

Dactylogyrids are highly pathogenic to their tilapia hosts, especially when they are present in high amounts. Infestations are mainly on the gills, where they give rise to marked hyperplasia and other proliferative changes in the epithelium, which leads to respiratory problems and mortality (Del Río-Zaragoza *et al.*, 2010). The genus *Cichlidogyrus* was first described by Paperna (1960), with the type species *Cichlidogyrus arthracanthus* collected in Israel from the wild host species *Tilapia zillii*. This genus was reported from cultured tilapia in Africa by Douëllou (1993). *Cichlidogyrus* spp. were introduced into America from Africa along with their host in the early 1980s (Kritsky & Thatcher, 1974; Arredondo-Figueroa,

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1983; Lazaro-Chávez, 1985; Prieto *et al.*, 1985; Kritsky *et al.*, 1994). In Cuba and Colombia massive infections of cultured tilapia by *Cichlidogyrus* spp. have been reported (Sánchez-Ramirez *et al.*, 2007). In Mexico, members of this genus have been reported with high prevalence in *O. niloticus* and *O. mossambicus* in Campeche, Veracruz and Yucatán (Vidal-Martínez *et al.*, 2001; Aguirre-Fey *et al.*, 2015; Paredes-Trujillo *et al.*, 2016a). Little is known about the biology of *Cichlidogyrus*, but apparently there is a link between poor water quality and high prevalence of this monogenean in aquaculture conditions.

The most widely distributed species of *Cichlidogyrus* in Latin America are *Cichlidogyrus sclerosus* and *C. tilapiae*, first recorded in Colombia, Mexico (Kritsky & Thatcher, 1974; Kritsky *et al.*, 1994) and Cuba (Prieto *et al.*, 1985). These species have been recorded infecting various species of tilapia and their hybrids, including blue tilapia (*O. aureus*), Mozambique tilapia (*O. mossambicus*), Nile tilapia (*O. niloticus*) and red tilapia (*O. urolepis*) (Bunkley-Williams & Williams, 1994; Santamaría & Medina, 2000; Jiménez-García *et al.*, 2001; Flores-Crespo & Flores-Crespo, 2003; Ghiraldelli *et al.*, 2006; Salgado-Maldonado, 2006; Lizama *et al.*, 2007a; Jeronimo *et al.*, 2011; Pantoja *et al.*, 2012; Lacerda *et al.*, 2013; Bittencourt *et al.*, 2014; Salgado-Maldonado & Rubio-Godoy, 2014; Aguirre-Fey *et al.*, 2015; Paredes-Trujillo *et al.*, 2016a). Infections with *C. sclerosus* have an important effect on the growth rate and relative condition factor of their hosts, which could have an economic effect on tilapia farmers (Sandoval-Gío *et al.*, 2008; Le Roux, 2010; Paredes-Trujillo *et al.*, 2016a). Sánchez-Ramirez *et al.* (2007) reported outbreaks of *C. sclerosus* during the winter months in *O. niloticus* under experimental culture in Yucatán, Mexico; apparently, the fish had a weak immune response in cold weather, which in turn favoured a high prevalence of this monogenean. The same epizootic pattern was reported by Aguirre-Fey *et al.* (2015), who found a significant negative correlation between water temperature and parasite abundance. Pantoja *et al.* (2012) recorded a prevalence of *C. tilapiae* of more than 90% in Nile tilapia farms in Amapá State, Brazil. Likewise, Salgado-Maldonado & Rubio-Godoy (2014) considered that *C. sclerosus* is the most common monogenean in tilapia cultured in Mexico, and it has also been identified in different species of native cichlid fishes (Jiménez-García *et al.*, 2001).

In a study of farmed *O. niloticus* from the Chavantes reservoir in Brazil, Martins (1998) showed that the dactylogyrids *Cichlidogyrus halli* and *Scutogyrus longicornis* were the most abundant monogeneans in the gills of this fish species. In cases of high infection intensity, these monogeneans can cause mortalities, especially in small fish (Jeronimo, 2009). *Cichlidogyrus dossoui* has been recorded from *Oreochromis* spp. cultured in Mexico, and has detrimental effects on the host (Aguirre-Fey *et al.*, 2015; Paredes-Trujillo *et al.*, 2016a). In addition, Roche *et al.* (2010) reported the presence of *C. dossoui* on wild *O. niloticus* collected in Panama.

Jiménez-García *et al.* (2001) first documented that *O. aureus* is also parasitized by the native monogenean *Sciadicleithrum bravohollisae*. This species was previously considered to be specific to American cichlids (Kritsky *et al.*, 1994; Salgado-Maldonado *et al.*, 1997). The lack of a co-evolutionary history may often render invasive species non-competent hosts, and thus acquisition of native parasite species may not take place. However, this does not seem to be the case here, because both introduced tilapia and American native cichlids are phylogenetically related (Cichlidae) and thus direct transmission of this monogenean to the non-native hosts is the most probable explanation for this transfer.

Neobenedenia melleni has a negative impact on tilapia aquaculture in both brackish and marine waters. Khalil *et al.* (1988) and Robinson *et al.* (1992) reported problems caused by '*Benedenia* sp.' (= *N. melleni*) in coastal marine aquaculture involving hybrid red tilapia (*O. mossambicus* × *O. aureus*) in southern Jamaica. Bunkley-Williams & Williams (1995) also found large amounts of *N. melleni* in blue tilapia (*O. aureus*), Mozambique tilapia (*O. mossambicus*) and hybrid red tilapia (*O. mossambicus* × *O. urolepis*) cultured in Puerto Rico and other areas of the Caribbean. They suggested that, as exotic species, these fishes do not have natural resistance against this monogenean species. High mortalities can occur in a very short time after the initial infestation. This was verified experimentally by Rubio-Godoy *et al.* (2011), who exposed *O. mossambicus* and Pargo-UNAM (a synthetic hybrid whose genetic composition is 50% Florida red tilapia, 25% Rocky Mountain tilapia, and 25% red variant *O. niloticus*) to seawater collected at Veracruz on the Gulf of Mexico. Both tilapia types became infected by *Neobenedenia* sp., and most of the fish died within a fortnight following exposure. Kaneko *et al.* (1988) reported serious infections of *N. melleni* in Mozambique tilapia (*O. mossambicus*) cultured in floating cages in the coastal area of Hawaii.

Digeneans

The species of the genus *Diplostomum* causing problems in cultured tilapia include *D. compactum* and *D. spathaceum*. However, both species are extremely difficult to distinguish from each other morphologically (Aguirre-Macedo, pers. com.). Nevertheless, since *D. compactum* is the most frequently reported species in Latin America (Conroy & Conroy, 2008), we will focus on it from now on. Metacercariae of *D. compactum* have been reported from the lens, retina, brain and vitreous humour, producing a condition known as 'eye fluke', 'cataract' or 'parasitic blindness' (Ostrowski de Núñez, 1982). Fish infected with *D. compactum* have impaired vision, which decreases their capacity to look for food normally and consequently they do not grow properly. These infected fish also tend to swim near the water surface, which is an ideal situation for predators such as fish-eating birds (Conroy & Conroy, 2008).

Diplostomosis is widely distributed in cichlids and other native fish species in fresh waters in Mexico and Central and South America and has been reported to cause disease problems in some native species (Jiménez-García *et al.*, 2001). García *et al.* (1993) described the histological alterations caused by *D. compactum* in the ocular globes, vitreous humour and brain of *O. aureus* and *O. mossambicus*, including corneal and conjuctival lesions, optic neuritis, iridocyclitis, eosinophilic infiltration, front and rear uveitis and cataracts. In the brain, histological

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lesions include multifocal gliosis, eosinophilic meningitis, spongiosis and parasitic cyst in the telencephalon. Pineda-López (1985) reported significant mortalities in farmed tilapia in Chiapas, Mexico as a result of diplostomatosis caused by *D. compactum*; they also mentioned that in most fish metacercariae were present in both eyes. González & González (1981) studied the effects of *D. compactum* metacercariae in native and introduced species of cichlids in Lake Valencia, Venezuela, finding between one and six metacercariae in each eye. *Diplostomum compactum* has been described by several authors as a native species of Latin America (Ostrowski de Núñez, 1982; García *et al*., 1993; Conroy, 2001), and for this reason tilapia farmers should consider the mechanical removal of the first intermediate host, *Biomphalaria* cf. *havanensis* (Violante-González *et al*., 2009).

Another important larval trematode in tilapia farming is *Clinostomum complanatum*. This species is present in fish as metacercariae, using them as a second intermediate host (Thatcher, 1981, Eiras *et al*., 1999; Sutili *et al*., 2014). The presence of this trematode has been described by several authors in different parts of the world and in different host species (Salgado-Maldonado, 2006), demonstrating that it is a cosmopolitan parasite. Salgado-Maldonado (2006) generated a helminth parasite checklist in 194 native and 18 introduced freshwater fish species from 30 families from Mexico, and reported that the metacercariae of *C. complanatum* are present in 12 families and 49 species. These metacercariae, often referred to as 'yellow grub' or 'the yellow spot disease', infect the skin, muscle, fins, head, viscera and intestine, causing pathologies and changes in the host's behaviour and feeding habits, leading to poor body weight gain and loss of fecundity, and may culminate in death, with economic losses in fish farms (Eiras, 1994; Mitchell *et al*., 2002; Pavanelli *et al*., 2002; Vianna *et al*., 2005; Silva *et al*., 2008; Sutili *et al*., 2014). In Brazil, *C. complanatum* has been a subject of study due to the economic losses caused by the poor appearance for fish marketing, due to the presence of yellow cysts under the skin (Thatcher, 1981; Eiras *et al*., 1999). García *et al*. (1993) found that the histological alterations produced by the metacercariae of *C. complanatum* encysted in the epidermis and dorsal fin caused an inflammatory reaction with eosinophilic infiltration in the skin of parasitized fish. In addition to the negative effect of the presence of *C. complanatum* in aquacultured fish, these metacercariae are potentially transmissible to humans (Dzikowski *et al*., 2004).

Centrocestus formosanus is an intestinal heterophyid trematode of Asian origin reported in birds and mammals, including humans (Scholz & Salgado-Maldonado, 2000). The metacercariae cysts in gills produce asphyxia and mortality, as well as delayed development, which in turn cause damage to fish farming (Mitchell *et al*., 2005). The histopathological severity of the effect of the larval stages of *C. formosanus* on the gills of the fish host depends on the number of individuals infecting each host. However, from field data, it is evident that in many cases thousands of parasites are infecting individual fish hosts, with mortality occurring more frequently in juvenile fish less than 30 days old (Paperna, 1996; Pironet & Jones, 2000; Salgado-Maldonado & Rubio-Godoy, 2014). Vogelbein & Overstreet (1988) noted that *C. formosanus* induces an inflammatory response characterized by an unusual proliferation of fibroblasts, forming a continuous encapsulation around the parasite, which eventually destroys the gill tissue. Arguedas-Cortés *et al*. (2010), in an effort to identify the species of trematode pathogens for tilapia fry in Costa Rica, made the first records of the presence of metacercariae of *C. formosanus*. These authors reported intensities of between 1018 and 1027 metacercariae per parasitized fish in experimental infections, and a high fry mortality. Recently, Pinto *et al*. (2014) reported that *C. formosanus* reached high prevalence (31%) and mean intensity of infection (3.42 (1–4.2)) in *O. niloticus* collected in an urban reservoir from Brazil, followed by the diplostomid *D. compactum* (29.5% and 1.27 (1–2)) recovered from eyes. The metacercariae of *Drepanocephalus* sp. and *Ribeiroia* sp. have also been found in the oral cavity of the fish but at low prevalence (8.2% and 1.6%, respectively) and intensities of infection (only one metacercaria of each species per fish). Records of these trematode species were reported for the first time by Pinto *et al*. (2014) in *O. niloticus* from South America.

Cestodes

Bothriocephalus acheilognathi was found in tilapia under intensive aquaculture conditions in Cuba (Prieto *et al*., 1991). The parasite causes mechanical damage and inflammation of the intestinal mucosa, anorexia, weight loss, abdominal distension, anaemia and a tendency to swim at the surface of the water (Prieto *et al*., 1991; Pineda-López & González-Enríquez, 1997; Gutiérrez-Cabrera *et al*., 2005; Salgado-Maldonado, 2006; Pérez-Ponce de León *et al*., 2009; Salgado-Maldonado & Rubio-Godoy, 2014).

Salgado-Maldonado & Rubio-Godoy (2014) demonstrated that *C. formosanus* and *B. acheilognathi* are extremely invasive helminths, currently found in virtually all of Mexico and characterized by very low host specificity, thus infecting native fishes belonging to several families and genera.

Carp

Carp are cultivated in several Latin American countries, mainly in extensive and semi-intensive aquaculture. In 2004, the production of carp in LAC reached 59,105 tonnes, behind only salmon and tilapia (FAO, 2014). Table 3 shows the helminth species recorded from farmed carp in Latin America and the Caribbean.

Monogeneans

Among *Dactylogyrus* species found on carp introduced into Latin America, *Dactylogyrus extensus* and *Dactylogyrus vastator* need special attention, due to their low host specificity and high pathogenicity (Ozer, 2002; Salgado-Maldonado & Rubio-Godoy, 2014). Several species of *Dactylogyrus* have been reported for cultured carp in Mexico (table 3); however, *D. extensus* is the most prevalent and abundant species in carp in this country (Salgado-Maldonado & Rubio-Godoy, 2014). In Peru, *D. vastator* was found in wild carp, presumably released from aquaculture facilities (Jara & Escalante, 1983), while in Argentina, *D. extensus* was found in both

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Table 3. Helminth species recorded from carp species farmed in Latin America.

Helminth	Host	Locality	Reference
Monogenea			
Cleidodiscus floridanus	*Cyprinus carpio*	México	Pérez-Ponce de León *et al.*, 1996; Flores-Crespo & Flores-Crespo, 2003; Hernández-Ocampo *et al.*, 2012
Dactylogyrus anchoratus	*Cyprinus carpio koi*, *Cyprinus carpio*	México	Salgado-Maldonado & Rubio-Godoy, 2014
Dactylogyrus dulkeiti	*Cyprinus carpio koi*	México	Hernández-Ocampo *et al.*, 2012; Salgado-Maldonado & Rubio-Godoy, 2014
Dactylogyrus extensus	*Cyprinus carpio*	México	Hernández-Ocampo *et al.*, 2012; Salgado-Maldonado & Rubio-Godoy, 2014
Dactylogyrus intermedius	*Cyprinus carpio*	México	Salgado-Maldonado & Rubio-Godoy, 2014
	Cyprinus carpio	Argentina	Waicheim *et al.*, 2014
Dactylogyrus vastator	*Cyprinus carpio koi*	México	Salgado-Maldonado & Rubio-Godoy, 2014
	Cyprinus carpio koi	Argentina	Waicheim *et al.*, 2014
Dactylogyrus sp.	*Cyprinus carpio koi*	México	Hernández-Ocampo *et al.*, 2012; Salgado-Maldonado & Rubio-Godoy, 2014
	Cyprinus carpio koi	Puerto Rico	Bunkley-Williams & Williams, 1994
	Cyprinus carpio koi	Argentina	Waicheim *et al.*, 2014
Gyrodactylus sp.	*Cyprinus carpio koi*, *Cyprinus carpio*	México	Hernández-Ocampo *et al.*, 2012; Salgado-Maldonado & Rubio-Godoy, 2014
		Argentina	Waicheim *et al.*, 2014
Digenea			
Centrocestus formosanus	*Cyprinus carpio*	México	Vélez-Hernández *et al.*, 1998; Scholz & Salgado-Maldonado, 2000
Clinostomum complanatun	*Cyprinus carpio*	México	Pérez-Ponce de León *et al.*, 1996; Vélez-Hernández *et al.*, 1998; Scholz & Salgado-Maldonado, 2000
Nematoda			
Contracaecum sp.	*Cyprinus carpio*	México	Monks *et al.*, 2005
Goezia sp.	*Cyprinus carpio*	México	Martins *et al.*, 2004
Pseudocapillaria tomentosa	*Cyprinus carpio koi*	México	Pérez-Ponce de León *et al.*, 1996
Spiroxys sp.	*Cyprinus carpio*	México	Falcón-Ordaz *et al.*, 2015
Cestoda			
Bothriocephalus acheilognathi	*Cyprinus carpio koi*	Brasil	Pavanelli & Takemoto, 1995; Rego, 1999
	Cyprinus carpio	Mexico	Salgado-Maldonado & Pineda-López, 2003; Gutiérrez-Cabrera *et al.*, 2005; Salgado-Maldonado & Rubio-Godoy, 2014; Falcón-Ordaz *et al.*, 2015
Acanthocephala			
Polymorphus sp.	*Cyprinus carpio*	Argentina	Waicheim *et al.*, 2014
Pomphorhynchus patagonicus	*Cyprinus carpio*	Argentina	Waicheim *et al.*, 2014

cultured and wild carp. There is little information on the histological damage caused by these monogeneans, or whether they produce heavy mortality in LAC. This is partially due to the low market price of carp and to the fact that they are normally released in natural waterbodies for extensive aquaculture. However, Buchmann *et al.* (2004) emphasized the damage produced by *D. vastator* in the gill epithelium of carp, hindering or preventing breathing. Golovina & Golovin (1988) showed that infection by *D. extensus* and *D. vastator* can lead to pathological changes in blood cells (gradual reduction in the number of lymphocytes).

Digeneans

The metarcercariae of the highly pathogenic non-native digenean *C. formosanus* have been reported in *Cyprinus carpio* in LAC. In Mexico, *C. formosanus* has been detected in several states in the country (Michoacán, Morelos, Veracruz, Tabasco, Jalisco, Hidalgo, Sonora, Tamaulipas and San Luis Potosí) (Aguilar-Aguilar *et al.*, 2008). However, the spread of this parasite to other states is highly probable (Salgado-Maldonado & Rubio-Godoy, 2014). Nevertheless, there are very few data on the pathogenicity of *C. formosanus* in fish hosts in Mexico. López-Jiménez (1987) reported that these metacercariae may cause severe pathological problems, decreasing the fish respiratory capacity and, in heavy infections, may lead to fry mortality. Vélez-Hernández *et al.* (1998) demonstrated the presence of moderate to severe hyperplasia of the primary lamellae of cartilage due to *C. formosanus*. Other histological findings included mild hyperplasia of the lymphoid tissue in the gills, epithelial hyperplasia of lamellae, gill hyperaemia and congestion (Mitchell *et al.*, 2000).

Clinostomun complanatum is another digenean that has been reported to infect farmed carp in Rio Grande do Sul, southern Brazil. This digenean has been reported to

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occur in wild fishes as well as in cultured carp, namely *Rhamdia quelen*, *O. niloticus*, *Salminus brasiliensis*, *Ctenopharyngodon idella* and *C. carpio* (Vélez-Hernández *et al.*, 1998; Scholz & Salgado-Maldonado, 2000). Dias *et al.* (2003) reported cysts in the eyes that did not cause complete blindness, but which certainly could impair fish vision, thereby facilitating predation by birds.

Cestodes

The Asian tapeworm *B. acheilognathi*, which may cause mortality in young carp, has successfully colonized many places in the world in which carp have been introduced (Scholz, 1999). The rapid spread of this parasite has been aided by fish trading for a variety of purposes, including aquaculture (Lafferty *et al.*, 2014). In South America, this endoparasite was first introduced into Brazil together with *C. carpio*. The first record of this non-native cestode was in the 1990s, in carp grown in the state of Paraná, southern Brazil (Rego, 1999). Mexican workers have documented carp losses associated with the presence of this parasite in official carp farms (Salgado-Maldonado & Rubio-Godoy, 2014). *Bothriocephalus acheilognathi* is widely distributed in practically all the states of Mexico, and it is present in several environments, including rivers, sinkholes, lakes and carp farms (Salgado-Maldonado & Rubio-Godoy, 2014). The pathology of the tapeworm in the fish gut includes intestinal blockage, flaking and erosion of the intestinal epithelium, and bowel perforation (Salgado-Maldonado & Pineda-López, 2003). Although there are few reports from other Latin American countries, in Brazil and Argentina *B. acheilognathi* has been identified in cultured carp without apparent mortalities.

Cultured native species

In most Latin American countries there is incipient aquaculture of native species in both freshwater and marine environments. Among the species under experimental or low-scale freshwater aquaculture are tambaqui or cachama (*Colossoma macropomum*), channel catfish (*Ictalurus punctatus*), silver catfish (*Rhamdia quelen*), Mayan cichlid (*Cichlasoma urophthalmus*), bay snook (*Petenia splendida*), fat snook (*Centropomus parallelus*), common snook (*Centropomus undecimalis*), pacu (*Piaractus mesopotamicus*), Argentinian silverside (*Odonthestes bonariensis*), pirarucu (*Arapaima gigas*) and bocachico (*Prochilodus magdalenae*). For seawater aquaculture, the species involved are Pacific bluefin tuna (*Thunnus thynnus*), yellowtail kingfish (*Seriola lalandi*), spotted red snapper (*Lutjanus guttatus*), sea bass (*Dicentrarchus labrax*) and snowy grouper (*Epinephelus niveatus*). There is no doubt that Latin American aquaculture will face serious problems with helminth parasites in the near future, with the increase in fish density in all kinds of facilities such as floating cages, earth or concrete ponds, raceways, etc. (Mujica & Armas de Conroy, 1985; Aragort & Moreno, 1997). Helminths with direct life cycles, such as monogeneans, are the ones that will probably appear under aquaculture conditions, especially in floating cages. Table 4 shows the helminth species recorded from freshwater native fish species farmed in Latin America.

Colossoma macropomum is the main native fish species cultured commercially in Brazil, Colombia, Cuba, Peru and Venezuela. In this fish species the most important monogenean species due to their high prevalence and mean abundance values are: *Dactylogyrus* sp., *Anacanthorus spatulatus*, *Linguadactyloides brinkmanni*, *Mymarothecium boegeri* and *Notozothecium janauachensis* (Ceccarelli *et al.*, 1990; Belmont-Jégu *et al.*, 2004; Centeno *et al.*, 2004; Cohen & Kohn, 2005; Tavares-Dias *et al.*, 2006; Dias *et al.*, 2015a). However, *A. spatulatus* is considered to be the main gill ectoparasite on cachama cultivated in LAC (Conroy & Conroy, 1998; Torres *et al.*, 2002b; Dias *et al.*, 2015a), being able to reach prevalence values of 98–100% in outbreaks in cultured cachama (Aragort, 1994; Torres *et al.*, 2002b). Moreover, *A. spatulatus* and *L. brinkmanni* have also been recorded in the gills of cachama reared in Peru (Conroy, 2001) and Venezuela (Mujica, 1982; Urquia, 1997), causing high mortality in both juveniles and adults (Mujica & Armas de Conroy, 1985; Urquia, 1997). Furthermore, Centeno *et al.* (2004) also reported *A. spatulatus* in the gills of the hybrid 'cachama' × 'morocoto' (*C. macropomum* × *Piaractus brachypomus*), with prevalence rates of above 70%. Likewise, Silva *et al.* (2013) and Dias *et al.* (2015a) investigated the parasitic fauna infesting the hybrid tambacu (*C. macropomum* × *P. mesopotamicus*) and tambatinga (*C. macropomum* × *P. brachypomus*) at fish farms in northern Brazil. Silva *et al.* (2013) reported prevalences above 77% for *A. spatulatus*, *N. janauachensis* and *Mymarothecium viatorum* in tambacu. Dias *et al.* (2015a) found infections by *L. brinkmanni* and *M. boegeri* in tambatinga. With respect to the histological lesions caused by these monogeneans in the gills of *C. macropomum*, Aragort *et al.* (2002) found that the affected fish showed a significant reduction in haematocrit counts and severe hyperplasia associated with mixed infections of *A. spatulatus* and *L. brinkmanni*. Similarly, Mujica (1982) reported that the main histological alterations caused by *L. brinkmanni* in the gill tissues of cachama were severe hyperplasia and hypertrophy.

With respect to digeneans, Paramphistomidae such as *Dadaytrema oxycephala* have been reported as parasites of cachama (Conroy, 1999). Regarding nematodes, Mujica (1982) reported *Chabaudinema americana* in the gut of *C. macropomum* broodstock kept in tanks in Venezuela. *Cucullanus colossomi*, *Procamallanus inopinatus* (Nematoda), Proteocephalidae larvae (Cestoda) and *Neoechinorhynchus buttnerae* (Acanthocephala) have been reported by Silva *et al.* (2013) and Dias *et al.* (2015a) from the hybrids tambacu and tambatinga in fish farms in Brazil.

Channel catfish, *I. punctatus*, is one of the most important fish species under intensive culture in LAC. In Mexico, the production of cultured channel catfish in 2008 was 970 tonnes (Comisión Nacional de Acuacultura y Pesca, 2008). However, there are few studies about the helminth species affecting the production of channel catfish (Rábago-Castro, 2010; Rábago-Castro *et al.*, 2011; Galaviz-Silva *et al.*, 2013; Benavides-González *et al.*, 2014). Recently, Galaviz-Silva *et al.* (2013) provided new data on the prevalence and abundance of the parasitic fauna on *I. punctatus* in Mexico. These authors demonstrated a great diversity

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Table 4. Helminth species recorded from freshwater native fish species farmed in Latin America. G = groups of parasites, as follows: M = Monogenea, D = Digenea, N = Nematode, C = Cestode, A = Acanthocephala, H = Hirudinea.

Fish/Parasite species	G	Geographical location	References
Cachama *Colossoma macropomum*			
Anacanthorus spatulatus	M	Brazil	Tavares-Dias *et al.*, 2006
		Perú	Conroy, 2001
		Venezuela	Mujica & Armas de Conroy, 1985; Aragort, 1994; Torres *et al.*, 2002b, Centeno & Silva, 2002; Centeno *et al.*, 2004
A. penilabiatus	M	Brazil	Pamplona-Basilio *et al.*, 2001
Dactylogyrus sp.	M	Brazil	Ceccarelli *et al.*, 1990
		Colombia	Eslava-Mocha *et al.*, 2001
Linguadactyloides brinkmanni	M	Brazil	Ceccarelli *et al.*, 1990
		Perú	Conroy, 2001
		Venezuela	Mujica, 1982; Mujica & Armas de Conroy, 1985, Aragort, 1994; Aragort *et al.*, 2002; Centeno & Silva, 2002
Mymarothecium boegeri	M	Brazil	Cohen & Kohn, 2005
Notozothecium janauachensis	M	Brazil	Belmont-Jégu *et al.*, 2004
Dadaytrema oxycephala	D	Venezuela	Conroy, 1999
Chabaudinema americana	N	Venezuela	Mujica, 1982
Cucullanus colossomi	N	Venezuela	Conroy, 1999; Centeno *et al.*, 2006
Goezia spinulosa	N	Venezuela	Conroy, 1999; Centeno *et al.*, 2006
Monhysterides iheringi	N	Venezuela	Conroy, 1999, Centeno *et al.*, 2006
Rondonia rondoni	N	Venezuela	Conroy, 1999; Centeno *et al.*, 2006
Spectatus spectatus	N	Venezuela	Conroy, 1999, Centeno *et al.*, 2006
Spirocamallanus sp.	N	Venezuela	Conroy, 1999; Centeno *et al.*, 2006
Neoechinorhynchus buttnerae	A	Brazil	Varella *et al.*, 2003
Channel catfish *Ictalurus punctatus*			
Cleidodiscus floridanus	M	México	Jiménez-Guzmán *et al.*, 1988; Flores-Crespo & Flores-Crespo, 2003
Dactylogyrus extensus	M	México	Salgado-Maldonado & Rubio-Godoy, 2014
Dactylogyrus sp.	M	México	Flores-Crespo & Flores-Crespo, 2003
Gyrodactylus sp.	M	México	Flores-Crespo & Flores-Crespo, 1993; Flores-Crespo & Flores-Crespo, 2003
Ligictaluridus floridanus	M	México	Rábago-Castro *et al.*, 2011; Galaviz-Silva *et al.* 2013; Benavides-González *et al.*, 2014; Salgado-Maldonado & Rubio-Godoy, 2014
Centrocestus formosanus	D	México	Scholz & Salgado-Maldonado, 2000; Rábago-Castro, 2010; Galaviz-Silva *et al.*, 2013
Diplostomum compactum	D	México	Galaviz-Silva *et al.*, 2013
Megalogonia ictaluri	D	México	Galaviz-Silva *et al.*, 2013
Corallobothrium fimbriatum	C	México	Galaviz-Silva *et al.*, 2013
Corallobothrium sp.	C	México	Rábago-Castro, 2010
Spinitectus tabascoensis	N	México	Galaviz-Silva *et al.*, 2013
Spiroxys sp.	N	México	Galaviz-Silva *et al.*, 2013
Silver catfish *Rhamdia quelen*			
Dactylogyrus sp.	M	Uruguay	Carnevia, 2002, 2003
Clinostomum complanatum	D	Brazil	Vianna *et al.*, 2005; Silva *et al.*, 2008, 2009; Lima *et al.*, 2013
Clinostomum sp.	D	Uruguay	Carnevia, 2003
Ligictaluridus floridanus	M	México	Benavides-González *et al.*, 2014
Proteocephalus bagri	C	Uruguay	Carnevia, 2002, 2003
Proteocephalus rhamdiae	C	Uruguay	Carnevia, 2002, 2003
Mayan cichlid *Cichlasoma urophthalmus*			
Cichlidogyrus sclerosus	M	México	Salgado-Maldonado & Rubio-Godoy, 2014
Sciadicleithrum mexicanum	M	México	Vidal-Martínez *et al.*, 1998
Centrocestus formosanus	D	México	Salgado-Maldonado & Rubio-Godoy, 2014
Echinochasmus leopoldinae	D	México	Vidal-Martínez *et al.*, 1998
Oligogonotylus manteri	D	México	Vidal-Martínez *et al.*, 1998
Bothriocephalus acheilognathi	C	México	Salgado-Maldonado & Rubio-Godoy, 2014
Contracaecum multipapillatum	N	México	Vidal-Martínez *et al.*, 1998
Mexiconema cichlasomae	N	México	Vidal-Martínez *et al.*, 1998
Bay snook *Petenia splendida*			
Cichlidogyrus sp.	M	México	DOF, 2013
Diplostomum sp.	D	México	DOF, 2013
Haplorchis pumilio	D	México	Salgado-Maldonado & Rubio-Godoy, 2014
Bothriocephalus acheilognathi	C	México	Salgado-Maldonado & Rubio-Godoy, 2014
Contracaecum spp.	N	México	DOF, 2013
Gnathostoma sp.	N	México	DOF, 2013

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Table 4. (*Cont.*)

Fish/Parasite species	G	Geographical location	References
Fat snook *Centropomus parallelus* and common snooks *Centropomus undecimalis*			
Rhabdosynochus hudsoni	M	Brazil	Tancredo *et al.*, 2015
R. rhabdosynochus	M	Brazil	Tancredo *et al.*, 2015
Acanthocollaritrema umbilicatum	D	Brazil	Tancredo *et al.*, 2015
Pacu *Piaractus mesopotamicus*			
Anacanthorus penilabiatus	M	Brazil	Martins & Romero, 1996; Martins, 1998; Tavares-Dias *et al.*, 2001; Martins *et al.*, 2002; Cohen & Kohn, 2005; Lizama *et al.*, 2007b; Franceschini *et al.*, 2013
A. spatulatus	M	Brazil	Lizama *et al.*, 2007b
Dactylogyrus sp.	M	Brazil	Ceccarelli *et al.*, 1990
		Colombia	Eslava-Mocha *et al.*, 2001
Linguadactyloides brinkmanni	M	Brazil	Boeger *et al.*, 1995
		Perú	Conroy, 2001
Mymarothecium viatorum	M	Brazil	Ceccarelli *et al.*, 1990
Mymarothecium sp.	M	Brazil	Lizama *et al.*, 2007b
Dadaytrema oxycephala	D	Brazil	Ceccarelli *et al.*, 1990
Chabaudinema americana	N	Venezuela	Centeno *et al.*, 2006
Rondonia rondoni	N	Brazil	Ceccarelli *et al.*, 1990
Metechinorhynchus jucundus	A	Brazil	Ceccarelli *et al.*, 1990
Silverside *Odontesthes bonariensis*			
Diplostomum mordax	D	Uruguay	Szidat, 1969
Heterophyidae (metacercariae)	D	Uruguay	Szidat, 1969
Pirarucu *Arapaima gigas*			
Dawestrema cycloancistrium	M	Brazil	Araújo *et al.*, 2009a, b; Marinho, 2013; Marinho *et al.*, 2013, 2015
		Perú	Mathews *et al.*, 2007; Mathews *et al.*, 2013; Serrano-Martínez *et al.*, 2015
Dawestrema cycloancistrioides	M	Brazil	Araújo *et al.*, 2009a; Marinho *et al.*, 2013; Marinho *et al.*, 2013, 2015
		Perú	Serrano-Martínez *et al.*, 2015
Caballerotrema brasiliense	D	Perú	Serrano-Martínez *et al.*, 2015
Schizochoerus liguloides	C	Perú	Serrano-Martínez *et al.*, 2015
Camallanus tridentatus	N	Brazil	Araújo *et al.*, 2009a, b
Capillostrongyloides arapaimae	N	Brazil	Portes-Santos *et al.*, 2008
Eustrongylides sp.	N	Brazil	Portes-Santos & Moravec, 2009a, b
Goezia spinulosa	N	Brazil	Araújo *et al.*, 2009a, b; Portes-Santos & Moravec, 2009a, b
Nilonema senticosum	N	Brazil	Portes-Santos & Moravec, 2009a, b
		Perú	Serrano-Martínez *et al.*, 2015
Rumai rumai	N	Brazil	Portes-Santos & Moravec, 2009a, b
Terranova serrata	N	Brazil	Araújo *et al.*, 2009a, b
Polyacanthorhynchus macrorhynchus	A	Brazil	Marinho, 2013; Marinho *et al.*, 2013, 2015
Bocachico *Prochilodus magdalenae*			
Dactylogyrus sp.	M	Colombia	Eslava-Mocha *et al.*, 2001
Tetraonchus sp.	M	Colombia	López-González, 1987
Calocladorchis ventrastomis	D	Colombia	Thatcher, 1993
Diplostomum sp.	D	Colombia	Chavarro, 1983
Lecithobotrioides mediacanoensis	D	Colombia	Thatcher & Dossman, 1974; Thatcher, 1993; Álvarez-León, 2007
Sacocoelios sp.	D	Colombia	Thatcher, 1993; Álvarez-León, 2007
Unicoeliun prochilodorum	D	Colombia	Thatcher & Dossman, 1974; Thatcher, 1993
Procamallanus sp.	N	Colombia	Thatcher, 1993
Raphidascaris sp.	N	Colombia	Sánchez-Páez, 1993
Spinitectus jamundensis	N	Colombia	Thatcher, 1993

of helminth parasites, including *Ligictaluridus floridanus* and *Corallobothrium fimbriatum*, and new locality records for *Megalogonia ictaluri*, *Centrocestus formosanus*, *Diplostomum compactum* and *Spiroxys* sp. They also reported a new host and distribution record for *Spinitectus tabascoensis*, originally described from *Ictalurus furcatus* from Tabasco, southern Mexico. In total, 12 helminth species have been reported from *I. punctatus* (Jiménez-Guzmán *et al.*, 1988; Flores-Crespo & Flores-Crespo, 1993, 2003; Scholz & Salgado-Maldonado, 2000; Rábago-Castro, 2010; Rábago-Castro *et al.*, 2011; Galaviz-Silva *et al.*, 2013; Benavides-González *et al.*, 2014; Salgado-Maldonado & Rubio-Godoy, 2014). Rábago-Castro *et al.* (2011) reported, for first time, the prevalence and mean

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intensitiesy of ectoparasites of cage-cultured channel catfish in an annual cycle. The results showed peaks of prevalence of *L. floridanus* in early autumn. However, the presence of *L. floridanus* was not associated with any fish mortality. In contrast, Benavides-González *et al.* (2014) showed that the gill monogenean *L. floridanus* is the most common parasite of cultured channel catfish, affecting fish growth and possibly promoting secondary infections.

With the exception of the papers of Vidal-Martínez *et al.* (1998), there are no records of parasites or diseases of *C. urophthalmus* under aquaculture conditions in Mexico. Vidal-Martínez *et al.* (1998) showed that the parasites that colonized caged *C. urophthalmus* were species with an active colonization strategy. This was the case for the monogenean *Sciadicleithrum mexicanum*, the larval digeneans *Echinochasmus leopoldinae* and *Oligogonotylus manteri*, and the nematodes *Mexiconema cichlasomae* and *Contracaecum multipapillatum*. Of these parasites, the most relevant for aquaculture is the monogenean *S. mexicanum*, due to its direct life cycle. This monogenean is also able to infect the Nile tilapia *O. niloticus* under experimental conditions (Jiménez-García *et al.*, 2001).

For bay snook *P. splendida*, the official statistics suggest the presence of several parasite species, such as *Cichlidogyrus* sp., *Contracaecum* spp., *Diplostomum* sp. and *Gnathostoma* sp. (DOF, 2013), the last being an emerging public health problem in Mexico, with several thousand cases reported (Herman & Chiodini, 2009; Diaz, 2015). However, these records need to be re-examined. For example, *Cichlidogyrus* is a very specific monogenean genus of African cichlids (e.g. tilapia). If the identification is correct, then this would be a new record of an African monogenean infecting a native Mexican cichlid fish. Therefore, we consider it necessary to evaluate further the parasitological material deposited in proper museum collections. Recently, Tancredo *et al.* (2015) investigated the metazoan parasite fauna of *C. parallelus* and *C. undecimalis*, bred in southern Brazil, and its influence on the condition factor of hosts. The monogeneans *Rhabdosynochus rhabdosynochus* and *Rhabdosynochus hudsoni* were recorded in the gills of both species, and the digenean *Acanthocollaritrema umbilicatum* was reported from their digestive tracts. Prevalence of *Rhabdosynochus* spp. was high (100%) in both species. In contrast, mean intensity and abundance were higher in *C. parallelus*. A negative correlation was found between monogenean abundance and condition factor in *C. parallelus*, suggesting that gill monogeneans do alter fish welfare. There was no correlation between abundance of *A. umbilicatum* and length or weight of either *C. parallelus* or *C. undecimalis*.

Piaractus mesopotamicus is cultured in several countries in LAC, including Brazil (Lizama *et al.*, 2007b). In Argentina, native pacu covers at least 30% of the domestic market demands (Macchi, 2004). Several species of monogeneans (*Anacanthorus penilabiatus*, *A. spatulatus*, *L. brinkmanni*, *Mymarothecium viatorum*, *Dactylogyrus* sp.) have been reported in aquaculture conditions (Ceccarelli *et al.*, 1990; Boeger *et al.*, 1995; Martins, 1998; Conroy, 2001; Tavares-Dias *et al.*, 2001; Martins *et al.*, 2002; Cohen & Kohn, 2005; Lizama *et al.*, 2007b). However, *A. penilabiatus* and *A. spatulatus* have been registered as the most important gill parasites in the aquaculture of *P. mesopotamicus* in Bolivia, Cuba, Peru, Venezuela and Brazil (Conroy & Conroy, 1998; Del Pozo, 2000; Tavares-Dias *et al.*, 2001). With respect to the histopathological damage caused by *A. penilabiatus* in cultured *P. mesopotamicus*, Martins & Romero (1996) found an inflammatory reaction and moderate hyperplasia of epithelial cells in the gills. In the same study, the authors pointed out that the damage produced by this monogenean was not extensive in low to moderate infections (<33 parasites/host). However, in heavy infections (>33 parasites/host) the parasite caused considerable changes in primary and secondary lamellae, associated with multiple sites of bleeding, detachment of respiratory tissue and numerous necrotic foci. Lizama *et al.* (2007b) also showed a negative correlation between the abundance of *A. penilabiatus* and the condition factor of farmed *P. mesopotamicus* in Brazil.

Knowledge on the helminth parasites infecting *A. gigas* under aquaculture conditions is scarce. Recently, Marinho *et al.* (2013) found in Brazil that the host condition factor was negatively correlated with the number of *Dawestrema cycloancistrium* and *Dawestrema cycloancistrioides*, which demonstrates the pathogenicity of these parasites in gills of farmed *A. gigas*. Araújo *et al.* (2009a, b) and Mathews *et al.* (2013) recorded the infection by *D. cycloancistrium* and *D. cycloancistrioides* as the most prevalent helminths parasitizing cultured *A. gigas* (100% and 85%, respectively). Aquaria, a specialized variant of aquaculture enterprises, have serious problems due to monogenean infections in *A. gigas* in LAC. This fish species experiences severe morbidity and heavy mortality due to *D. cycloancistrium* (Mathews *et al.*, 2007) in aquaria. In addition, infections by the nematodes *Goezia spinulosa* (Caldas-Menezes *et al.*, 2011), *Terranova serrata* and *Camallanus tridentatus* have also been reported from *A. gigas* in aquaria (Araújo *et al.*, 2009a, b). However, with the exception of monogeneans, the nematodes will eventually be lost in aquaria if the intermediate hosts needed to complete the life cycle are not present. A single report exists of the digenean *Caballerotrema brasiliense* in *A. gigas* from farms of the Peruvian Amazon (Serrano-Martínez *et al.*, 2015).

The bocachico, *P. magdalenae*, is a native of Colombia's Magdalena region and the fourth most frequently cultivated species in Colombia. This fish has been cultivated for several years in ponds (Sarmiento & Rodríguez, 2013), and several helminth species have been recorded infesting farmed *P. magdalenae*, including *Dactylogyrus* sp., *Tetraonchus* sp., *Calocladorchis ventrastomis*, *Diplostomum* sp., *Lecithobotrioides mediacanoensis*, *Sacocoelios* sp., *Unicoeliun prochilodorum*, *Procamallanus* sp., *Raphidascaris* sp. and *Spinitectus jamundensis* (Nickol & Thatcher, 1971; Thatcher & Dossman, 1974, 1975; Thatcher & Padilha, 1977; Chavarro, 1983; López-González, 1987; Sánchez-Páez, 1993; Thatcher, 1993; Eslava-Mocha *et al.*, 2001; Álvarez-León, 2007). However, so far, there are apparently no specific records of diseases caused by helminths in cultivated bocachicos.

Mariculture enterprises may also be hampered by severe parasitic helminth infections. Table 5 presents the helminth species recorded from native seawater species farmed in Latin America.

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Table 5. Helminth species recorded from seawater native fish species farmed in Latin America. Groups of parasites (G) were as follows: M = Monogenea, D = Digenea, N = Nematode, C = Cestode, A = Acanthocephala.

Fish/Parasite species	G	Geographical location	Reference
Pacific bluefin tuna *Thunnus thynnus*			
Anisakis spp.	N	México	Sánchez-Serrano & Cásares-Martínez, 2011
Acanthocephala (Polymorphidae)	A	México	Sánchez-Serrano & Cásares-Martínez, 2011
Koellikeriinae	D	México	Sánchez-Serrano & Cásares-Martínez, 2011
Nephrodidymotrematinae	D	México	Sánchez-Serrano & Cásares-Martínez, 2011
Yellowtail kingfish *Seriola lalandi*			
Benedenia seriolae	M	México	Avilés-Quevedo & Castello-Orvay, 2004
		Chile	Oliva, 1986
Zeuxapta seriolae	M	México	Avilés-Quevedo & Castello-Orvay, 2004
		Chile	Oliva, 1986
Spotted red snapper *Lutjanus guttatus*			
Euryhaliotrema mehen	M	México	Soler-Jiménez *et al.*, 2015
E. perezponcei	M	México	Soler-Jiménez *et al.*, 2015
Haliotrematoides guttati	M	México	Soler-Jiménez *et al.*, 2015
Snowy grouper *Epinephelus niveatus*			
Pseudorhabdosynochus sp.	M	Brazil	Santos *et al.*, 2000

Marine aquaculture of bluefin tuna is based on fattening wild juveniles. Consequently, it makes sense to consider the parasites and diseases that these juveniles bring into floating cages. Sánchez-Serrano & Cásares-Martínez (2011) reported nematodes of the genus *Anisakis* spp., trematodes of the subfamilies Nephrodidymotrematinae and Koellikeriinae, and acanthocephalans of the family Polymorphidae. The nematodes of the *Anisakis* genus are accidental parasites of humans, producing the disease known as anisakiasis. Consequently, sanitary measures should be adopted to avoid the presence of these parasites in tuna fillets. In the case of caged yellowtail (*Seriola lalandi*) in Mexico, the infections by the monogeneans *Benedenia* sp. and *Heteraxine* sp. are considered important because they produce decreases in feeding rate, anaemia, weakness and mortality (Avilés-Quevedo & Castello-Orvay, 2004). In Chile, *S. lalandi* is one of the most important candidates for commercial aquaculture. In sea cages in northern Chile, *S. lalandi* is parasitized by the monogenean *Benedenia seriolae* (Capsalidae) on the body surface and by *Zeuxapta seriolae* (Heteraxinidae) as a sanguineous gill fluke (Oliva, 1986).

In official statistics, *Neobenedenia* has been reported infecting *Lutjanus guttatus* in aquaculture conditions in Mexico (DOF, 2013). However, we found no published records on this parasitic association. Other ectoparasites reported infecting *L. guttatus* in floating cages in Mexico were the monogeneans *Euryhaliotrema perezponcei*, *Euryhaliotrema mehen* and *Haliotrematoides guttati* (Soler-Jiménez *et al.*, 2015). The authors stressed that even under the juvenile fish densities studied (789/m^3) no mortality was found, and a high number of *E. perezponcei* was reached (prevalence = 100%; mean intensity = 154–296 parasites per infected host) during 9 months of exposure. The authors concluded that the infection should be monitored over time to prevent outbreaks and mortality, especially under intensive aquaculture conditions. In fact, sublethal effects of the dactylogyrid monogeneans infecting cultured *L. guttatus* should also be considered carefully, since Del Río-Zaragoza *et al.* (2010) found that a high level of infection (≥100 monogeneans per fish) caused changes in the number of blood cells and histological alterations in gill tissue.

Cultured ornamental species

Ornamental fish export has emerged as an important activity, generating foreign exchange, for several Latin American countries (e.g. Brazil, Colombia, Mexico, Peru and Uruguay) (Carnevia, 1999; Carnevia & Speranza, 2003; Tavares-Dias *et al.*, 2009a). For example, from 2006 to 2007 the revenue of the south-east region of Brazil included US$418,572 from sales of freshwater ornamental fish. In 2007, sales of freshwater ornamental fish increased 100% (Tavares-Dias *et al.*, 2009a). However, most of the income came from sales of ornamental fish captured from natural environments (principally the Amazonian basin) and only a small amount was generated from sales of fish from fish farms. Despite this, the demand for cultured ornamental fish is increasing, and consequently parasitic infections can be one of the most important problems for cultured fish in the region. However, few studies regarding parasitic infection of cultured ornamental fish have been published for LAC. Piazza *et al.* (2006), Martins *et al.* (2007) and Tavares-Dias *et al.* (2009a) recorded high prevalence rates of metazoan parasites, such as monogeneans and nematodes, from cultured ornamental fish farms or pet shops in Brazil. In table 6 we present the helminth species recorded from cultured ornamental fish in LAC.

Ornamental fish in intensive culture are continuously affected by management practices such as handling, crowding, transport and poor water quality that provoke stress to fish, rendering them susceptible to a variety of parasites. For LAC, there are several records of helminths affecting ornamental fish cultivated mainly in Brazil and Mexico. However, there are a few records of catastrophic negative impacts where a helminth is involved as a causative agent. For example, mixed infections by monogeneans such as *Gyrodactylus* sp. and *Dactylogyrus* sp. on gills and skin have been responsible for high mortality

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Table 6. Helminth species recorded from ornamental fish species farmed in Latin America. G = groups of parasites, as follows: M = Monogenea, D = Digenea, N = Nematode, C = Cestode, A = Acanthocephala.

Helminth	G	Host	Locality	Reference
Dactylogyrus sp.	M	*Symphysodon discus*, *Carassius auratus*	Brazil	Dambros, 2007
			Colombia	Noreña-Serna, 1981; Ajiaco-Martinez and Ramirez-Gil, no date
			México	Pers. Obs.
			Perú	Gonzáles-Fernández, 2012b
			Uruguay	Carnevia, 1999; Carnevia & Speranza, 2003
Gyrodactylus gemini	M	*Semaprochilodus insignis*	Brazil	Silva *et al.*, 2011
Gyrodactylus sp.	M	*Carassius auratus*, *Paracheirodon axelrodi*, *Poecilia sphenops*, *Poecilia latipinna*, *Xiphophorus variatus*	Colombia	Noreña-Serna, 1981; Guinard-Voelkl & Morales-Morales, 1990; Ajiaco-Martinez and Ramirez-Gil, no date
			Uruguay	Carnevia, 1999; Carnevia & Speranza, 2003
			México	FAO, 2016; Pers. obs.
			Perú	Gonzáles-Fernández, 2012b
			Brazil	Tavares-Dias *et al.*, 2009b
Urocleidoides sp.	M	*Xiphophorus* sp.	Brazil	García *et al.*, 2003
Monogenean species	M	*Beta splendens*, *Carassius auratus*, *Gymnocorymbus ternetzi*, *Poecilia sphenops*, *Pterophyllum scalare*, *Xiphophorus helleri*, *Xiphophorus maculatus*	Brazil	Piazza *et al.*, 2006, Tavares-Dias, 2009b
Ascocotyle sp. (metacercaria)	T	*Beta splendens*, *Gymnocorymbus ternetzi*, *Xiphophorus helleri*, *Xiphophorus maculatus*	Brazil	Piazza *et al.*, 2006
Centrocestus formosanus	T	*Carassius auratus*, *Carassius* spp., *Poecilia sphenops*, *Poecilia reticulata*, *Xiphophorus maculatus*, *Xiphophorus helleri*, *Danio rerio*, *Hypostomus plecostomus*, *Trichogaster trichopterus*, *Cichlasoma nigrofasciatum*, *Nimbochromis venustus*	México	Salgado-Maldonado *et al.*, 1995; Scholz & Salgado-Maldonado, 2000; Ortega *et al.*, 2009; Hernández-Ocampo *et al.*, 2012; FAO, 2016; Pers. obs.
Clinostomum marginatum	T	*Pterophyllum escalare*	Brazil	Alves *et al.*, 2001
Diplostomum sp.	T	–	Colombia	Ajiaco-Martinez and Ramirez-Gil, no date
Haplorchis pumilio	T	*Carassius auratus*	México	Pers. obs.
		Rivulus harti	Venezuela	Tavares-Dias *et al.*, 2008
Uvulifer sp.	T	–	Colombia	Ajiaco-Martinez and Ramirez-Gil, no date
Camallanus cotti	N	*Poecilia reticulata*, *Beta splendes*	Brazil	Alves *et al.*, 2000, Menezes *et al.*, 2006
C. maculatus	N	*Poecilia sphenops*, *Xiphophorus maculatus*	Brazil	Piazza *et al.*, 2006; Martins *et al.*, 2007
Camallanus sp.	N	*Xiphophorus maculatus*	Mexico	FAO, 2016
Capillaria sp.	N	*Pterophyllum escalare*	Brazil	Fujimoto *et al.*, 2006
Procamallanus inopinatus	N	*Semaprochilodus insignis*	Brazil	Silva *et al.*, 2011
Procamallanus sp.	N	*Discus* sp., *Paracheirodon axelrodi*	Argentina	Tanzola *et al.*, 2009
		Paracheirodon axelrodi	Brazil	Tavares-Dias *et al.*, 2009b
Cestode species	C	*Puntius conchonius*, *Xiphophorus helleri*, *Xiphophorus maculatus*	Brazil	Piazza *et al.*, 2006

rates (60–70%) within a few days among golden carp, *Carassius auratus*, in aquarium fish in Peru (Gonzáles-Fernández, 2012b). In this case, the pathology described was increased mucus in the gills, as well as a strong detachment of the epidermis and the loss of the caudal fin. Likewise, in Brazil, Alves *et al.* (2000) reported high mortalities of *Poecilia reticulata* in fish farms due to infection with the nematode *Camallanus cotti*. This mortality was due to the pathology caused by *C. cotti*, with haemorrhage, congestion, oedema and extensive areas of eroded mucosa in the intestine and rectum (Menezes *et al.*, 2006). Ortega *et al.* (2009) found gill infections by *Centrocestus formosanus* metacercarie in 11 out of 25 species of ornamental fish cultured in Mexico, where the most affected species was goldfish, *C. auratus*. The negative effect of *C. formosanus* on farmed fish was confirmed in moribund individuals that manifested respiratory abnormality and, histologically, showed severe branchial lesions caused by metacercariae (Ortega *et al.*, 2009). These authors stressed the low host specificity of *C. formosanus*, which is the main reason for a great variety of fish being infected with different degrees of prevalence and severity (Scholz & Salgado-Maldonado, 2000; Vidal-Martínez *et al.*, 2001).

Discussion

The present contribution shows that more than 90% of the helminth parasites affecting finfish in aquaculture conditions in LAC are non-native. For example, 40 species of helminths have been introduced to Mexico, among which 33 are monogeneans (Salgado-Maldonado & Rubio-Godoy, 2014). This means that most of these helminths have been introduced with their hosts by commercial trade, suggesting an almost complete lack of application of biosecurity measures in LAC countries.

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However, there is a general trend among the aquaculture farm owners of the region to consider helminth parasites as non-pathogenic, because many of them do not produce significant mortalities or visible pathologies. The authors consider that this assumption is a mistake because helminth parasites can become harmful under the challenging environmental circumstances typical of fish farms (e.g. high temperature and productivity, low water exchange rate and high fish density) (Paredes-Trujillo *et al.*, 2016a). This is especially true for monogeneans, which are recognized as the most common, abundant and aggressive helminths affecting farmed fish (Whittington *et al.*, 2001; Ernst *et al.*, 2002; Whittington, 2005; Soler-Jiménez *et al.*, 2015).

In LAC, there are several anecdotal reports of high mortalities of farmed fish caused by helminths, especially monogeneans, representing severe economic losses (Mujica & Armas de Conroy, 1985; Kaneko *et al.*, 1988; Conroy, 2001; García-Vásquez *et al.*, 2011). For example, infections with *C. sclerosus* have important effects on the growth rates and relative condition factors of their hosts, which in turn affects tilapia farmers economically (Sandoval-Gío *et al.*, 2008; Le Roux, 2010; Paredes-Trujillo *et al.*, 2016a). Moreover, other helminth species, such as the 'yellow grub', are argued to produce economic losses due to the poor appearance that they produce in farmed fish (Mitchell *et al.*, 2002; Pavanelli *et al.*, 2002; Vianna *et al.*, 2005; Silva *et al.*, 2008; Sutili *et al.*, 2014). Unfortunately, none of these studies has included a bioeconomic analysis to determine the financial resources lost due to the presence of helminths in fish cultured in LAC. Such analyses are urgently needed.

It is difficult to calculate the economic costs attributable to helminth infections due to the complex interplay of numerous environmental and management factors that vary among individual fish farms at the global level. Similar concerns have been expressed by Shinn *et al.* (2015) with respect to salmonid diseases in temperate latitudes, and complexity is even more extreme in LAC, partly due to the reluctance of the farm owners to share information on the causes of fish mortality. As a notable exception, Paredes-Trujillo *et al.* (2016b) were able to obtain information on the mortality, environmental and management variables of 21 tilapia farms in Yucatan, Mexico, thanks to the kind collaboration of their owners. Using this dataset, a multivariate regression analysis was undertaken using the percentage of mortality as a dependent variable and 12 environmental and management variables (out of 45 variables), including the abundance of all the parasite species found per individual fish as an independent variable (table 7). The results of this analysis suggest that helminths can contribute to fish mortality, but only in synergy with other environmental and management variables. For the 21 tilapia farms in Yucatan, the mean percentage of mortality (± standard deviation) due to all those variables (including abundance of helminths) was 36 ± 43% (table 7). Considering the price of a kilogram of whole tilapia, between US$3 and 5 (https://www.alibaba.com/products/F0/tilapia_wholesale_price), the economic cost produced by mortality was between US$7821 ± 21,991 and US$13,034 ± 36,652 per year per farm. When an analysis was made considering only the effects of helminth parasites on fish mortality, the result was not significant (ANOVA with linear regression; $F_{1,396} = 0.76$; $P = 0.49$). However, it is still possible that helminth parasites do not kill the fish, but that they produce a subtle and important debilitating effect on the condition factor of the tilapia at farms in Yucatan (Paredes-Trujillo *et al.*, 2016b). This generalized debilitation should be considered as part of the synergy mentioned above. The authors were not able to obtain datasets for salmonids or carp, similar to the one for tilapia, to quantify the economic cost of helminth infections. However, it is considered that the tilapia farms in Yucatan are a good model when trying to understand the sanitary circumstances of finfish aquaculture in LAC, with the results obtained here applying to rural areas of most countries where tilapia and other freshwater or marine fishes are farmed. The reason for the large values of the standard deviation of the percentage of mortality is associated with the fact that LAC farmers often lack the technical expertise in proper sanitary management at farm level. Very often, when disease occurs in the farm, chemotherapeutic treatments are applied, without strict dose control. However, the most important side-effects of the use and misapplication of chemical products (e.g. antibiotics, disinfectants) are microbial and parasite resistance, chemical toxicity and persistence of chemical residues (Chávez-Sánchez & Montoya-Rodríguez, 2004). Without a doubt, aquaculture in LAC needs appropriate biosecurity measures, including risk analysis, surveillance and monitoring, as well as planning to respond effectively to outbreaks of diseases in aquatic animals (Bondad-Reantaso *et al.*, 2005). To reach this level of development in LAC, basic and applied research on specific sanitary problems of farmed aquatic animals is necessary, as well as institutional strengthening and human resource development (good extension programmes, education for both aquaculture farm owners and technicians, as well as training for aquatic animal health experts).

Therefore, preventive and control measures should be implemented to limit the size of the helminth populations in cultured fish and to minimize the probability of potential diseases. A successful helminth control programme consists of the selection of fish free of helminth parasites from the place of origin, proper quarantine, good husbandry practices, prophylactic measures, correct diagnosis and, if necessary, therapeutic treatment (Abayomi *et al.*, 2013). Preventive measures in fish parasite control (including helminths), such as effective quarantine, are often ignored, resulting in a much higher economic expenditure to eliminate imported pathogenic parasites. It must be emphasized that prevention is the key and therapeutic treatment should be seen as the last alternative.

Nowadays, avoiding the entry of new helminth species to the region is one of the main challenges that aquaculture is facing in LAC. This is a very important topic because, in the same way that viral diseases have been translocated into LAC (e.g. white spot in shrimps in Mexico and infectious salmon anaemia (ISA) in salmonid fishes in Chile) (http://www.oie.int/en/), other harmful helminth parasites could be translocated into LAC. Unfortunately, it must be recognized that surveillance programmes for aquatic diseases in many LAC regions are weak. In addition, their implementation presents many problems: (1) the lack of standardization of diagnostic tests; (2) socio-economic factors and the lack of technological development in many regions in LAC; (3)

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Table 7. Multivariate regression analysis using the percentage of mortality as a dependent variable, and the best 12 environmental and management independent variables (out of 45 variables) (see supplementary table S1) selected by a stepwise procedure. The coefficient of determination of this model was $R^2 = 0.71$ for $N = 399$. The best regression model was chosen based on the lowest values of the CpMallows (model selection method) and variance inflation factor (VIF) statistics. The maximum P value for each variable to entry the model was 0.01, and the maximum value for retention of the variable was 0.05. The normality of all variables was verified using Wilk–Shapiro rankit plots (WS), and if normality was not attained (WS > 0.8), then the variables were transformed to natural logarithms + 1.

Coefficient	Estimate	Std Error	Lower limit (95%)	Upper limit (95%)	T statistic	P value	CpMallows	VIF
Constant	47.96	29.30	−9.64	105.56	1.64	0.1024		
Closeness of human communities to the farm (km)	36.86	2.80	31.37	42.36	13.18	<0.0001	185.35	1.48
Ln (Age of organisms) + 1 (weeks)	−51.93	4.96	−61.68	−42.18	−10.47	<0.0001	121.42	2.16
Salinity (psu)	6.59	3.93	48.87	64.32	14.41	<0.0001	219.10	2.81
Temperature (°C)	4.29	0.79	2.73	5.86	5.41	<0.0001	41.18	3.31
Presence of vectors (e.g. dogs, birds, turtles, other fish species)	7.98	1.08	5.86	10.11	7.39	<0.0001	66.41	1.35
Drug use for therapeutic treatments	−9.42	1.28	−11.95	−6.90	−7.34	<0.0001	65.81	2.11
Ln (Temperature * *C. sclerosus*) + 1	−2.63	0.82	−4.23	−1.02	−3.21	0.0014	22.30	1.24
Origin of organisms	13.89	2.91	8.17	19.60	4.78	<0.0001	34.78	2.23
Fish tanks capacity (m^3)	−1.24	0.55	−2.32	−0.16	−2.25	0.0247	17.07	2.21
Number of workers per farm	−22.12	3.60	−29.20	−15.03	−6.14	<0.0001	49.58	2.39
C. sclerosus * NO_3	−2.00	0.60	−3.18	−0.82	−3.34	0.0009	23.14	1.29
Stocking density	−8.07	2.26	−12.51	−3.64	−3.58	0.0004	24.77	1.81

the diversity of cultivated species, range and complexity of the environment; and (4) the intensity of practice, variety of farming systems and management types (Bondad-Reantaso *et al.*, 2005). Moreover, it is important to realize that one of the most important current challenges in LAC is the lack of capacity to diagnose accurately and report diseases in aquatic animals. Vidal-Martínez (2012) reviewed the capacity of countries within LAC to diagnose and report selected World Organization for Animal Health (OIE)-listed diseases of aquatic animals, based on 16 years of data available in the OIE databases. This author found that diagnosis performance and reporting of OIE-listed diseases were significantly associated with aquaculture production in the countries. Three groups of countries were determined. The first group included countries with aquaculture production >200,000 tonnes/year, which had maintained their diagnostic capacities for 15 years (e.g. Brazil, Chile and the USA). The second group included countries with less than 200,000 tonnes of aquaculture production per year, which had maintained their diagnostic capacities for 10–15 years (e.g. Canada, Colombia and Mexico). The third group included countries that had been unable to maintain consistent diagnostic reporting for more than 5 years for OIE diseases (73% of the analysed countries in LAC). Countries in the third group are unprotected against the potential introduction of OIE-listed diseases and other kinds of important helminth parasites in aquaculture. Clearly, there is an urgent need to develop sound biosecurity programmes in these countries, as well as the physical and human capacity to deal with the proper diagnosis of these diseases and parasites (including helminths). Therefore, it is necessary to propose strategies to address transboundary diseases affecting the sector of Latin American aquaculture, including compliance with the international codes established by the World Organisation for Animal Health (OIE, 2015).

Vidal-Martínez (2012) proposed two strategic lines that should be considered for the development of the sanitary aspects of aquaculture in LAC in the near future. First, due to the incipient development of the diagnostic capacity for OIE-listed diseases and helminth parasitic diseases affecting aquaculture in LAC, there is a need for more experts in diseases of fish in the region. The freshwater and marine aquaculture producers need the support of experts, in view of the imminent development of the market in the region (see FAO, 2015). Second, academic institutions throughout the whole region need to be in touch with the producers, to generate the kind of experts needed to warrant the sanitary development of aquaculture in LAC. In addition, awareness at all levels (managers, officers, employees) of the correct application of sanitary measures, is one of the most important challenges that LAC faces to reduce the spread of diseases (FAO, 2016).

Therefore, the importance of health standards, surveillance and monitoring programmes suggested by international organizations (e.g. FAO, OIE) and enforced by national authorities, which guarantee and certify the quality of aquatic products that are distributed inside and outside each country, is evident. While these are not carried out properly, the future of sustainable aquaculture in LAC is uncertain.

Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S0022149X16000833

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Conflict of interest

None.

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