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Invasion note

The Asian fish tapeworm *Bothriocephalus acheilognathi*: a potential threat to native freshwater fish species in Mexico

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Abstract

Introduction of the parasite *Bothriocephalus acheilognathi* Yamaguti, 1934 with the herbivorous carp *Ctenopharyngodon idellus*, and other cyprinids, has been documented in almost every continent, except Antarctica. This study presents the current geographical distribution of this cestode in the freshwater fish of Mexico, highlighting infections in autochthonous and endemic species. It compiles existing information and presents original data. *B. acheilognathi* is widely dispersed among the freshwater fish of Mexico, being recorded to date in 49 fish species from 26 genera, 7 families and 5 orders. *B. acheilognathi* is reported from Mexico for the first time in *Dionda ipni*, *Notropis celayensis*, *Yuriria alta*, *Gambusia vittata*, *Poecilia butleri*, *P. mexicana*, *Poeciliopsis baenschi*, *Poeciliopsis* sp., *Cichlasoma cyanoguttatum* and *C. labridens*. The new hosts identified in this study bring the total number of known host species to 102 in 14 families and 7 orders of freshwater fishes around the world. Given its wide distribution among Mexican freshwater fish species, the abundance of the parasite and its high pathogenicity, parasitological data for *B. acheilognathi* should be considered as an important factor in native fish conservation policies. Biological changes in the freshwater habitats in Mexico caused by the introduction of exotic fish species and their parasites are virtually ubiquitous and extremely difficult to eradicate once established. As such, they should be considered as one of the most serious threats to native fish conservation.

Introduction

Invasions of exotic species of parasites of freshwater fishes, and their impacts on hosts, have been the subject of concern for many decades around the world (Bauer and Stolyarov 1961; Dogiel 1966; Kennedy 1994; Paperna 1996). While no one synthesis is available that summarizes the biogeography and effects of such invasions, several well-known species have now achieved a nearly-cosmopolitan distribution, while showing continued signs of spread (Paperna 1996; Dove 1998; Scholz and Salgado-Maldonado 2001).

We report here on the current status of the Asian fish tapeworm *Bothriocephalus acheilognathi* Yamaguti, 1934 in Mexico. This cestode principally parasitizes carps (Pisces: Cyprinidae). The natural host and geographical origin of this tapeworm is the grass carp *Ctenopharyngodon idellus* of the Amur River (Yamaguti 1934; Bauer et al. 1973; Andrews et al. 1981; Chubb 1981; Paperna 1996). Introduction of infected Asian carps into Europe also exposed *B. acheilognathi* to native European fishes. It has subsequently established itself in cultivated and wild fish around the world as these carp have been introduced for aquaculture and aquatic weed control. Definitive host fish acquire this cestode by ingesting cyclopoid copepods that carry the infectious larvae. These copepods are, in turn, parasitized by ingestion of the coracidium

larvae hatched from the cestode eggs expelled through feces of the parasitized fish.

Introduction of *B. acheilognathi* with the herbivorous carp *C. idellus*, and other cyprinids, has been documented on almost every continent, except Antarctica. It has been recorded in Russia, Bulgaria, France, Germany, Great Britain, Hungary, Poland, Yugoslavia and South Africa (see references in Paperna 1996), as well as in the Czech Republic (Scholz 1989), Italy (Scholz and Di Cave 1992), Australia (Dove et al. 1997; Dove 1998; Dove and Fletcher 2000), Hawaii (Font and Tate 1994; Font 1997a, b, 1998), mainland United States of America (Hoffman 1980; Heckmann 2000; Heckmann et al. 1986, 1987, 1993; Brouden and Hoffnagle 1997), Mexico (López Jiménez 1981) and Brazil (Rego 2000).

Bothriocephalus acheilognathi can cause serious damage in fry and small fish at high infection levels. Potential damages include: intestinal abrasion and disintegration, loss and separation of intestinal microvilli and enterocytes, blockage and perforation of the intestinal tract, emaciation and anemia in chronic infections, decrease in intestinal, hepatic and pancreatic enzymes, reduction in growth and reproductive capacity, muscular fatigue, decrease in hemoglobin content, weakened swimming capacity and secondary bacterial infections (Bauer et al. 1973; Scott and Grizzle 1979; Hoffman 1980; Heckmann 2000; Heckmann et al. 1986; Alarcón-González 1988; Hoole 1994; Hoole and Nisan 1994; Paperna 1996).

This cestode can cause massive fish kills in cultivated fish, as has been recorded in fish farms. However, it can also have pathogenic effects in fish from natural environments as suggested by Musselius and Strelkov (1968) and Bauer et al. (1973). Laboratory studies have shown that *B. acheilognathi* significantly reduces survival in the mosquito fish, *Gambusia affinis* (Granath and Esch 1983). Therefore, this parasite species clearly has the potential to regulate fish populations (Clarkson et al. 1997).

Bothriocephalus acheilognathi was introduced to Mexico in 1965, along with the herbivorous carp *C. idellus* (López-Jiménez 1981). From this time on, this cestode has actively invaded native and endemic fis species. Data recorded 10 years ago showed a host spectrum of 15 fish species belonging to 4 families (Salgado-Maldonado et al. 1986; García-Prieto and Osorio-Sarabia 1991; Pineda-López and González 1997). Currently, *B. acheilognathi* is the helminth species parasitizing the greatest number of fish species in the Balsas river basin, in southern Mexico, and in the Lerma–Santiago river basin, in the central Mexican Highland Plateau (Salgado-Maldonado et al. 2001a, b).

This study presents the current geographical distribution of this cestode in the freshwater fish of Mexico, highlighting infection levels in autochthonous and endemic species. It compiles existing information on *B. acheilognathi* infection in freshwater fish in Mexico as well as original data from our own research.

Materials and methods

As part of an ongoing parasitological investigation into the helminth fauna of the freshwater fishes of Mexico, a review of the literature dealing with *B. acheilognathi* parasitizing freshwater fish in Mexico was made. In addition, a total of 1766 fish of 36 species (Table 1), from localities in the Papaloapan and Panuco river basins (Gulf of Mexico coastal plain), and the Ayuquila river, Sierra de Manantlan Biosphere Reserve (western slope of Mexico) was examined for the presence of helminths from May 1997 to February 2001.

At each site, fish were captured using electrofishing or gill nets. The number of fish examined at each locality and collection data are given elsewhere (Salgado-Maldonado et al. 1997, 2001a, b). After capture, the fish were taken live to the laboratory and examined within 48 h using standard procedures. Briefly, the entire gut of each fish host was examined under a stereomicroscope, and all the helminths encountered in each fish were counted. Cestodes were fixed in hot 4% neutral formalin, and were stained with Mayer's paracarmine or Ehrlich's haematoxylin, dehydrated using a graded alcohol series, cleared in methyl salicylate, and whole mounted. Voucher specimens have been deposited in the National Helminth Collection (Colección Nacional de Helmintos (CNHE)), Institute of Biology, National Autonomous University of Mexico (UNAM), Mexico City.

Results

As can be seen in Table 1, *B. acheilognathi* is widely dispersed among the freshwater fish of Mexico, being recorded to date in 49 fish species from 26 genera, 7 families and 5 orders. Twenty-nine (fifty-nine percent) of these species are endemic to Mexico and are indicated as threatened or in danger according to the

Table 1. Known distribution of *B. acheilognathi* in Mexican freshwater fishes.

Host	Locality	Drainage basin	Reference
Order Cypriniformes			
Cyprinidae			
Algansea lacustris[a]	Pátzcuaro lake, Michoacán	L-S	Mendoza-Garfias et al. (1996)
A. rubescens[a]	Chapala lake, Jalisco	L-S	García-Prieto and Osorio-Sarabia (1991)
A. tincella[a]	Ignacio Allende reservoir, Guanajuato	L-S	Salgado-Maldonado et al. (2001b)
Carassius auratus	La Goleta reservoir, Estado de México	P	Sanabria-Espinosa and Sánchez-Santana (1989)
C. carassius	Fish farm Atlangatepec, Tlaxcala		Alarcón-González and Castro-Aguirre (1988) Alarcón-González (1988)
Ctenopharyngodon idella	Fish farm Tezontepec, Hidalgo		López-Jiménez (1981)
	Infiernillo reservoir, Michoacán	B	
	Fish farm Atlangatepec, Tlaxcala		Guillen-Hernández et al. (1991)
Cyprinus carpio	Pátzcuaro lake, Michoacán	L-S	Salgado-Maldonado et al. (1986)
	Fish farm Tezontepec, Hidalgo		García-Prieto and Osorio-Sarabia (1991)
	Ciénaga de Lerma (wetland), Estado de México	L-S	León-Regàgnon (1992)
	Ignacio Ramírez reservoir, Estado de México	L-S	Salgado-Maldonado et al. (2001b)
	Trinidad Fabela reservoir, Guanajuato	L-S	Salgado-Maldonado et al. (2001b)
Dionda ipni[a]	Quemada, Querétaro	L-S	Present work
	Río Grande (river), Querétaro	P	Present work
	Los Vázquez spring, Querétaro	P	Present work
	Río Amajac (river), Hidalgo	P	Present work
Hybopsis boucardi[a]	Río Cuyotepeji (river), Oaxaca	B	Salgado-Maldonado et al. (2001a)
	Huajuapan de Léon (river), Oaxaca	B	Salgado-Maldonado et al. (2001a)
	Río Petatlán (river), Guerrero	B	Salgado-Maldonado et al. (2001a)
	Río San Gerónimo (river), Ixtapan de la Sal		
	Estado de México	B	Salgado-Maldonado et al. (2001a)
	Río Petlalcingo (river), Oaxaca	B	Salgado-Maldonado et al. (2001a)
	Río Michapa (river), Oaxaca	B	Salgado-Maldonado et al. (2001a)
	Río Amacuzac (river), Huajintlán, Morelos	B	Salgado-Maldonado et al. (2001a)
Megalobrema amblycephala	Fish farm Tezontepec, Hidalgo		García-Prieto and Osorio Sarabia (1991)
Notropis celayensis[a]	Río Las Zúñigas (river), Querétaro	P	Present work
N. sallei[a]	Ciénaga de Lerma (wetland), Estado de México	L-S	León-Regàgnon (1992)
	Ignacio Allende reservoir, Guanajuato	L-S	Salgado-Maldonado et al. (2001b)
	Río Quiotillos (river), Querétaro	P	Present work
Yuriria alta[a]	Río Los Galvanes (river), San Miguel de Allende, Guanajuato	P	Present work
	Ignacio Allende reservoir, Guanajuato	L-S	Salgado-Maldonado et al. (2001b)
	Río Xote (river), Querétaro	L-S	Present work
Order Characiformes			
Characidae			
Astyanax fasciatus	Río Cuyotepeji (river), Oaxaca	B	Salgado-Maldonado et al. (2001a)
Order Cyprinodontiformes			
Goodeidae			
Alloophorus robustus[a]	Pátzcuaro Lake, Michoacán	L-S	Peresbarbosa-Rojas et al. (1994)
Allotoca diazi[a]	Pátzcuaro Lake, Michoacán	L-S	Peresbarbosa-Rojas et al. (1994)
Girardinichthys multiradiatus[a]	Ciénaga de Lerma (wetland), Estado de México	L-S	León-Regàgnon (1992)
	Chicnahuapan lake, Estado de México	L-S	Salgado-Maldonado et al. (2001b)
	La Lagunilla (wetland), Estado de México	L-S	Salgado-Maldonado et al. (2001b)

Table 1. Continued.

Host	Locality	Drainage basin	Reference
	Ignacio Ramírez reservoir, Estado de México	L-S	Salgado-Maldonado et al. (2001b)
	Trinidad Fabela reservoir, Estado de México	L-S	Astudillo-Ramos and Soto-Galera (1997)
Goodea atripinnis[a]	Chapala Lake, Jalisco	L-S	García Prieto and Osorio-Sarabia (1991)
	El Batán reservoir, Querétaro	P	Pineda-López and González-Enríquez (1997)
	Río Los Galvanes (river), San Miguel de Allende, Guanajuato	L-S	Present work
	Río Xote (river), Querétaro	L-S	Present work
	Rayas reservoir, Querétaro	P	Pineda-López and González-Enríquez (1997)
Xenotoca variatus[a]	Río Los Galvanes (river), San Miguel de Allende, Guajuato	P	Present work
	Constitución 1917 reservoir, Queretáro	L-S	Pineda-López and González-Enríquez (1997)
	Ignacio Allende reservoir, Guanajuato	L-S	Salgado-Maldonado et al. (2001b)
	Río Xote (river), Querétaro	L-S	Present work
	Río Jalpan (river), Querétaro	L-S	Pineda-López and González-Enríquez (1997)
	Rayas reservoir, Querétaro	P	Pineda-López and González-Enríquez (1997)
Poeciliidae			
Gambusia yucatana	Cenote Homún (sinkohole) Yucatán	Y-P	Scholz (1997)
G. vittata[a]	Río Venados (river), Hidalgo	P	Present work
Heterandria bimaculata[a]	Río Amacuzac (river), Contlalco and Huajintlán, Morelos	B	Salgado-Maldonado et al. (2001a)
	El Carmen reservoir, Querétaro	P	Present work
Poecilia butleri	Río Ayuquila (river), Manantlán Achacales, Palo Blanco, Jalisco	M	Present work
P. mexicana	Río Venados (river), Hidalgo	P	Present work
	El Realito (spring), Guanajuato	L-S	Present work
	Tributary to Acamaluco river	P	Present work
P. sphenops	Río Petlalcingo (river), Oaxaca	B	Salgado-Maldonado et al. (2001a)
	Río Xochihuehuetlán (river), Guerrero	B	Salgado-Maldonado et al. (2001a)
	Río Amacuzac (river), Huajintlán, Morelos	B	Salgado-Maldonado et al. (2001a)
P. reticulata	Río Acatlán (river), Guerrero	B	Salgado-Maldonado et al. (2001a)
Poeciliopsis baenschi[a]	Río Ayuquila (river), El Grullo, Jalisco	M	Present work
P. gracilis	Río Amacuzac (river), Contlalco, Morelos	B	Salgado-Maldonado et al. (2001a)
	Tepecoacuilco reservoir, Guerrero	B	Salgado-Maldonado et al. (2001a)
Poeciliopsis sp.	Río Amajac (river), Hidalgo	P	Present work
Order Atheriniiformes			
Athernidae			
Atherinella crystallina[a]	Aguamilpa reservoir, Río Santiago, Nayarit	L-S	Salgado-Maldonado et al. (2001b)
Chirostoma arge[a]	Río San Pedro (river), Querétaro	L-S	Present work
C. attenuatum[a]	Pátzcuaro lake, Michoacán	L-S	García Prieto and Osorio-Sarabia (1991) Pérez et al. (1994)
	Zirahuén lake, Michoacán	L-S	Espinosa-Huerta et al. (1996)
C. estor[a]	Pátzcuaro lake, Michoacán	L-S	Osorio-Sarabia et al. (1986) Salgado-Maldonado et al. (1986) Salgado-Maldonado and Osorio-Sarabia (1987) Guillén-Hernández et al. (1991)
C. grandocule[a]	Pátzcuaro lake, Michoacán	L-S	García-Prieto and Osorio-Sarabia (1991)
C. humboldtianum[a]	Cointzio reservoir, Michoacán	L-S	Astudillo-Ramos and Soto-Galera (1997)

Table 1. Continued.

Host	Locality	Drainage basin	Reference
C. jordani[a]	La Biznaga reservoir, Guanajuato	L-S	Salgado-Maldonado et al. (2001b)
	Ignacio Allende reservoir, Guanajuato	L-S	Salgado-Maldonado et al. (2001b)
C. labarcae[a]	Ignacio Allende reservoir, Guanajuato	L-S	Salgado-Maldonado et al. (2001b)
C. ocotlanae[a]	Chapala lake, Jalisco	L-S	García-Prieto and Osorio-Sarabia (1991)
C. riojai[a]	Santiago Tilapa lake, Estado de México	L-S	Salgado-Maldonado et al. (2001b)
Chirostoma sp.[a]	El Batán reservoir, Quéretaro	L-S	Pineda-López and González-Enríquez (1997)
	Constitución 1917 reservoir, Querétaro	L-S	Pineda-López and González-Enríquez (1997)
Melaniris balsanus	Infiernillo reservoir, Michoacán	B	García-Prieto and Osorio-Sarabia (1991)
Order Perciformes			
Centrarchidae			
Micropterus salmoides	Pátzcuaro lake, Michoacán	L-S	Salgado-Maldonado et al. (1986) Salgado-Maldonado and Osorio-Sarabia (1987)
Cichlidae			
Cichlasoma cyanoguttatum	Río Atlapexco (river), Hidalgo	P	Present work
C. istlanum[a]	Tepecoacuilco reservoir, Guerrero	B	Salgado-Maldonado et al. (2001a)
	Río Ayuquila (river), El Chacalito, Jalisco	M	Present work
C. labridens[a]	Río Talol (river), Hidalgo	P	Present work
C. meeki	Nuevo Becal (lake), Campeche	Y-P	Vidal-Martínez et al. (2001)
C. urophthalmus	Río Jonuta (river), Tabasco	G-U	Salgado-Maldonado et al. (1997)
	Celestún, coastal lagoon, Yucatán	Y-P	Salgado-Maldonado et al. (1997)
C. nigrofasciatum	Río Amacuzac (river), Morelos	B	Salgado-Maldonado et al. (2001a)
Oreochromis niloticus	Constitución 1917 reservoir, Querétaro	L-S	Pineda-López and González-Enríquez (1997)
	Río Concá (river), Querétaro		Pineda-López and González-Enríquez (1997)

[a]Species endemic to Mexico.
Drainage basins: B – Río Balsas; G-U – Grijalva–Usumacinta River System; L-S – Río Lerma Santiago; M – Río Ayuquila, Sierra de Manantlán Biosphere Reserve, Jalisco; P – Río Pánuco; Y – Yucatán Peninsula.

Mexican Law (NOM-059-ECOL-1994). This parasite has been found in fish from all basins studied in the Mexican neotropics, with records for the Yucatan Peninsula (in the southeast); the Papaloapan and Pánuco river basins (Gulf of Mexico coastal plain); the Balsas river basin (in the southwest), and the Ayuquila River in the Sierra de Manantlán, Jalisco (western slope of Mexico). It has also been recorded in the Nearctic zone of Mexico, including the Lerma–Santiago river basin (central Mexican Highland Plateau).

Discussion

Data of this study add to the list of definitive host species for *B. acheilognathi* presented by Dove and Fletcher (2000) a total of 37 species, 1 family and 1 more order. The new hosts identified in this study bring the total number of known host species to 102 in 14 families and 7 orders of freshwater fishes around the world.

Because of its wide geographical distribution, *B. acheilognathi* is considered one of the most successful helminth parasites of freshwater fish (Dove and Fletcher 2000). This accomplishment is related to attributes that make this species a successful invader and a good colonizer (Kennedy 1994). First of all, it was introduced anthropogenically into Mexico along with the herbivorous carp, greatly favouring its capacity for natural dispersal. It is a generalist species with wide host specificity, capable of invading a variety of definitive and intermediate hosts. In addition, the cyclopoid copepods that *B. acheilognathi* uses as intermediary hosts are widely distributed in Mexico, greatly contributing to its wide dispersal.

Another important aspect improving *B. acheilognathi* performance as an invader is that helminth communities in freshwater fish in Mexico are poor, with many vacant niches (*sensu* Kennedy 1994). In many

cases, the intestines of individual fish are parasite-free, or have only a single helminth species (Salgado-Maldonado et al. 2001a, b), therefore, *B. acheilognathi* can easily colonize these depauperate communities. This cestode has successfully invaded freshwater fish in Mexico by finding new and appropriate definitive and intermediate hosts for its life cycle in sufficient population densities.

The hydrological basins of Mexico studied to date have also offered *B. acheilognathi* an ample advantage in successfully transmitting itself in whatever season and location it arrives, i.e. the transmission window (*sensu* Kennedy 1994) is open for all or much of the year. The parasite is thermophilic, and its development from eggs to coracidium take only few days in temperatures between 16 and 25 °C (Bauer et al. 1973; Chubb 1981; Granath and Esch 1983). This temperature range is very common in freshwater habitats in Mexico. For example, in Pátzcuaro Lake, Michoacán, an environment with low winter ambient temperatures, water lake temperature fluctuates between 18 and 22 °C (Orbe-Mendoza and Acevedo 1995), allowing *B. acheilognathi* to develop year-round.

Dispersal of this parasite is also possible through anthropogenic translocation of infected native fish species. In environments where carps have not been introduced, parasitized Poecilids (Poeciliidae) can transport *B. acheilognathi* to other fish hosts (Font and Tate 1994; Font 1997a, b, 1998; Scholz et al. 1996). Aquatic birds can also be passive carriers of this cestode. It has been shown experimentally (Prigli 1975) that common duck *Anas platyrhynchos* fed on young carps infected with *B. acheilognathi* defecated viable eggs of this cestode 1–3 days after ingesting the fish. These eggs hatched into normal coracidia four days later.

From its initial introduction into Mexico in 1965, the speed and effectiveness with which *B. acheilognathi* has dispersed itself into the different hydrological basins of the country point to a general, very broad distribution. Data presented in this work show that sometime since 1965 this parasite increased by five times the number of host species it infects. In contrast, *B. acheilognathi* does not seem to have adapted to South American hosts, seeing as in Brazil it has only been recorded in its principal host, *C. carpio* (Rego 2000).

The data presented in this work suggest a potential threat of this tapeworm for native Mexican fishes resulting from a combination of at least three factors: host range, abundance of the parasite and pathology associated with the parasite. *B. acheilognathi* is the most widely distributed species in the Balsas river basin and Lerma–Santiago river basin of Mexico (Salgado-Maldonado et al. 2001a, b). It is one of the most widespreaded helminth parasites amongst fishes of the Ayuquila river system, Sierra de Manantlán Biosphere Reserve and Pánuco and Papaloapan river basins (unpubl. data). Along with wide host range, the abundance of the parasite is also high. High prevalences and high intensities of this tapeworm are well documented amongst freshwater fishes of Mexico (see Salgado-Maldonado et al. 2001a, b). The prevalence of *B. acheilognathi* frequently exceeds 30% amongst fish species examined from several basins of Mexico.

Pathology is usually associated with high parasite intensities. High host density lead to high parasite intensities in small artificial ponds ('bordos') or in fish impoundments into small dams. However, conclusive studies of pathology of this parasite to natural Mexican freshwater fish populations are lacking.

In Mexican law (NOM-059-ECOL-1994), the majority of freshwater fish in Mexico have been considered as threatened or in danger to extinction, primarily because of pollution, fragmentation and desiccation of habitats. Biological changes in the freshwater habitats in Mexico caused by the introduction of exotic fish species and their parasites are virtually ubiquitous and extremely difficult to eradicate once established. As such, they should be considered as one of the most serious threats to native fish conservation. Given its wide distribution among Mexican fish species, the abundance of the parasite and its high pathogenicity, parasitological data for *B. acheilognathi* should be considered as an important factor in native fish conservation policies.

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