Biodiversity of Metazoan Parasites Infecting Channel Catfish (*Ictalurus punctatus*), Blue Catfish (*Ictalurus furcatus*), and C×B Hybrid Catfish (Female *Ictalurus punctatus* × Male *Ictalurus furcatus*) in Earthen Pond Aquaculture

by

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Abstract

This 1-year in-pond study documents the metazoan parasite biodiversity in channel catfish (*Ictalurus punctatus*), blue catfish (*Ictalurus furcatus*), and C×B hybrid catfish (female *Ictalurus punctatus* × male *Ictalurus furcatus*) in earthen pond aquaculture. A total of 750 individuals per fish species were stocked into 3, 0.1-arce earthen ponds (each pond comprising a replicate). A total of 112 (mean of 3 per month per pond) channel catfish, 74 (mean of 2 per month per pond) blue catfish, and 209 (mean of 6 per month per pond) C×B hybrid catfish were seined and examined by routine parasitological necropsy using light microscopy during January, February, April, May, June, July, September, October, November 2010, and January, February 2011, totaling 11 collection events. All parasites were observed alive before being heat-killed, fixed in 10% neutral buffered formalin, 70% EtOH, 95% EtOH, or glacial acetic acid, and identified to the lowest taxonomic level using the published literature and previously-collected specimens.

Based on morphological criteria, specimens comprising a total of 15 metazoan parasite species were collected from these catfishes. Channel catfish was infected by14 species: 4 myxozoans *Henneguya* cf. *postexilis*, *H.* cf. *exilis*, *H.* cf. *adiposa*, and *H.* cf. *ictaluri* (combined prevalence of 81.3%), 2 monogeneans *Ligictaluridus mirabilis* and *L. pricei* (99.1%), 5 cestodes *Corallobothrium fimbriatum*, *C. parafimbriatum*, *Corallotaenia intermedia*, *Megathylacoides* cf. *giganteum*, and *M. thompsoni* (57.1%), 1 nematode *Spiroxys* cf. *contortus* (0.9%), and 2 copepods *Neoergasilus japonicus* and *Achtheres* cf. *percarum*/ *sandrae* (16.1%). C×B hybrid catfish was infected by 12 species: 3 myxozoans *Henneguya* cf. *postexilis*, *H.* cf. *exilis*, and *H.*

cf. *adiposa* (36.4%), 2 monogeneans *Ligictaluridus mirabilis* and *L. pricei* (90.4%), 3 cestodes *Corallobothrium fimbriatum*, *C. parafimbriatum*, *Corallotaenia intermedia* (47.8%), 1 nematode *Spiroxys* cf. *contortus* (0.5%), 1 unionid *Pyganodon* cf. *grandis* (2.9%), and 2 copepods *Neoergasilus japonicus* and *Achtheres* cf. *percarum*/ *sandrae* (6.7%). Blue catfish was infected by 7 species, 2 myxozoans *Henneguya* cf. *postexilis* and *H.* cf. *ictaluri* (9.5%), 2 monogeneans *Ligictaluridus mirabilis* and *L. pricei* (93.2%), 2 cestodes *Corallobothrium fimbriatum* and *C. parafimbriatum* (35.1%), and 1 copepod *Neoergasilus japonicus* (21.6%). Although hybrid catfish resistance to disease has yet to be tested for most parasite infections, these results clearly show that this hybrid is no refractory to initial infection by the parasites that infect its parental species.

New host records reported herein comprise *Henneguya postexilis* in C×B hybrid catfish and blue catfish, *H. exilis* in C×B hybrid catfish, *H. adiposa* C×B hybrid catfish, *Ligictaluridus mirabilis* in C×B hybrid catfish, *L. pricei* infected C×B hybrid catfish, *Corallobothrium fimbriatum* in blue catfish and C×B hybrid catfish, *C. parafimbriatum* in channel catfish, blue catfish and C×B hybrid catfish, *Corallotaenia intermedia* in channel catfish and C×B hybrid catfish, *Spiroxys* cf. *contortus* in channel catfish and C×B hybrid catfish, *Pyganodon* cf. *grandis* in blue catfish and C×B hybrid catfish, *Neoergasilus japonicus* in C×B hybrid catfish, and *Achtheres* cf. *percarum*/*sandrae* in channel catfish and C×B hybrid catfish.

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Chapter 1

INTRODUCTION

1.1. Justification

Catfish farming is the largest food fish aquaculture industry in the United States in terms of total production (Jiang et al., 2008) because it has long been established, has wide market acceptability (Giudice, 1966; Li et al., 2008), and high adaptability to different environmental culture conditions (Giudice, 1966). In 2007, despite a steady decline in per capita consumption of catfish (compared to 2006), catfish placed sixth among the top 10 seafoods consumed in the United States (Hanson and Sites, 2009). Among U.S. catfish farms, channel catfish, *Ictalurus punctatus* (Rafinesque, 1818) (Siluriformes: Ictaluridae) is currently the primary cultivated species (Dunham et al., 1993), constituting 99% of cultured catfish in the U.S. (Li et al., 2008); however, because channel catfish are less uniform in size at harvest than blue catfish (coefficients of variation in body weight at harvest of channel catfish are as twice as that of blue catfish) (Dunham et al., 1994) and usually evade seining, the future culturing this catfish species has been called into question (Li et al., 2008). Additionally, increasing production of imported frozen catfish fillets from Vietnam and China, which accounts for 50% of 2008 total catfish products consumed in the U.S. (Hanson and Sites, 2009), seriously threatens the sustainability of the U.S. Farm-raised Catfish Industry. Moreover, since none of the current farm-raised catfish species, channel catfish and blue catfish, *Ictalurus furcatus* (Lesueur, 1840) (Siluriformes: Ictaluridae), possess optimal traits (high growth rate, parasite/disease resistance, and environmental adaptability) for a wide range of aquaculture environments (Li et al., 2008), the U.S. Farm-raised Channel Catfish Industry is seeking alternative species that have better resistance to infectious disease, higher growth rate, lower feed conversion ratio, and better adaptability to adverse environments and seasons.

Tucker and Robinson (1990), Dunham et al. (1994), Bostworth et al. (2005), and Griffin et al. (2010) have considered culturing other catfishes, such as blue catfish, as it can reach larger marketable sizes (Giudice, 1966), generally resist infection by the bacterium *Edwardsiella ictaluri* (Hawke, McWhorter, Steigerwalt, and Brenner, 1981) (Enterobacteriales: Enterobacteriaceae) (Tucker and Robinson, 1990) and the myxozoan *Henneguya ictaluri* (Pote, Hanson, and Shivaji, 2000) (Bivalvulida: Myxobolidae) (Griffin et al., 2010), and exhibit better performance in farm culture environments (Dunham et al., 1994). Similarly, female *I. punctatus* × male *I. furcatus* hybrid catfish (hereafter preferred to as "hybrid catfish"), is being considered as an alternative species to channel catfish because of its better growth rate [net gain was 41% higher than channel catfish when mix-stocked at 75 individuals/species/acre after 1-year period (Giudice, 1966; Bosworth et al., 2005)], survival rate [94−99% compared to 80−94% in channel catfish (Dunham et al., 1987)], higher dress-out and fillet percentages [61.1% and 45.7% compared to 57.5% and 42.5%, respectively in channel catfish (Argue et al., 2003)], and higher tolerance to low dissolved oxygen [when dissolved oxygen drop to below 1.0mg/l, mortalities were 7.5% and 50.5% in ponds, 51.0% and 87.5% in cages, and 33.0% and 100.0% in tanks among channel catfish and hybrid catfish, respectively (Dunham et al., 1983)]. Those advantages suggest that, in addition to channel catfish, blue and hybrid catfishes are good candidates for the future of the U.S. Farm-raised Catfish Industry. However, commercial production of hybrid catfish is currently limited relative to channel catfish because of inefficient reproduction methods, high costs for producing hybrid fry, and processing constraints due to smaller head size than channel catfish (Li et al., 2004; Bosworth et al., 2005). Similarly, blue catfish is less commonly cultured in commercial scales because of poor feed conversion rate, poor spawning success in captivity, late maturation age (4−7 years), and stress sensitivity when handling

(Graham, 1999). Jiang et al. (2008) suggested that slight improvements in production and processing traits of cultured catfishes could eventually lead to substantial increases in million kilograms of total production and subsequently higher benefits for farmers and The Industry. Hence, studies for both positive and negative characteristics of those catfishes are crucial for the sustainable development of The Industry because they inform decisions about catfish species optimal for seasons and regions.

No comprehensive taxonomic survey of metazoan parasites of hybrid catfish has been published to date. Although case reports and surveys of parasites and diseases of channel and blue catfishes are numerous in the current literature (Essex, 1929; Herman and Putz, 1970; Baker and Crites, 1976; Minchew, 1977; Casanova-Bustillos, 1984; Klassen and Beverley-Burton, 1985; Dechtiar and Nepszy, 1988; Dechtiar et al, 1988; Galaviz-Silva et al., 1990; Hoffman, 1999; Choudhury and Perryman. 2003; Camus et al., 2006), equivalent published studies remain limited on hybrid catfish (Tables 1 and 2). The unpublished MSc Thesis of S. B. Shrestha (1977) reported some gill and skin ectoparasites (*Trichodina* sp., *Scyphidia* sp., *Ichthyophthirius* sp., *Cleidodiscus* sp.) on several hybrid catfish strains (*I. furcatus* × *I. punctatus*, Auburn; *I. catus* × *I. furcatus*; *I. catus* × *I. punctatus*, Auburn; *I. punctatus*, Marion × *I. punctatus*, Kansas; *I. punctatus*, Auburn × *I. furcatus*; *I. punctatus*, Auburn × *I. catus*; *I. punctatus* × *I. punctatus*, Rio Grand). Recent studies on the parasites and diseases of female *I. punctatus* × male *I. furcatus* hybrid catfish have concentrated on proliferative gill disease (PGD), which is associated with infections by the myxozoan *Henneguya ictaluri* (see Bosworth et al., 2003; Griffin et al., 2010). Hybrid catfish were slightly less susceptible to PGD than channel catfish but much more susceptible relative to blue catfish (Bosworth et al., 2003; Griffin et al., 2010).

In the present study, I assess metazoan parasite biodiversity among three catfish species used in Southeastern United States aquaculture to test if hybrid catfish are less susceptible to parasite infection than either of its parental species. Although no such study has been conducted on hybrid catfish, it is nevertheless assumed that hybrid catfish inherits the best (i.e., being refractive to infection by metazoan parasites) from each parental species rather than the worst (i.e., being susceptible to the known parasites of both blue and channel catfishes). Quantitative data on parasite species, host specificity and biodiversity in hybrid catfish has yet to be published, existing only as a non-species specific, unpublished MSc thesis by S. B. Shrestha (1977; Tables 3 and 4). Conducting a comparative study on parasite biodiversity, host, and temporal distributions on channel, blue, and hybrid catfishes in pond-raised aquaculture has a practical impact for the U.S. Farm-raised Catfish Industry, involving the future promotion of multi-catfish species aquaculture industry, because it informs selection of future cultured catfish species and helps predict infections by certain parasite groups in earthen pond aquaculture. On the other hand, the present study will obviously generate new information on parasite biodiversity among hybrid catfish which has not been previously reported and may potentially lead to the discovery of emerging pathogens or undescribed parasite species.

1.2. Objectives and hypothesis

1.2.1. Objectives

Objective 1: Document hybrid catfish susceptibility to parasitic infection relative to its parental species in earthen pond aquaculture over a 12 month period.

Objective 2: Document prevalence and intensity of metazoan parasites infecting channel, blue, and hybrid catfishes in pond aquaculture.

1.2.2. Hypothesis

Biodiversity, prevalence and intensity of metazoan parasite species infecting hybrid catfish is less than that of either of its parental species.

1.3. Review on hybrid vigor

Hybrids are produced when different strains within a species or different species in the same or different genera are crossed (Bartley et al., 2001). This biological phenomenon is commonly recognized among fishes, especially in freshwater fishes (Colombo et al., 1998; Hubbs, 1955; Scribner et al., 2001). Fish hybrids can either be produced interspecifically (i.e., crossing individuals of two different species assigned to different genera) or intergenerically (i.e., crossing individuals of two species each assigned to different genera) (Reddy, 2000). Hybridization among fishes, either as a natural phenomenon (Buck and Hooe, 1986; Fries and Harvey, 1989; Hammar et al., 1991; Smith et al., 1994; and Baxter et al., 1997; Colombo et al., 1998; Reddy, 2000) or as an artificial activity (Colombo et al., 1998; Reddy, 2000), has increasingly played a more important role in global food security since inherited benefits from hybrids could further develop potential candidates for aquaculture (Henderson-Arzapalo and Colura, 1984; Henderson-Arzapalo et al., 1994, Basavaraju et al., 1995; James et al., 1999). For example, several species of tilapias, including Nile tilapia [*Oreochromis niloticus* (Linnaeus, 1758) (Perciformes: Cichlidae)], Mosambique tilapia [*O. mossambicus* (Peters, 1852) (Perciformes: Cichlidae)], blue tilapia [*O. aureus* (Steindachner, 1864) (Perciformes: Cichlidae)], Athi River tilapia [*O. spilurus* (Gunther, 1894) (Perciformes: Cichlidae)], Wami tilapia [*O. hornorum* (Trewavas, 1966) (Perciformes: Cichlidae)], blackchin tilapia [*Sarotherodon melanotheron* (Ruppell, 1852) (Perciformes: Cichlidae)], and several red tilapia hybrids (Yan and Wang, 2010), are now widely cultured, especially in developing countries (Verdegem et al., 1997). Anthropogenic hybridization in aquaculture is thought to be more

common than natural hybridization, although natural hybrids do occur in nature [i.e., European eel, *Anguilla anguilla* (Linnaeus, 1758) (Anguilliformes: Anguillidae) × American eel, *A. rostrata* (Le Sueur, 1821) (Anguilliformes: Anguillidae)] (Scribner et al., 2001).

Hybridization among fishes can inadvertently or purposely occur in natural or artificial conditions. Smith et al. (1994) explained the natural hybridization between black crappie, *Pomoxis nigromaculatus* (Lesueur, 1829) (Perciformes: Centrarchidae) and white crappie, *P. annularis*) (Rafinesque, 1818) (Perciformes: Centrarchidae) occurs as a results of an increase in water turbility during spawning seasons, similarities in spawning cycles and duration, natural water tidal regimes, and possibly fishes themselves when misidentifying their mating congeners. Hybrids between rohu, *Labeo rohita*, (Hamilton, 1822) (Cypriniformes: Cyprinidae) and catla, *Catla catla*, (Hamilton, 1822) (Cypriniformes: Cyprinidae) are produced due to dam building systems that interferes water currents in downstream areas (Reddy, 2000). In a recent review paper, Scribner et al. (2001) attributed hybridization among fishes to four contributing factors, including i) habitat loss-caused by human intervention and disturbance of animals' spawning areas; ii) range expansion-either natural and anthropogenic breakdowns of ecological and geographical barriers formerly established; iii) interspecies crosses in aquaculture, and iv) introduction or invasion of new species to different habitats.

The benefit of crossbreeding remains controversial. Epifanio and Nielsen (2001) reviewed 2 contradictory arguments about hybridization: destructive process that mainly producing sterile and weakly viable hybrid populations and constructive process that increasing genetic diversity. Since each cultured fish species has its own disadvantages and barriers for aquaculture in certain regions or culture settings, scientists and aquaculturists are selectively looking for only certain traits on cultured fishes. Therefore, hybridization, as a part of genetic improvement programs, is

one of the most common methods for creating and selecting new species for future aquaculture (James et al., 1999; Reddy, 2000).

It is well-known that crossbreeding can produce more vigorous progenies in growth than either their parental species (Shull, 1908; Castle, 1925; Bryden et al., 2004). This phenomenon was also well-recognized by plant and animal researchers (Shull, 1908; Crow, 1948). The term "heterosis" (hybrid vigor) was originally suggested by Shull (1914) as the simplification of the terms "heterozygotic stimulation" or "stimulus heterozygosis", which is the better performance of hybrid individuals having strain- or species-dissimilar chromosomal sets in their genomes.

Numerous surveys and observations in freshwater and marine fishes with consistent results lead Hubbs (1955) to conclude that hybrids exhibit intermediate characters, both externally (coloration, body shape, head size, length, and number of body parts) and internally (visceral organs, and gonadal or skeleton structures) between their parental species (Henderson-Arzapalo and Colura, 1984, Colombo et al., 1998) as they inherit each half of their genetic factors through the interspecific or intergeneric combinations. However, the exceptions from this transitional heredity are better performance (heterosis), relative to either of their parental species (Hubbs, 1955).

Crow (1948) suggested a widely accepted explanation for hybrid vigors, known as "Dominance hypothesis". According to this concept, hybrid vigors occur when dominant alleles exist and superiorly exhibit their own traits on phenotypes over the recessive alleles. In addition, the most "vigorous" individuals usually possess the highest number of dominant alleles. However, vigor may be lost in cross-bred individuals by increasing homozygosity (Crow, 1948; Yan and Wang, 2010). Alternatively, Milborrow (1998) reviewed a different hypothesis of hybrid vigor and stated that higher numbers of existing alleles in hybrids could allow them to

exhibit greater biochemical diversity and higher resistance to environmental changes. His novel explanation for hybrid vigors involved the biochemical mechanism of "Reduced Control" hypothesis. Hybrid vigors of cross-bred individuals result from less restrictions of internal genetic factors in two distinct allelic sources that normally limited maximum growths and metabolism rates in homozygotes.

In a review paper on hybridization of fishes, Scribner et al. (2001) reported hybrids that have occurred in 19 fish families, including Acipenseridae, Aguillidae, Atherinidae, Catostomidae, Centrarchidae, Cichlidaae, Clariidae, Clupeidae, Cottidae, Cyprinidae, Cyprinidontidae, Esocidae, Fundulidae, Ictaluridae, Moronidae, Osmeridae, Percidae, Poeciliidae, and Salmonidae, either naturally and anthropogenically. Among those, Cyprinidae is the most common family, having 68 fish species, followed by Centrachidae and Salmonidae with 18 and 15 fish species, respectively (Colombo et al., 1998; Scribner et al., 2001). Among anthropogenic hybridizations, aquacultural purposes are the most decisive factors contributing to the abundance of hybrids (Scribner et al., 2001; Green and Smitherman, 1984; Bartley, 1998). In aquaculture and fisheries, desirable characteristics of hybrids are disease resistance, higher growth rate, single-gender control of population, better environmental tolerance, higher flesh quality, and sometimes better harvestability (Bartley et al., 2001).

1.3.1. Enhanced growth rate

Enhancement in growth rate (intermediate or superior) is the most important character for selecting new fish candidates in aquaculture (Salami et al., 1993; Bartley, 1998; and Bartley et al., 2001) because it produces more individuals of expected sizes within a population (Buck and Hooe, 1986; Smith et al., 1994). Cyprinid fishes, trouts and salmons, tilapias, catfishes, and other

freshwater and marine fishes have produced hybrids to enhance growth rate (Bartley et al., 2001).

Hybrid crosses among carps (Cyprinidae) (Bryden et al., 2004) include silver carp, *Hypophthalmichthys molitrix* (Richardson, 1845) (Cypriniformes: Cyprinidae) × bighead carp hybrids, *Hypophthalmichthys nobilis* (Richardson, 1845) (Cypriniformes: Cyprinidae) (Green and Smitherman, 1984), rohu × catla, catla × fringe-lipped peninsular carp, *Labeo fimbriatus* (Bloch, 1795) (Cypriniformes: Cyprinidae) (Basavaraju et al., 1995; Reddy, 2000), rohu × kalbasu, *L. calbasu* (Hamilton, 1822) (Cypriniformes: Cyprinidae), catla × kalbasu, fringe-lipped peninsular carp × rohu, common carp, *Cyprinus carpio* (Linnaeus, 1758) (Cypriniformes: Cyprinidae) × rohu, and mrigal carp, *Cirrhinus cirrhosus* (Bloch, 1795) (Cypriniformes: Cyprinidae) × catla (Reddy, 2000).

Among salmonids, it has been shown that diploid hybrids exhibited very poor or no survivals whereas triploids seemed to have a better viability and growth rates (Gray et al., 1993; Galbreath and Thorgaard, 1997). In spite of the assumption of being less likely to produce vigorous performance for aquaculture in salmonid hybridization (Gray et al., 1993; Seeb, 1993; Bryden et al., 2004), prospective characteristics were still reported in some crosses, such as tiger trout or brown trout, *Salmo trutta* (Linnaeus, 1758) (Salmoniformes: Salmonidae) × brook trout, *Salvelinus fontinalis* (Mitchill, 1814) (Salmoniformes: Salmonidae) (Scheerer and Thorgaard, 1983; Scheerer et al., 1987), triploid hybrids of Atlantic salmon, *Salmo salar* (Linnaeus, 1758) (Salmoniformes: Salmonidae) × brown trout *S. trutta* (Galbreach and Thorgaard, 1997), lake trout, *Salvelinus namycush* (Walbaum, 1792) (Salmoniformes: Salmonidae) × brook trout (Snucins, 1993).

Among cichlids, currently, several tilapia species, including *Oreochromis niloticus*, *O. mossambicus*, *O. aureus*, *O. spilurus*, *O. hornorum*, *Sarotherodon melanotheron* and several red tilapia hybrids, are widely cultured around the world as they possess many good characters for aquaculture, such as high fecundity, high tolerance to environmental conditions, and disease resistance (Verdegem et al., 1994; Yan and Wang, 2010). Additionally, in some tilapia hybridizations, the hybrids also exhibit superior growths to their parental species (Siddiqui and Al-Harbi, 1995; Bryden et al., 2004): Nile tilapia × blue tilapia (Lahav and Lahav, 1990; Siddiqui and Al-Harbi, 1995), Mossambique tilapia × Wami tilapia (Ernst et al., 1989; Ernst et al., 1991; Head et al., 1994), and Nile tilapia × blackchin tilapia (Yan and Wang, 2010).

Hybrid vigors are recognized commonly through interspecific and intergeneric crosses among catfishes (Clariidae and Siluridae) (Nwadukwe, 1995; Bryden et al., 2004), and several catfish hybrids are now extensively used for commercial aquaculture (Salami et al., 1993; Nwadukwe, 1995; Rahman et al., 1995). Some examples are hybrids of African catfish, *Clarias gariepinus* (Burchell, 1822) (Siluriformes: Clariidae) × broadhead catfish, *C. macrocephalus* (Gunther, 1864) (Siluriformes: Clariidae) (Pongchawee et al., 1995; Minh, 1998), African catfish × vundu catfish, *Heterobranchus longifilis* (Valenciennes, 1840) (Siluriformes: Clariidae) (Salami et al., 1993; Nwadukwe, 1995), African catfish × African clariid catfish, *H. bidorsalis* (Hilaire, 1809) (Siluriformes: Clariidae) (Salami et al., 1993), Asian catfish, *C. batrachus* (Linnaeus, 1758) (Siluriformes: Clariidae) × African catfish (Rahman et al., 1995), and channel catfish × blue catfish (Giudice, 1966; Dunham et al., 1990; Wolters et al., 1996; Dunham and Argue, 1998).

Hybrids with promising growth rate are also found in other groups of fresh water fishes: black crappie × white crappie (Hooe et al., 1994; Smith et al., 1994), Muskellunge, *Esox*

masquinongy (Linnaeus, 1758) (Esociformes: Esocidae) × northern pike, *E. lucius* (Linnaeus, 1758) (Esociformes: Esocidae) (Beyerle, 1973; Brecka et al., 1995), green sunfish, *Lepomis cyanellus* (Rafinesque, 1819) (Perciformes: Centrarchidae) × bluegill, *L. macrochirus* (Rafinesque, 1819) (Perciformes: Centrarchidae) (Wills et al., 1994).

Hybridization is also used to produce good growth rate hybrids (intermediate or superior relative to parental species) (Henderson-Arzapalo and Colura, 1984; Henderson-Arzapalo et al., 1994) in some pairs of brackish and marine fishes, including black drum, *Pogonias cromis* (Linnaeus, 1766) (Perciformes: Sciaenidae) × red drum, *Sciaenops ocellatus* (Linnaeus, 1766) (Perciformes: Sciaenidae) (Henderson-Arzapalo and Colura, 1984; Henderson-Arzapalo et al., 1994), Beluga, *Hosu hosu* (Linnaeus, 1758) (Acipenseriformes: Acipenseridae) × Russian sturgeon, *Acipenser guldenstadti* (Brandt, 1833) (Acipenseriformes: Acipenseridae) (Gorshkova et al., 1996; Bartley et al., 2001), white bass, *Morone chrysops* (Rafinesque, 1820) (Perciformes: Moronidae) × striped bass, *M. saxatilis* (Walbaum, 1792) (Perciformes: Moronidae) (Kerby et al., 1987; Wolters and DeMay, 1996; Colombo et al., 1998), gilt-head seabream, *Sparus auratus* (Linnaeus, 1758) (Perciformes: Sparidae) × red seabream, *Pagrus major* (Temminck and Schlegel, 1843) (Perciformes: Sparidae) (Colombo et al., 1998), red seabream × common dentex, *Dentex dentex* (Linnaeus, 1758) (Perciformes: Sparidae) (Colombo et al., 1998), yellow fin seabream, *Acanthopagus latus* (Houttuyn, 1782) (Perciformes: Sparidae) × sobiaty seabream, *Sparidentex hasta* (Valenciennes, 1830) (Perciformes: Sparidae) (Bartley, 1998), brown-marbled grouper, *Epinephelus fuscoguttatus* (Forsskal, 1775) (Perciformes: Serranidae) × camouflage grouper, *E. polyphekadian* (Bleeker, 1849) (Perciformes: Serranidae) (James et al., 1999), and blue mussel, *Mytilus edulis* (Linnaeus, 1758) (Mytiloida: Mytilidae) × bay mussel, *M. trossulus* (Gould, 1850) (Mytiloida: Mytilidae) (Penny et al., 2002, 2006, 2007, 2008, and 2011).

1.3.2. Sterile or single-sex population control

Growth rate can be strongly sex-dependent, as one particular gender may grow faster than the other, e.g. males of giant freshwater prawn, *Macrobrachium rosengergii* (De Man, 1879) (Decapoda: Palaemonidae) and tilapias usually grow faster than females (Lahav and Lahav, 1990), but salmonids (Salmonidae) and sparids (Sparidae) have faster growing females (Bartley et al., 2001). Hybridization, which combines two distinct chromosomal structures from 2 different sources, usually results in sterility (Scheerer and Thorgaard, 1983; Salami et al., 1993) or reduction in reproductive possibility among hybrids (Bartley et al., 2001). Moreover, single-sex population can lessen the likelihood of early maturity in mixed-sex fish populations (Lahav and Lahav, 1990; Bartley et al., 2001). However, those common "consequences", though it may not expectful for fishes themselves, are more likely beneficial in aquaculture (Lahav and Lahav, 1990; Galbreath and Thorgaard, 1995; Colombo et al., 1998) because they may encourage the hybrid fishes to primarily use the absorbed energy/nutrients to develop their physical musculature, rather than on their gonadal development (Wills et al., 1994; Bartley, 1998; Bartley et al., 2001).

In certain cases, crossing between two distinct species or genera can produce mostly or all single-male hybrids [Nile tilapia × blue tilapia (Lahav and Lahav, 1990; Wohlfarth, 1994), Nile tilapia × Wami tilapia, Nile tilapia × long-finned tilapia, *O.macrochir* (Boulenger, 1912) (Perciformes: Cichlidae) (Wohlfarth, 1994), Mossambique tilapia × Wami tilapia (Head et al.,1994; Wohlfarth, 1994)] or single-female offspring [striped bass × yellow bass, *Morone mississipiensis* (Perciformes: Moronidae) (Jordan and Eigenmann, 1887) (Wolters and Demay, 1996)]. Those hybrids were proved to exhibit different improvement levels in their growth rates in comparison to their parental species.

1.3.3. Environmental tolerance and disease resistance

Enhancement in disease resistance is one of the most important goals in genetic improvement programs among fishes (Bartley, 1998). Losses caused by adverse environmental conditions and disease outbreaks are increasingly become the main concern in aquaculture. Dunham et al. (1983) mentioned the importance of seasonal low dissolved oxygen in catfish losses in intensive culture systems, whereas bacterial diseases are main pathological factors in tilapia production (Cai et al., 2004). Producing certain strains or species of fishes that possess predominant traits of environmental tolerance and parasite and disease resistance would theoretically result in a substantial decrease in the final mortality of cultured fishes (Dunham et al., 1983). Those positive characters considerably involved the hybridization in fishes.

Common environmental tolerance selections include normal (or even increased) growth rates in wide ranges of salinity [chum salmon, *Oncorhynchus keta* (Walbaum, 1792) (Salmoniformes: Salmonidae) × chinook salmon, *O. tshawytscha*) (Walbaum, 1792) (Salmoniformes: Salmonidae) (Seeb et al., 1993), Mossambique tilapia × Wami tilapia (Head et al.,1994; Ernst et al., 1989; Ernst et al., 1991), Nile tilapia × mango tilapia, *Sarotherodon galilaeus* (Linnaeus, 1758) (Perciformes: Cichlidae) (Yan and Wang, 2010), Beluga × Russian sturgeon (Gorshkova et al., 1996; Bartley et al., 2001)]; in low-pH reservoirs [lake trout, *Salvelinus namaycush* (Walbaum, 1792) (Salmoniformes: Salmonidae) × brook trout, *S. fontinalis* (Snucins, 1992)]; and low dissolved oxygen levels [green sunfish × bluegill (Wills et al., 1994), and channel catfish × blue catfish (Dunham et al., 1983; Dunham and Argue, 1998)] in culture systems. Additionally, hybrids of African catfish × broadhead catfish were also reported to have high tolerance to adverse environmental conditions in Southeast Asian countries (Minh, 1998). Other interspecific and intergeneric crosses can help improving the disease resistance among hybrids,

as been shown in the crosses of coho salmon, *Oncorhynchus kisutch* (Walbaum, 1792) (Salmoniformes: Salmonidae) × rainbow trout, *O. mykiss* (Walbaum, 1792) (Salmoniformes: Salmonidae) (Dorson et al., 1991), brook trout × rainbow trout (Dorson et al., 1991), Nile tilapia × blue tilapia (Cai et al., 2004), African catfish × broadhead (Pongchawee et al., 1995), and channel catfish × blue catfish (Wolters et al., 1996; Dunham and Argue, 1998; Griffin et al., 2010)

1.3.4. Improved flesh quality and fillet yields

Some of the preferred benefits in hybridizing fish species invole improvements in overall fillet processing production and flesh flavors. Particularly, crosses between yellow fin seabream × sobiaty seabream (Bartley, 1998) and African catfish × broadhead catfish (Minh, 1998) have been proved to create hybrids with better flesh quality, which enhance market acceptability, in comparison with one or either their parental species. The increase in marketability was predicted on the hybrids of green sunfish and bluegill (Wills et al., 1994). Additionally, Head et al. (1994) conducted a survey in Puerto Rico on the consumption of saltwater-cultured Florida red tilapia (*Oreochromis urolepis hornorum* × *O. mossambicus*) and concluded prospective market demands on this type of tilapia as they have better appearance (red skin), tasty flavor, and stronger texture than their parental species. Similarly, hybrids of catla × fringe-lipped peninsular carp (Basavaraju et al., 1995; Reddy, 2000), rohu × catla (Reddy, 2000), and channel catfish × blue catfish were repeatedly reported improvements in fillet yields in several studies in the Southern United States (Dunham and Argue, 1998; Argue et al., 2003).

Recently, Penny et al. (2002, 2006, 2007, 2008, and 2011) have published many comparative studies on aquacultural performance of two cultured mussel species, blue mussel and bay mussel, and their hybrids in natural and communally-stocked populations. They concluded the

intermediate performance of hybrids in shell strength, shell thickness, and ratio of total fresh meat weight/ total weight, although these authors further pointed out poorer performance in ratio of total dry meat weight/ total weight. Overall, the hybrids show improvements as compared to one of their parents in certain favorable characters for aquaculture.

In some circumstances, skin colors can also an important factor affecting the consumption of particular cultured fishes. Tilapias, for example, with red skin seem to be more favorable to culture than those in grey/dark colors as they have better market acceptability (Wohlfarth, 1994; Head et al., 1994). Crosses between certain strains of Nile tilapia and either blue tilapia or Wami tilapia can help producing red skin hybrids (Wohlfarth, 1994).

1.3.5. Harvestability

A main method for collecting fish at the end of culture cycle is seining (as trapping, Lewis, 1986), which remains challenging because some fish are nearly always missed. As such fish culturists tend to select easily-harvestable species to reduce incomplete harvesting and fish losses due to stresses and injuries during harvest (Green and Smitherman, 1984). Therefore, selection of certain strains or species through hybridization may result in easier-to-catch fishes that increase production yield (Tave et al., 1996; Dunham and Argue, 1998). Supporting this idea, Donalson et al. (1957) proved better catchability between two strains (wild and domesticated) of cutthroat trout (*Salmo clarkii*) hybrids in laboratory and field conditions after two fishing seasons. Similarly, Green and Smitherman (1984) observed the easier harvestability as well as the handling tolerance of bighead carp (*Hypophthalmichthys nobilis*) and its hybrid relative to silver carp (*Hypophthalmichthys molitrix*) when seining in earthen pond aquaculture.

In a genetic improvement study, Tave et al. (1981) selectively cultured of faster growing hybrids to improve harvestability because those larger fishes within a culture system tend to have more

aggressive behaviors. Channel × blue catfish hybrids reportedly have better seinability than channel catfish (Wolters et al., 1996) as they inherit the trait of easy harvest from their paternal species, blue catfish (Tave et al., 1981; Dunham and Argue, 1998). This catfish hybrid shows many positive characters for aquaculture but remains limited in commercial scales due to the isolating mechanisms in reproduction (Dunham and Argue, 1998).

1.3.6. Subtractive heterosis

An infrequent bottleneck of hybridization practices is the poorer performances among hybrids, which is known as subtractive heterosis (Milborrow, 1998). In some crosses, hybrids may become smaller in size relative to their parents, which has been explained as an effect of dysgenesis or deteriorative heredity (Milborrow, 1998). This phenomenon is rarely reported since most workers creating hybrids intend to improve the species not reduce its viability, but interesting examples can be found in the crossing of inbred parental lines (Milborrow, 1998). Subtractive heterosis is a distinct phenomenon to negative heterosis (performance of F1 hybrids have shorter time to reach the maturity or growing period than their parental species) (Stern, 1948; Milborrow, 1998). However, in interspecific and intergeneric crosses, desirable and unexpected traits can be simultaneously present among hybrids. Wills et al. (1994) noted the maturation of hybrid sunfish (*Lepomis cyanellus* × *L. macrochirus*) at small sizes. Correspondingly, Yan and Wang (2010) reported the earlier maturation among hybrids between *Oreochromis niloticus* × *Sarotherodon galilaeus*, associating with their superior growth and salinity tolerance, as compared to their parental pure lines. Those studies raised a critical concern in crossbreeding fishes, along with heterosis, whether hybrids can also inherit negative traits from their parental species?

1.4. Review of parasites and infectious diseases of commercially-valued catfishes

In commercial aquaculture, disease problems, usually in synergy with but not dependent upon unfavorable environmental conditions, are the most significant factors (Meyer, 1991) contributing to annual fish mortalities in most culture systems. Since variation exists in the efficacy levels of treatment and since few approved therapeutants exist (Meyer, 1991), preventing diseases in culture environments and implementing proper controlling methods to reduce disease outbreaks play vital roles for successful cohorts of cultured fishes. Tonguthai (1997) stressed the importance of preventative methods to minimize disease-causing losses in aquaculture settings. Several studies on important diseases on cultured catfishes have been carried out with the efforts of better understanding the infection sources, portals of entry, and possible disease controls or treatments. Although increasing attention among scientists and massive progresses have been made on studying parasitic diseases in aquaculture, effective controls of outbreaks and transmissions remain elusive and require further study (Scholz, 1999).

In many cases, particular diseases can be diagnosed through external signs exhibited on the hosts. Unfortunately, outside abnormalities caused by parasitic diseases are case-nonspecific and commonly comprise emaciation, excess mucus, fin erosion, clubbed gills, abrasions, petechiae, anemia, listless, erratic swimming, and anorexia (Meyer, 1975). In nursing channel catfish, parasites, especially *Scyphidia* sp., usually play as a strong limiting factor to eventual survival rates (Bryan and Allen, 1969). Generally, smaller fish tend to suffer higher rates of parasite infection and can continuously be killed with daily mortality rate of 5% (Meyer, 1975, 1991). However, in adult hosts, most of the parasitic diseases do not cause high economic losses (Meryman, 1975; Meyer, 1975, 1991).

Among parasitic taxa, protozoan parasites infect and cause significantly negative impacts on freshwater and marine fish species grown in aquaculture settings (Scholz, 1999). Major causative

protozoan parasites commonly belong to the genera of *Piscionodinium*, *Ichthyobodo*, *Ichthyophthirius*, *Amyloodinium*, *Trypanoplasma*, *Cryptocaryon*, *Loma*, *Chilodonella*, and *Cryptokryon* (Meyer, 1991; Scholz, 1999). Among channel, blue, and hybrid catfishes, current important parasitic diseases associated with high mortalities in commercial aquaculture involve ichthyophthiriasis (caused by *Ichthyophthirius multifiliis*) and proliferative gill disease (PGD, caused by *Henneguya ictaluri*).

1.4.1. Ichthyophthiriasis

1.4.1.1. General biology

The etiological agent of Ichthyophthyriasis, also known as "white spot disease" or "Ich", (Hoffman, 1999; Alvarez-Pellitero, 2004; Matthews, 2005; Francis-Floyd and Reed, 2009), is *Ichthyophthirius multifiliis* (Fouquet, 1876) (Hymenostomatida: Ichthyophthiriidae). Ich is one of the most significant parasitic diseases in freshwater aquaculture. *Ichthyophthirius multifiliis* is the largest known protozoan parasite, reaching 0.5−1.0 mm in diameter at mature individuals (Hoffman, 1999; Francis-Floyd and Reed, 2009). This species is widely distributed in tropical and temperate regions and can infect a multitude of freshwater fish species, either wild or cultured, including carps, rainbow trout, tilapias, eels, catfishes, and seemingly any ornamental fish species in an aquarium, with rapid and effective transmission rates (Hoffman, 1999; Scholz, 1999; Buchmann et al., 2001; Alvarez-Pellitero, 2004; Woo, 2007; Francis-Floyd and Reed, 2009; Heinecke and Buchmann, 2009; Osman, 2010). It mainly infects gills and skin, but can invade the eye in heavy infections (Alvarez-Pellitero, 2004; Osman et al., 2009; Yao et al., 2010).

Abnormal breathing, flashing swimming behavior, and reduced feeding are common external signs associated with Ichthyophthiriasis, as a result of osmotic and respiratory limitations on the

hosts (Scholz, 1999; Alvarez-Pellitero, 2004; Francis-Floyd and Reed, 2009). Although tolerant (Heinecke and Buchmann, 2009), this parasite's life cycle is highly temperature-dependant (Hoffman, 1999), ranging from 2 days at 24−26°C and may become as long as 30 days as temperature drops to 10°C (Hamrs, 1996; Francis-Floyd and Reed, 2009). Optimum temperature for Ich development ranges from 18−24°C, while disease outbreaks usually start at early spring when temperatures rise to 18°C (Hoffman, 1999; Matthews, 2005). Initially, parasitic trophonts encyst into and feed on the host epidermal layer. As reaching mature stages, trophonts usually leave the hosts and move down in water column to become encysted forms (tomonts), attaching to vegetation or any other substrates. Subsequently, tomonts further develop through tomontocyst stage by dividing into thousands individual cells before releasing the cysts to become free-swimming tomites and following infective theronts. Those forms complete the life cycle by penetrating epithelial layers of the hosts as parasitic trophonts (Harms, 1996; Matthews, 2005; Woo, 2007; Osman et al., 2009). Notably, free-swimming tomites are considered as obligate parasites since they cannot survive unless finding their hosts within 48 hours (Swennes et al., 2007; Francis-Floyd and Reed, 2009).

Diagnostic methods of this parasite include histology, fish behavioral observations, skin scraping, gill and fin biopsy, necropsy, and histopathology (Hamrs, 1996; Alvarez-Pellitero, 2004). Mature trophonts (white spots-individual trophonts) can be identified microscopically (typical C-shaped, or sausage or horseshoe-shaped macronuclei) or grossly (Hoffman, 1999; Alvarez-Pellitero, 2004; Francis-Floyd and Reed, 2009; Osman, 2009; Xu et al., 2011).

1.4.1.2. Disease significance

Severe mortalities among farm-raised and ornamental fishes caused by heavy Ich infections have been well-documented in many publications (Traxler et al., 1998; Scholz, 1999; Alvarez-

Pellitero, 2004; Matthews, 2005; Yao et al., 2010; Xu et al., 2011). Alternatively, Ich can cause considerable reductions of final production in non-lethal or sub-clinical infections (Scholz, 1999). Losses may range up to 100 % in many culture settings, especially in crowded populations and recirculating-involved designs (Swennes et al., 2007; Francis-Floyd and Reed, 2009; Heinecke and Buchmann, 2009). In catfishes, tank challenging studies of Xu et al. (2011) resulted in accumulative mortalities of 86.3% and 80.6% of channel catfish and blue catfish, reaching 100% at day 10. Theront densities of 10,000cells/l resulted in 100% mortality at day 8.

1.4.1.3. Catfish resistance to Ichthyophthiriasis

Resistance to *I. multifiliis* re-infection is similarly well-documented (Hoffman, 1999; Buchmann et al., 2001; Alvarez-Pellitero, 2004; Swennes et al., 2007). The presence of numerous proteins (known as immobilization antigens) in the cilia and vortex of Ich cells are capable of inducing a specific immune response in fish (Swennes et al., 2007). Therefore, intraperitoneal injection or immersion bath of live theronts or sonicated trophonts can stimulate channel catfish to produce a specific humural response (antibodies) against Ich (Wang and Dickerson, 2002; Xu et al., 2004; Xu et al., 2006; Woo, 2007; Swennes et al., 2007).

Susceptibility to Ich infection can vary among different fishes. Nile tilapia was less vulnerable to Ich infection than channel catfish when co-challenged in the same facilities (Xu and Klesius, 2006). Similarly, blue catfish used to be believed less resistant to Ich infection than channel catfish (Dunham et al., 1994). However, Xu et al. (2011) using in-tank comparative experiments among channel catfish, blue catfish, and hybrid catfish, revealed no statistical difference of susceptibility among catfishes, although channel catfish exhibited slightly higher mortalities than blue catfish and hybrid catfish.

1.4.1.4. Control and prophylaxis

Widespread losses attributable to *I. multifiliis* infections in aquaculture around the world lead to substantial preventive strategies and treatment methods. This ciliate parasite has only two susceptible free-swimming stages (theronts and tomites) but multiple resistant developmental stages with protective encysted or penetrated forms, consequently it is difficult to remove out of culture operations using only a single treatment (Harms, 1996; Hoffman, 1999; Francis-Floyd and Reed, 2009; Xu et al., 2009). Therefore, extended and repeated treatments, which are more expensive, are required to clear the parasites from the water column and sediment (Harms, 1996; Scholz, 1999). Tonguthai (1997) suggested several methods of parasite control, giving as manual removals, topical cleaners, management practices, nutritional improvement, vaccination, chemoprophylaxis, chemotherapy, quarantine, and certification. However, approved drugs for successfully controlling Ich remain under study for future development (Xu et al., 2009). This barrier additionally creates more challenges for maintaining cultured fish health against this pathogenic agent in aquaculture.

Various drugs have been tried to alleviate Ichthyophthiriasis with varing success (Scholz, 1999; Harms, 2006; Yao et al., 2010). Malachite green has been widely used to treat various groups of parasites since the 1950s, most effectively on *Ichthyophthirius multifiliis* in 1960s in cultured settings (Sudova et al., 2007). As the discovery of cancer- and mutation-causing factors associated with malachite green, it was first banned for using in aquaculture since the year of 2000 in Europe (Sudova et al., 2007; Yao et al., 2010). Although the high potential toxicity to human and fish health as well as governmental prohibition, malachite green still may be used by farmers because of its strong and rapid effects in clearing several infectious diseases (Sudova et al., 2007; Francis-Floyd and Reed, 2009). Other chemicals have been tried with different efficacies: formalin, hydrogen peroxide, potassium permanganate, sodium percarbonate,

peracetic acid, sodium chloride, praziquantel, chloramines T, copper sulfate, and salt (sodium chloride) (Yao et al., 2010). Among those chemicals, formalin (tanks), copper sulfate, and potassium permanganate (ponds) are most frequently used to control this protozoan parasite (Alvarez-Pellitero, 2004; Francis-Floyd and Reed, 2009). Alternatively, some have used herbal treatments with reportedly promising results for killing Ich (Buchmann et al., 2003; Ekanem et al., 2004; Yao et al., 2010). Further studies will clarify the feasibility and applicability of these herbs for treatment of ichthyophthiriasis.

Besides treating methods, preventative awareness should not be underestimated. As disease outbreaks happen, fish losses (small to entire culture facilities) are unavoidable (Tonguthai, 1997). Applying chemical treatments partially helps but environmental and human risks, such as parasite resistance, chemical toxicity and persistence, may dominate the gaining benefits (Scholz, 1999). Numerous parasite preventing strategies have been suggested as priority practices in aquacultures (Harms, 1996; Tonguthai, 1997; Scholz, 1999; Sudova et al., 2007; Francis-Floyd and Reed, 2009; Heinecke and Buchmann, 2009). Common suggestions are selection of disease-resistant stocks, appropriate stocking densities, and water quality managements (filtration and partial exchange, routine fish health examination and quarantine, early diagnosis, and maintenance of high water temperature within fish optimal ranges).

Since vaccination is a cost-effective method for clearing many infectious diseases (Vinitnantharat et al., 1999; Pridgeon and Klesius, 2010), a recent immunological approach against ichthyophthiriasis involes vaccine development. Currently, there is no commercially-approved vaccine against a fish parasite (Sommerser et al., 2005) although some achievements in protective immunity have been obtained from live sonicated parasites (Matthews, 2005). Currently, culturing of Ich isolates for commercial vaccine development is not fully successful as

they soon lose infection capacities after repeated passages (Xu and Klesius, 2004; Matthews, 2005). In spite of the fact that most fish vaccine studies were related to bacterial pathogens, anti-parasitic agents or parasitic vaccines can also be feasible because of increasing knowledge on parasitology and host-parasite interactions in recent decades (Tonguthai, 1997; Scholz, 1997; Sommerser et al., 2005). Early protection of channel catfish against Ich has been recorded by two immobilized serotypes of *Ichthyophthirius multifiliis* (Swennes et al., 2007). Future studies on Ich vaccines are expected (Sommerser et al., 2005).

1.4.2. Proliferative gill disease (PGD)

1.4.2.1. General biology

Henneguya ictaluri was discovered as the causative agent of proliferative gill disease, which also commonly known as "hamburger gill" (Mitchell et al., 1998; Belem and Pote, 2001; Hawke and Khoo, 2004; Griffin et al., 2008a, 2009, 2010; Wise et al., 2008; Beecham et al. 2010). PGD was first reported in 1981 in commercial channel catfish culture (Griffin et al., 2008a; Wise et al., 2008). Thiyagarajah (1993) reported infections of wild largemouth bass, *Micropterus salmoides* (Lacepede, 1802) (Perciformes: Centrarchidae) and bluegill sympatric channel catfish. Those two new hosts, however, were believed as accidental hosts [host that is not normally infected the parasite species, Poulin (1992)] since no inflammatory reaction was observed on their gill filaments (Thiyagarajah, 1993). This myxozoan parasite is relatively host and site specific, but exhibits some pathological variations when infecting different hosts (Bosworth et al., 2003; Griffin et al., 2010). The life cycle of *H. ictaluri* includes two distinct stages: a myxospore that infects fish and an actinospore that infects the benthic oligochaete *Dero digitata*, which is widely distributed in earthen catfish production ponds (Wise et al., 2008; Griffin et al., 2010). Actinospores are commonly found in pond water, even in the absence of PGD (Whitaker

et al., 2005). After releasing from the host, actinospores are infective within 24−48 h (Wise et al., 2008; Griffin et al., 2009, 2010)

Most of PGD outbreaks are associated with severe losses optimally occurring during spring at temperatures of 16−25°C (Mitchell et al., 1998; Hawke and Khoo, 2004; Griffin et al., 2008a, 2009, 2010; Wise et al., 2008). Although sometimes damaging larger fish, PGD generally causes more severe effects on younger catfishes (Hawke and Khoo, 2004). When moderately or heavily infected, fish swim erratically or listlessly at the pond surface and crowd to aerated areas. Gill damage includes swelling, hemorrhage, inflammation, and molting on the gill filaments (Mitchell et al., 1998; Hawke and Khoo, 2004; Griffin et al., 2008a, 2009, 2010; Wise et al., 2008).

H. ictaluri infection initiates from invasions of sporozoites into the fish host's tissues. In the acute stage of the infection, sporozoites disperse evenly throughout the skin, spleen, kidney, liver, heart, stomach, brain, and finally to the target tissue, gill filaments (Mitchell et al., 1998; Belem and Pote, 2001; Griffin et al., 2010). Portals and mechanisms of entry are indeterminate but probably comprise the gut (Belem and Pote, 2001). After 96 hrs, actinospores are difficult to detect in non-gill tissue (Belem and Pote, 2001) but levels of infection and particular changes can be varied among different host species. A recent physiological study from Beecham et al. (2010) in hematic effects of PGD on channel catfish, blue catfish, and hybrid catfish fingerlings held in cages showed significant changes in selected blood parameters. The 96 h analysis of the bloodstream revealed reductions in oxygen partial pressure, increase in carbon dioxide pressure, accompanying with decreases pH level and increases in lactate concentration on channel catfish and hybrid catfish. Conversely, those changes were not observed, suggesting the less severe infections among blue catfish (Beecham et al., 2010).

Traditional diagnosis of PGD involved gross examinations of gill filaments or microscopic observations of the gill wet-mounts and histopathology (Whitaker et al., 2005). "Hamburger gill disease" can be currently confirmed by histologically examining the typical multinucleated trophozoites, which positively correlation to disease acuteness, surrounded by inflammation (Mitchell et al., 1998; Wise et al., 2008; Griffin et al., 2008a). This method has high efficacy only on young fish with small gill filaments and that are harbored intense infections; it usually fails to diagnose subclinical *H. ictaluri* infections because of undetectable trophozoite levels (Whitaker et al., 2005; Griffin et al., 2008a). Some myxozoan specialists tried to overcome this problem by using standard PCR (polymerase chain reaction) to detect actinospores in pond water, in oligochaetes, and in fishes (Whitaker et al., 2005). Later, Griffin et al. (2008a) developed a specific, rapid and sensitive real-time PCR protocols to quantitatively detect *H. ictaluri* in pond water and gill tissues at early developmental stages for farm-raised channel catfish.

1.4.2.2. Disease significance

PGD is currently estimated as the third most devastating disease in catfish industry, particularly in channel catfish aquaculture, following enteric septicemia of catfish (ESC) and columnaris diseases (Bosworth et al., 2003; Camus et al., 2006; Griffin et al., 2008a, 2009, 2010; Wise et al., 2008). During the period 1997-2005, 20% of the total disease cases sent to the Aquatic Diagnosis Laboratory at the Thad Cochran National Warmwater Aquaculture Center (TCNWAC) in Stoneville, Mississippi, were diagnosed as PGD (Mitchell et al., 1998; Bosworth et al., 2003; Camus et al., 2006; Griffin et al., 2008a; 2010; Wise et al., 2008; Beecham et al., 2010).

The development of *H. ictaluri* sporoplasms can cause hypertrophy or hyperplasia, leading to chondrocytic lysis in gill filaments. More seriously, when the gill surface epithelium is highly damaged, it becomes poorly fuction in osmoregulation and respiration (Griffin et al., 2008a, 2009, 2010; Wise et al., 2008). In heavy PGD outbreaks, massive fish mortalities are more likely caused by hypoxia rather than imbalanced osmoregulation due to gill filament damage (Mitchell et al., 1998; Beecham et al., 2010). Once suffering severe gill injuries, fishes have limited capacities to osmoregulate and exchange gases. Moreover, as fish are exposed to more stresses, PGD itself and other opportunistic pathogens are then more likely to kill the fish (Griffin et al., 2010). In addition, despite of variations in other hematic parameters during disease progress, calcium concentration seems to remain unchanged during exposures of channel catfish, blue catfish, and hybrid catfish to infective PGD agents, which suggesting insignificant contributions of osmotic loss to fish kill. However, compensating mechanisms for the calcium deficiency in diseased fish are still uncertain (Beecham et al., 2010). In sub-lethal infections, PGD can cause anorexia and eventually slow growth rates for cultured fishes (Mitchell et al., 1998; Griffin et al., 2008a).

1.4.2.3. Catfish resistance to PGD

Bosworth et al. (2003) conducted the first comparative challenge studies on different strains and breeding lines among channel catfish, blue catfish, and hybrid catfish. Results from their research were consistent with previous observations that blue catfish families tend to be more resistant to PGD than those of channel catfish. Although slightly more resistant than channel catfish, hybrid catfish families were still far more susceptible to PGD compared to families of blue catfish.

The second study by Beecham et al. (2010) consolidated findings from Bosworth et al.'s (2003) results. Blood parameters (oxygen partial pressure, carbondioxide partial pressure, pH value) for channel, blue, and hybrid catfishes exposed to infective actinospores of *H. ictaluri* supported resistance to PGD among blue catfish.

Griffin et al. (2010) compared histopathology and molecular techniques to study PGD infection. After several 5-7 day challenges, 66.2%, 63.6%, and 3.7% of channel catfish, hybrid catfish, and blue catfish, respectively, were histologically positive for PGD lesions on gill filaments; whereas 98.7%, 95.7%, and 45.9% of channel catfish, hybrid catfish, and blue catfish, respectively, revealed positive results when using quantitative PCR technique. PGD showed almost no further plasmodial development on blue catfish when kept longer in the infective PGD ponds, although high levels of gill damage and large number of fully-developed plasmodia were associated with both gills of channel catfish and hybrid catfish. Those data obviously suggested higher resistance among blue catfish and higher susceptibility of channel catfish and hybrid catfish to PGD infections (Griffin et al., 2010).

1.4.2.4. Control and prophylaxis

No effective treatment against PGD is commercially available (Mitchell et al., 1998) but selective stocking methods are promising for curbing the spread of the disease among cultured catfishes (Griffin et al., 2008a, 2009, 2010; Wise et al., 2008; Beecham et al., 2010) using intraspecific or interspecific crosses (Bosworth et al., 2003). Additionally, in terms of disease diagnosis, Belem and Pote (2001) proposed the process of indirect fluorescent antibody test (IFAT), which detects different developmental stages of *H. ictaluri* from post-24 h infection in different channel catfish tissue. Subsequently, Griffin et al. (2008a) successfully developed the specific quantitative PCR technique for early detection of PGD infection in channel catfish

aquaculture. The application of this technique and other management procedures are expected to accurately diagnose early infection of the disease. Moreover, alleviation of potential PGD-caused losses can be possible by maintaining good dissolved oxygen levels, keeping chloride concentration above 100 mg/l, and reducing feed rates (Beecham et al., 2010). Griffin et al. (2010) suggested the reconsideration of blue catfish as the potential main cultured catfish or at least alternating cohorts of channel and blue catfishes to break the PGD cycle. They further recommended removing infected fish from infection sources as they may recover within 14 days post-quarantine (also Wise et al., 2008; Griffin et al., 2009).

An alternative treatment is given by Mitchell (2002) for effectively treating PGD in tank and pond operations. This consists of applying indefinite treatments at low concentrations, approximately 2-3 ppm of Chloramine-T, accompanying with operating aerators 1 h and 35 h prior and subsequent to chemical implement, respectively, without removing diseased fishes out of the culture facilities. According to the author, 2-inch catfish can be cleared of PGD after treatment with Chloramine-T during the daytime with strictly following the appropriate drug concentrations; recommended withdraw period is ≥9 days pre-harvest. As an aside, Chloramine-T is applicable for the treatment of external columnaris, gill flukes, ESC, and other parasitic infections (Mitchell, 2002), though it is not approved by the U.S. Food and Drug Administration.

1.4.3. Previously-reported parasites of channel, blue, and hybrid catfishes

Table 2 shows the most recent, comprehensive listing of parasites that infect channel, blue, and hybrid catfishes. Many parasites have been reported from these fishes because channel catfish has been cultured since the early 1960s (Meyer, 1975; Shrestha, 1977; Jiang et al., 2008; Xu et al., 2011). Most of these records are from wild hosts because typically few parasite species are capable of adapting to cultured environments (Meyer, 1991). Possible reasons may involve i)

short culture duration cycles; ii) less host species diversity in food chains, which are one of the main transmission routes of most parasites (i.e., lack of required intermediate hosts); iii) the restricted biological and ecological interactions among organisms of culture environments (Meryman, 1975; Shrestha, 1977). However, the mean intensity of parasitic infections among cultured fish stocks are typically far greater than those observed in natural environments due to the higher availability of target hosts for transmission in confined spaces (Meyer, 1991; Scholz, 1999).

Table 1. Number of parasite species previously reported from channel, blue, and hybrid catfishes (see Table 2 for detailed summary of each parasite record).

parasite phyla	channel catfish	blue catfish	hybrid catfish
Fungi	2	0	0
Rhizopoda	2	0	0
Ciliophora	13	1	3
Mastigophora	7	0	0
Chlorophyta	1	0	0
Cnidaria	11	5	1
Platyhelminthes	62	29	1
Nematoda	16	17	0
Acanthocephala	7	2	0
Annelida	7	1	0
Arthropoda	12	5	0
Mollusca	1	0	0
Total	141	60	5

Previously-reported parasites on channel catfish, blue catfish, and hybrid catfish belong to 12 phyla, comprising 5 protozoan (Fungi, Rhizopoda, Ciliophora, Mastigophora, and Chlorophyta) and 7 metazoan phyla (Platyhelminthes, Nematoda, Acanthocephala, Annelida, Arthropoda, Cnidaria, and Mollusca) (Table 1).

Channel catfish harbors the highest number of parasite records among the three catfishes with total 141 parasite species. It is followed by blue catfish and hybrid catfish with 60 and 5 reported species, respectively (Table 1). However, these numbers are probably biased by the fact

that channel catfish is the most commonly-studied fish due to its commercial value and by the fact that few researchers have access to hybrid catfish for parasitological studies.

Among reported parasite phyla, Platyhelminthes, including monogeneans (gill and skin flatworms), digeneans (flukes), and cestodes (tapeworms), outnumber other presented phyla in channel catfish and blue catfish with almost half of the described parasites belong to this phylum [62 of 141 (43.97%) in channel catfish and 29 of 60 (48.33%) in blue catfish)]. Nematodes are the second most diverse phylum to infect channel and blue catfishes, 16 and 17 species, respectively. Other phyla occupy insignificant proportions in total numbers of discovered parasite species on channel and blue catfishes, except for the Ciliophora and Arthropoda that account for 13 and 12 species on channel catfish, respectively. Consistently, since not being extensively studied, very few parasites (5 species) have been reported on hybrid catfish. A study on multiple types of hybrid catfishes (fry) among channel, blue, and white catfish, *Ictalurus catus* (Linnaeus, 1758) (Siluriformes: Ictaluridae) conducted by S. B. Shrestha (1977) provided very limited and rather dubious information on parasites of hybrid catfish, assessing only to genus-level of *Trichodina*, *Ichthyophthirius*, *Scyphidina*, and *Cleidodiscus*. Other comparative studies among channel catfish, blue catfish, and hybrid catfish focused on some particular parasitic *Henneguya* species (Bosworth et al., 2003; Griffin et al., 2010; Beecham et al., 2010), and *Ichthyophthirius* (Xu et al., 2011).

The present study, therefore, will provide species-level identifications and more knowledge for a fair comparison, in term of parasitism susceptibility, among the three mentioned catfish species, focusing on hybrid catfish.

Chapter 2

MATERIALS AND METHODS

2.1. Pond stocking
2.2. Pond management
2.3. Catfish collection
2.4. Catfish identification, necropsy, and parasite examination
2.5. Parasite fixation and identification
2.6. Statistical analysis

2.1. Pond stocking

In the late January 2010, 750 individuals of each hatchery-reared species of channel catfish (initial average weight 14.83 g/fish), blue catfish (18.92 g/fish), and hybrid catfish (9.92 g/fish) were communally stocked in each of three 0.04 ha static water earthen ponds at E. W. Shell Fishery Center, Auburn University, Auburn, Alabama. Each pond was treated as an equal replicate.

2.2. Pond management

Catfishes were fed once daily to apparent satiation (based on catfish feeding response) and temperature (no feeding activity during winter) with 32−36% protein floating pelleted feed. Water depth in each pond was maintained at 1.2−1.5 m. Water was supplied without filtering. Aerators were used during times of low dissolved oxygen (July 2010−January 2011). No other pond treatments were employed.

2.3. Catfish collection

Ten individuals of each catfish species from each pond per collection event were sampled monthly from January 2010 (including the stocking time) through February 2011. Hatchery seines (mesh sizes vary with the growth of catfishes) were used to collect catfishes from the three ponds. Seines were handled manually by 2 or 3 people. Fish were placed in buckets containing pond water and individual aerators, and immediately transported to the Aquatic Parasitology Laboratory for catfish necropsy and parasite examination.

2.4. Catfish necropsy and parasite examination

After seining, channel catfish, blue catfish, and hybrid catfish were morphologically identified initially at the ponds (according to the morphological differences described by Masser and Dunham, 1998). In the laboratory, catfish identifications were confirmed by observing

characteristics of the swim bladders. Generally, channel catfish lacks a swim bladder constriction; whereas blue catfish has a medial constriction and hybrid catfish has a posterior constriction (Figs. 1.1−6). All catfishes were euthanized with Tricaine Methanesulfonate (MS-222) at 300 mg/L before dissection. Catfish organs were extracted and placed in physiological saline, their lumen opened with scissors, and examined for the presence of parasites. A stereo dissecting microscope (Meiji RZ 3288) fitted with a digital camera (Jenoptik HDD076-CMT) was used for fish necropsy and gross parasite examinations. Compound microscopes (Meiji MX5310L and Leica DM2500) equipped with phase contrast optics and differential interference optics components were used for observing further structures of microscopic parasites. Parasites attaching tissues were photographed before being removed from catfish organs for fixation.

2.5. Parasite fixation and identification

Helminth parasites (Monogenea and Cestoda) were heat-killed in hot water (approximately 60 ^{o}C) or flame-killed before fixation in 10% neutral buffer formalin (nbf). Nematode parasites were removed alive from the gut and mesentery before being killed with glacial acetic acid and subsequently being fixed in 10% nbf. Other parasite groups (Myxozoa, Copepoda, Protozoa, and Unionidae) were fixed directly in 10% nbf or 70% ethanol. Specimens were kept separately in labeled vials and whirl pack sample containers. For the purpose of this thesis, no protozoan parasite was studied.

Parasites were morphologically characterized and compared to the published literature (Rudolphi, 1819; Say, 1829; von Nordmann, 1883; Kudo, 1929; Harada, 1930; Mueller, 1936, 1937; Sneed, 1950; Jones, Kerley, and Sneed, 1956; Yin, 1956; Freze, 1965; Befus and Freeman, 1973; Minchew, 1977; Klassen and Beverley-Burton, 1985; Hayden and Rogers, 1998; Moravec,

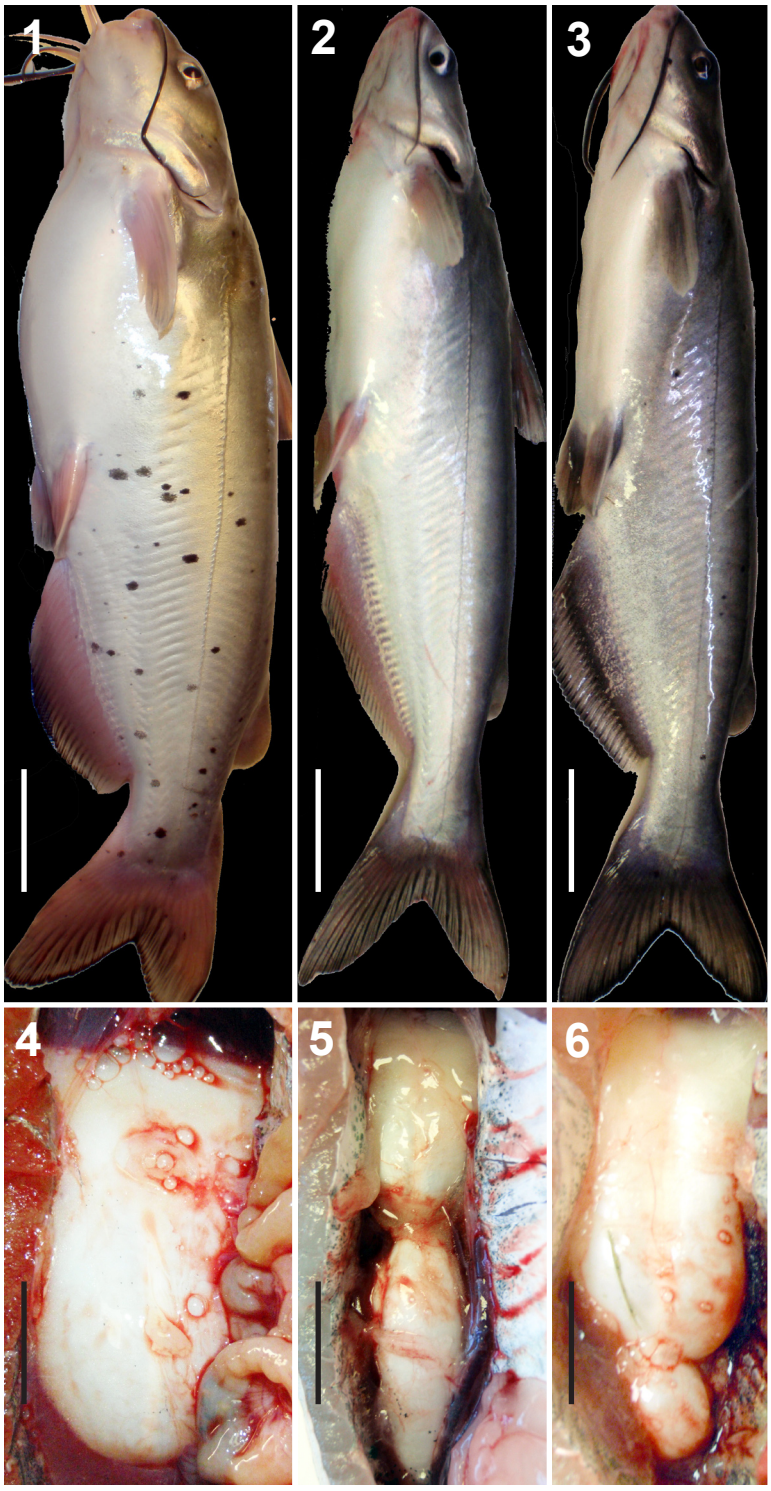

PLATE 1. Morphological comparisons among channel catfish, blue catfish, hybrid catfish, and their swim bladders. 1. Channel catfish. 2. Blue catfish. 3. Hybrid catfish. 4. Swim bladder, channel catfish. 5. Same, blue catfish. 6. Same, hybrid catfish. Scale bars: Figures 1–3 = 3cm, Figures 4–6 = 6cm.

1998; Hoffman, 1999; Pote et al., 2000; Piasecki et al., 2006; Griffin et al., 2008, 2009a,b, 2010) to facilitate identification.

Helminth parasites were stained with Van Cleave's and Ehrlich's or Delafield's hematoxylins or Semichon's acetocarmine before being permanently mounted on glass slides using Canada Balsam (Cestoda) or Gray and Wess medium (Monogenea). Myxozoan parasites were identified by comparative measurements (total spore length, caudal process length, spore length and width, polar capsule length and width, number of turns within polar filaments, etc.) between species reported in the literature and specimens in this study (Kudo, 1929; Minchew, 1977; Pote et al., 2000; Griffin et al., 2008, 2009a,b, 2010). Copepoda groups were wet-mounted on microscopic slides and identified based on the diagnostic keys on their appendages. Nematode and Unionidae groups, when observed in larval stages, were identified to the level of genus since diagnosing immature specimens of these taxa is not presently possible.

For each catfish individual, intensity was qualitatively estimated/categorized for each parasite taxon on each catfish individual by the following ranges: Myxozoa (plasmodia, < 10 = low; 10−20 = medium; > 20 = high), Monogenea (individuals, < 30 = low; 30−50 = medium; > 50 = high), Cestoda (individuals, < 3 = low; 3−8 = medium; > 8 = high), Nematoda, Unionidae, and Copepoda (individuals, < 2 = low; 2−5 = medium; > 5 = high). Data on qualitative intensity was then calculated and reported as mean intensity for each parasite taxon by the following: low = 1.00, medium = 2.00, high = 3.00. Prevalence of each parasite taxon was calculated by the ratio between total infected catfish and total examined catfish.

All line drawings (by pencils) of parasites species were done under the compound microscope (Leica DM2500) with the aid of drawing tube and digital camera (Leica CH-9435

Heerbrugg DFC420). The line drawings were then inked to make plates for illustrations of each identified parasite species.

For the purposes of this thesis, figures and plates will be referred to by the plate number followed by the numbered figure(s) within each plate, e.g., Plate 1, Figure 2 = Fig. 1.2); plate with a single figure will be referred to as Plate x, with "x" indicated the number of that plate, e.g., Plate 4.

Chapter 3

TAXONOMIC DESCRIPTION OF METAZOAN PARASITES COLLECTED FROM CHANNEL, BLUE, AND HYBRID CATFISHES IN THE PRESENT STUDY

Phylum: Cnidaria
- Class: Myxozoa
  - Family: Myxobolidae
    - Genus: *Henneguya* (Thélohan, 1892) Davis, 1944
      - *Henneguya* cf. *postexilis* Minchew, 1977 (Plate 2−3)
      - *Henneguya* cf. *exilis* Kudo, 1929 (Plate 3−4)
      - *Henneguya* cf. *adiposa* Minchew, 1977 (Plate 3, 5)
      - *Henneguya* cf. *ictaluri* Pote, Hanson, and Shivaji, 2000 (Plate 3, 6)

Phylum: Platyhelminthes
- Class: Monogenea
  - Family: Dactylogyridae
    - Genus: *Ligictaluridus* Beverley-Burton, 1984
      - *Ligictaluridus mirabilis* (Mueller, 1937) Klassen and Beverley-Burton, 1985 (Plate 7−8)
      - *Ligictaluridus pricei* (Mueller, 1936) Beverley-Burton, 1984 (Plate 9−10)
- Class: Cestoda
  - Family: Proteocephalidae
    - Genus: *Corallobothrium* (Fritsch, 1886) Freze, 1965
      - *Corallobothrium fimbriatum* Essex, 1928 (Plate 11−12)
      - *Corallobothrium parafimbriatum* Befus and Freeman, 1973 (Plate 13−14)
    - Genus: *Corallotaenia* (Freze, 1965) Befus and Freeman, 1973
      - *Corallotaenia intermedia* (Fritts, 1959) Freze, 1965 (Plate 15−16)
    - Genus: *Megathylacoides* (Jones, Kerley, and Sneed, 1956) Freze, 1965
      - *Megathylacoides* cf. *giganteum* (Essex, 1928) Freze, 1965 (Plate 17)
      - *Megathylacoides thompsoni* Jones, Kerley, and Sneed, 1956 (Plate 18−19)

Phylum: Nematoda
- Order: Spirurida
  - Family: Gnathostomatidae
    - Genus: S*piroxys* Schneider, 1886
      - *Spiroxys* cf. *contortus* (Rudolphi, 1819) (Plate 20−21)

Phylum: Mollusca
- Class: Bivalvia
  - Family: Unionidae

Genus: *Pyganodon* Fischer and Crosse, 1894
Pyganodon cf. *grandis* (Say, 1829) (Plate 22−23)
Phylum: Arthropoda
Class: Maxillopoda
Familiy: Ergasilidae
Genus: *Neoergasilus* Yin, 1956
Neoergasilus japonicus (Harada, 1930) Yin, 1956 (Plate 24−25)
Family: Lernaeopodidae
Genus: *Achtheres* von Nordmann, 1832
Achtheres cf. *percarum* von Nordmann, 1883 or *A.* cf. *sandrae* Gadd, 1901 (Plate 26−27)

During the study period, 15 species of metazoan parasites were found infecting channel catfish, *Ictalurus punctatus* (Rafinesque, 1818) (Siluriformes: Ictaluridae), blue catfish *I. furcatus* (Lesueur, 1840) (Siluriformes: Ictaluridae), and female *I. punctatus* × male *I. furcatus* hybrid catfish, including four species of Myxozoa (Cnidaria), two species of Monogenea (Platyhelminthes), five species of Cestoda (Platyhelminthes), one morphotype comprising the 3rd stage larva of a species of Nematoda (Nematoda), 1 species of Unionidae (Mollusca), and two species of Copepoda (Arthropoda).

Phylum: Cnidaria

Class: Myxozoa

Family: Myxobolidae

Genus: *Henneguya* (Thélohan, 1892) Davis, 1944

Diagnosis: Spore ovoid with two polar capsules at anterior end. Posterior end of shell valves prolonged into more or less extended processes. Body of spore biconvex and compressed parallel to sutural plane. Sporoplasm with an iodinophile vacuole. Mostly tissue parasites, usually forming cyst. Polysporous.

Taxonomic summary

Type species: Henneguya psorospermica Thélohan, 1895 (Bivalvulida: Myxobolidae)

Other species: 204 described species. Currently, 21 species known infecting ictalurids (Iwannowicz et al., 2008), and of those species, 11 known infecting ictalurid fishes in Southeastern United States (Griffin et al., 2008), including *H. gurleyi* Kudo, 1920 (Bivalvulida: Myxobolidae); *H. exilis* Kudo, 1929 (Bivalvulida: Myxobolidae); *H. limatula* Meglitsh, 1937 (Bivalvulida: Myxobolidae); *H. ameiurensis* Nigrelli and Smith, 1940 (Bivalvulida: Myxobolidae); *H. adiposa* Minchew, 1977 (Bivalvulida: Myxobolidae); *H. diverisis* Minchew, 1977 (Bivalvulida: Myxobolidae); *H. longicauda* Michew, 1977

(Bivalvulida: Myxobolidae); *H. pellis* Minchew, 1977 (Bivalvulida: Myxobolidae); *H. postexilis* Minchew, 1977 (Bivalvulida: Myxobolidae); *H. ictaluri* Pote, Hanson, and Shivaji, 2000 (Bivalvulida: Myxobolidae); *H. sutherlandi* Griffin, Pote, Wise, Greenway, Mauel, and Camus, 2008 (Bivalvulida: Myxobolidae).

Host family: Wide variety of freshwater, estuarine, and marine fishes, including Ictaluridae in North America.

***Henneguya* cf. *postexilis* Minchew, 1977** (Plates 2−3)

Supplemental observations based on 12 myxozoan plasmodia and 249, 7, and 41 wet-mounted spores in channel, blue and hybrid catfishes, respectively, with measurements in microns: Cysts small with shape variable from round, void, to elongate; cyst wall thick, fragile with numerous developing and developed spores; cyst dimension 198.08 (70–395; n=12) in length and 136.67 (55–270, n=12) in breath (Figs. 3.1, 3.3). Spores with ellipsoid or elongate spore body and slender caudal process; total spore length generally shorter than other *Henneguya* spp. infecting ictalurid fishes in Southeastern United States, 56.59 (40–70; n=249) long in channel catfish, 54.14 (48–61; n=7) in blue catfish, and 55.63 (47–69; n=41) in hybrid catfish (Table 5). Spore body length roughly 4 × longer than wide, 15.69 (12–23; n=249) long in channel catfish, 15.71 (15–17; n=7) in blue catfish, and 16.41 (12–19; n=41) in hybrid catfish in body length and 4.19 (3–6; n=249) in channel catfish, 4 (n=7) in blue catfish, and 4.59 (4–6; n=41) in hybrid catfish in body width; spore body widest part usually medial or sometimes anterior. Polar capsule in pair, elongate, equal or unequal, usually close together, vertically symmetrical to body dividing line; polar capsule anterior half of spore body, longer polar capsule length 6.48 (4–8; n=249) in channel catfish, 7 (6–8; n=7) in blue catfish, and 6.59 (6–8; n=41) in hybrid catfish, shorter polar capsule 6.12 (4–8; n=249) in channel catfish, 6.29 (6–7; n=7) in blue catfish, and 6.09 (5–8; n=41) in hybrid catfish; polar capsule width generally consistent, 2 (n=249) in channel catfish, 2

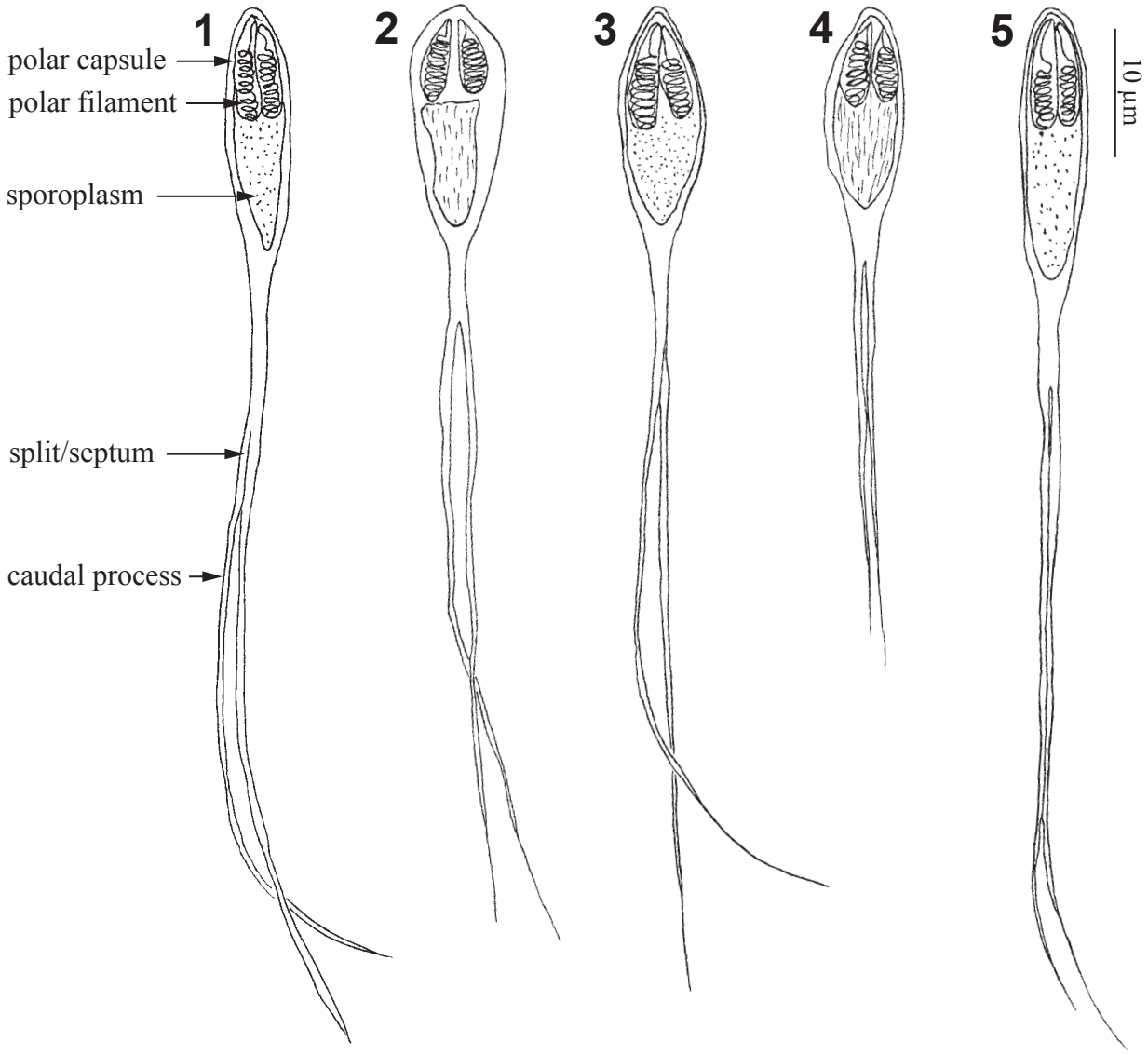

PLATE 2. *Henneguya* cf. *postexilis* Minchew, 1977 from gill of blue and hybrid catfishes studied herein, line illustrations from light microscopy. Figures 1–5. Variations in the morphology of the species. Scale bar: Figures 1–5 = 10µm.

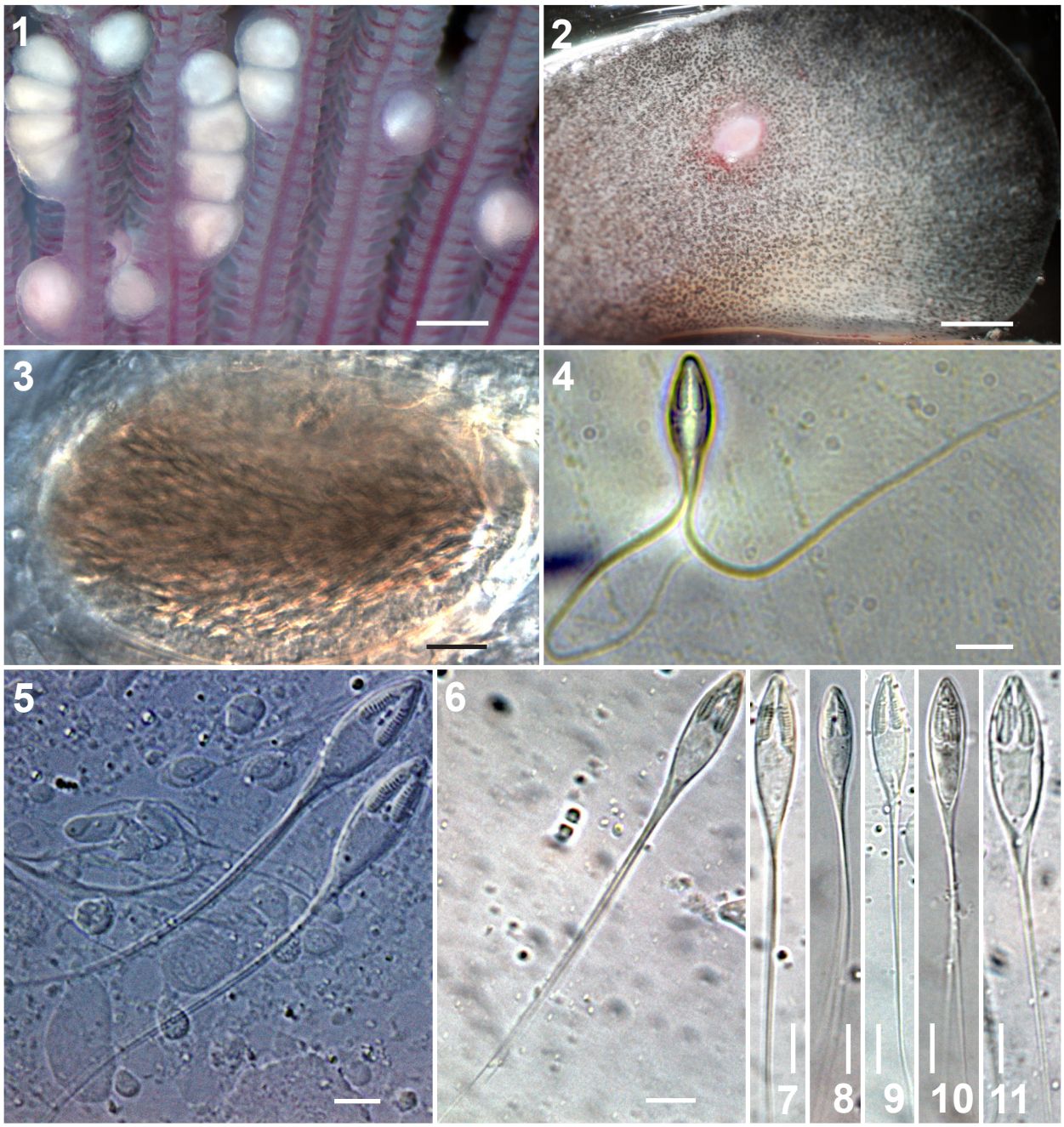

PLATE 3. *Henneguya* spp. from gill and adipose fin of channel, blue, and hybrid catfishes studied herein, photograph illustrations. 1. Gill-enysted plasmodia. 2. Adipose fin-encysted plasmodia. 3. High magnification of a gill-encysted plasmodium. 4–11. Released spores in wet-mount microscopic slides. Scale bars: Figure 1 = 400µm, Figure = 20mm, Figure 3 = 50µm, Figures 4–11 = 5µm.

(n=7) in blue catfish, and 2.02 (2–3; n=41) in hybrid catfish (Figs. 2.1−5; Table 5). Polar filament coils present in each polar capsule, 9–12 turns each; turns present medially and posteriorly in the polar capsule; polar filaments sometimes extrusive out of polar body as flagella-like structure (Figs. 2.1−5; Figs. 3.4−11). Sporoplasm posterior half of spore body, roughly equal to polar capsule in length, 6.23 (4–10; n=249) in channel catfish, 6.29 (6–7; n=7) in blue catfish, and 7.09 (4–9; n=41) in hybrid catfish; sporoplasm width less variable, 3.18 (3–5; n=249) in channel catfish, 3 (n=7) in blue catfish, and 3.20 (3–4; n=41) in hybrid catfish (Figs. 2.1−5; Figs. 3.4−11).

Caudal process normally bifurcating, much longer relatively to spore body, 41.16 (25–55; n=249) in channel catfish, 37.71 (31–45; n=7) in blue catfish, and 39.32 (31–51; n=41) in hybrid catfish; septum always visible anteriorly to caudal process; caudal process splitting variable from anteriorly, medially to posteriorly, or not in wet-mounted slides under light microscopy; caudal process branches tapered posteriorly, similar width, equal or unequal length (Figs. 2.1–5; Figs. 3.4−11).

Taxonomic summary

Type host: Ictalurus punctatus.

Other previously-reported hosts: None.

New host records for this species: I. furcatus and hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Gill filaments (within lamellar connective tissue and within individual capillaries).

Prevalence and mean intensity: 91 of 112 individual channel catfish (*Ictalurus punctatus*) (81.3%), 7 of 74 individual blue catfish (*Ictalurus furcatus*) (9.5%), and 76 of 209 individual hybrid catfish (*Ictalurus punctatus* × *Ictalurus furcatus*) (36.4%) infected *Henneguya* spp. (H. *postexilis*, *H. exilis*, *H. adiposa*, and *H. ictaluri*). Specifically, *H. postexilis* was found

infecting all of the three catfishes during the study period. Mean intensity of overall *Henneguya* spp. is 2.09 (1.00−3.00) on channel catfish, 1.40 (1.00−3.00) on blue catfish, and 1.17 (1.00−2.20) on hybrid catfish.

Type locality: Private cultured in Saline Co., Missouri, U.S.A.

Other localities: Alabama (present study, *Ictalurus punctatus*, *I. furcatus*, and hybrid *I. punctatus* × *I. furcatus*).

Remarks

Henneguya postexilis was originally known to infect channel catfish (Minchew, 1977). In this study, two new host records, blue catfish and hybrid catfish, are provided in mix-stocked cultured ponds. It is interesting to know from the present study that this parasite species was found to co-infect host gill filaments with other species of *Henneguya*, namely *H. exilis* and *H. ictaluri* on the same individuals of both channel catfish and hybrid catfish.

Minchew (1977) described *Henneguya postexilis* as infrequently having non-splitting caudal processes, whereas the splitting character was found frequent among the present specimens, which is variable as anterior, medial or posterior (Figs. 2.1−5). This observation strongly proves that this species actually has anterior bifurcating caudal processes and splitting is highly dependable to specimen preparation, e.g. whether specimens were wet-mounted with/without pressure on more/less liquid, which allow the separation of branches of the spore caudal process. This feature was probably underestimated in previous studies, simply described as anterior, posterior, or non-splitting caudal processes.

Cyst measurements and spore dimensions were generally less variable among spores infecting catfishes although those spores in blue catfish were slightly smaller and shorter than those infecting channel catfish and hybrid catfish. Among species of *Henneguya* infecting the

three catfishes in present study, *H. postexilis* was most prevalent and particularly on hybrid catfish, relatively to others *Henneguya* species.

Considerable variation in spore morphology was found on this species infecting different catfishes over the study period. Some spores have elongate spore bodies and the others are lanceolate. Similarly, some spores appear shorter than others (Figs. 2.1−5). However, average morphological measurements of present materials are close to those reported by the original author (Minchew, 1977). This difference can possibly be explained as inconsistency in examination of different developmental stages of cysts and spores or limitation of the current light microscopes in this study (also problematic for all currently known light microscopes) to differentiate less than 2 unit variation among measurements when observing at high magnifications (as the myxozoan spores were measured at 2000×). Other assumption is the variation of wet-mounted techniques among different studies, e.g., changeable pressures of cover slips at preparation can result in differences in total spore length (unrecognizable damaged spores) and splitting characters of the caudal process.

Myxozoan taxonomy is challenging without moleculer markers because there are relatively few morphological characteristics that have been reported as useful. Lom and Arthur (1989), Pote et al. (2000), Kent et al. (2001), Eszterbauer (2002, 2004), Hogge et al. (2004, 2008), Iwanowicz et al. (2008), and Griffin et al. (2009a,b) noted that species of *Henneguya* possess many overlapping measurements but few distinct morphological characteristics. Those authors further suggested the combination of morphological characteristics with records on host tissue predilection, host specificity, reported locations (which are applied in the present study), and recently the molecular techniques (Griffin et al., 2009a,b). This present study is under agreement with those mentioned authors' opinion since collected specimens of species of *Henneguya* from

catfishes have many overlapping morphological measurements, making their specific diagnosis challenging.

***Henneguya* cf. *exilis* Kudo, 1929** (Plates 3−4)

Supplemental observations based on 52 and 71 wet-mounted spores in channel and hybrid catfishes, respectively, with all measurements in microns: Cysts in thick wall, polysporous translucent; shape variable as round, ovoid, or elongate. Spore body elongate, roughly 4 × longer than wide; spore body length 17.52 (15–20; n=52) in channel catfish and 18.34 (15–21; n=71) in hybrid catfish; spore body width widest medially, 4.62 (4–6; n=52) in channel catfish and 4.73 (4–6; n=71) in hybrid catfish; total spore length longer than *H. adiposa*, *H. postexilis*, *H. gurleyi*, *H. diversis*, *H. sutherlandi*, but shorter than *H. pellis*, *H. ictaluri*, *H. longicauda*, 67.44 (55–83; n=52) long in channel catfish and 66.40 (54–82; n=71) long in hybrid catfish (Plate 4; Table 5). Polar capsules elongate, anterior half to spore body, vertically symmetrical, close together; polar capsule present in pair with slightly unequal or equal in sizes; polar capsule length averagely less than half size of spore body with longer capsule length 7.10 (6–8; n=52) in channel catfish and 7.59 (6–9; n=71) in hybrid catfish, and shorter capsule length 6.87 (6–8; n=52) in channel catfish and 7.46 (6–9; n=71) in hybrid catfish; polar capsule width relatively consistent across different spores, 2 (n=52) in channel catfish and 2 (n=71) in hybrid catfish (Figs. 3.4−11; Plate 4; Table 5). Polar filament coils present in each polar capsule, 9–13 turns each; turns present medially and posteriorly in polar capsule. Sporoplasm posterior half in spore body, slightly shorter than polar capsule in length; sporoplasm length 6.96 (5–9; n=52) in channel catfish and 6.79 (3–10; n=71) in hybrid catfish; sporoplasm width 3.62 (3–5; n=52) in channel catfish and 3.63 (3–4; n=71) in hybrid catfish (Figs. 3.4−11; Plate 4).

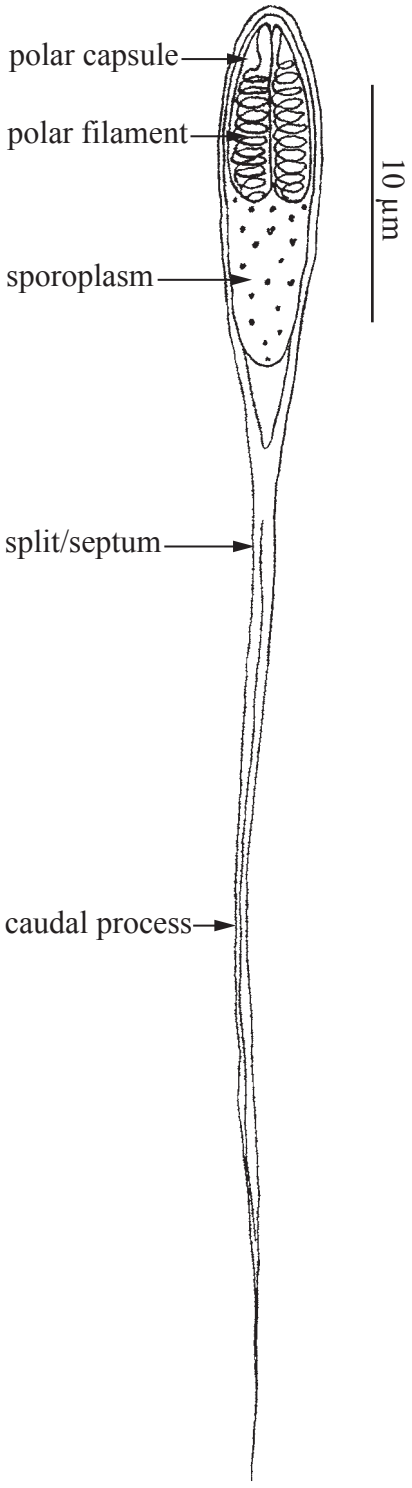

PLATE 4. *Henneguya* cf. *exilis* Kudo, 1929 from gill of hybrid catfish studied herein, line illustrations from light microscopy. Scale bar = 10 µm.

Caudal process slender, bifurcating, posterior in spore with length closely 3 × longer than spore body, 49.52 (36–66; n=52) in channel catfish and 48.76 (38–63; n=71) in hybrid catfish; septum always present, anterior to caudal process, right next to posterior end of spore body; caudal process splitting variable as anterior, medial, posterior, or not in wet-mounted microscopic slides; caudal process branches equal or unequal, tapered posteriorly (Figs. 3.4−11; Plate 4).

Taxonomic summary

Type hosts: Ictalurus punctatus

Other previously-reported hosts: Black bullhead, *Ameiurus melas* (Rafinesque, 1820) (Siluriformes: Ictaluridae), brown bullhead, *A. nebulosus* (Lesueur, 1819) (Siluriformes: Ictaluridae).

New host records for this species: Hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Gill filaments.

Prevalence and mean intensity: As previously mentioned, information on the prevalence and mean intensity of *H. exilis* specifically was not recorded, but this species was found infecting channel catfish and hybrid catfish (none of blue catfish were infected) during the study period. Mean intensity of overall *Henneguya* spp. is 2.09 (1.00−3.00) on channel catfish, and 1.17 (1.00−2.20) on hybrid catfish.

Type locality: Sterling, Germany.

Other localities: Mississippi (Minchew, 1977, Lin et al., 1999, *I. punctatus*), Alabama (this study, *Ictalurus punctatus*, hybrid *I. punctatus* × *I. furcatus*).

Remarks

Henneguya exilis was originally described from *Ictalurus punctatus* by Kudo (1929). Additionally, this parasite species was also found infecting hybrid catfish in this study but none

of the blue catfish were infected. Most of morphological measurements of present specimens are consistent with those from the original descriptions of Kudo (1929), except for slightly smaller values of spore length among those infecting channel catfish and polar capsule length of those infecting both channel and hybrid catfishes. On the other hand, specimens from hybrid catfish appear to be slightly shorter in caudal process length and total spore but longer for other values than those infecting channel catfish (Table 5). Possible explanations for these variations are similar to those in the remarks of *H. postexilis*.

As mentioned previously, the splitting character of the caudal process of *Henneguya spp.* infecting catfishes recorded in this study needs to be reconsidered. Kudo (1929) illustrated the caudal process of his specimens of *H. exilis* as "anterior end is bluntly pointed" with no specific information on splitting character. After Kudo (1929), caudal process of *H. exilis* was subsequently described as "no split" in the study of Pote et al. (2000). In the present specimens, *H. exilis* was observed to possess caudal processes with various splitting characters, varying from anterior, medial, posterior to no splitting (Fig. 3.4−11; Plate 4). This finding shows that *H. exilis* actually has anterior splitting caudal process as variation observed. Moreover, re-examination of the illustrations on spore morphology of *H. exilis* made by the original author, Kudo (1929), showed consistent characteristics with the new finding in this present study (anterior splitting in caudal process).

***Henneguya* cf. *adiposa* Minchew, 1977** (Plates 3, 5)

Supplemental observations based on 22 and 10 wet-mounted spores in channel and hybrid catfishes: (measurements in microns) Cysts irregular, white, nodular, thick wall, polysporous, relatively deep into infected tissue (Fig. 3.2). Spores with spore body and caudal process; total length generally longer than *H. postexilis*, *H gurleyi*, *H. diversis*, *H. sutherlandi*, but smaller than other ictalurid-infecting *Henneguya* spp., 60.23 (50–72; n=22) long in channel catfish and 64

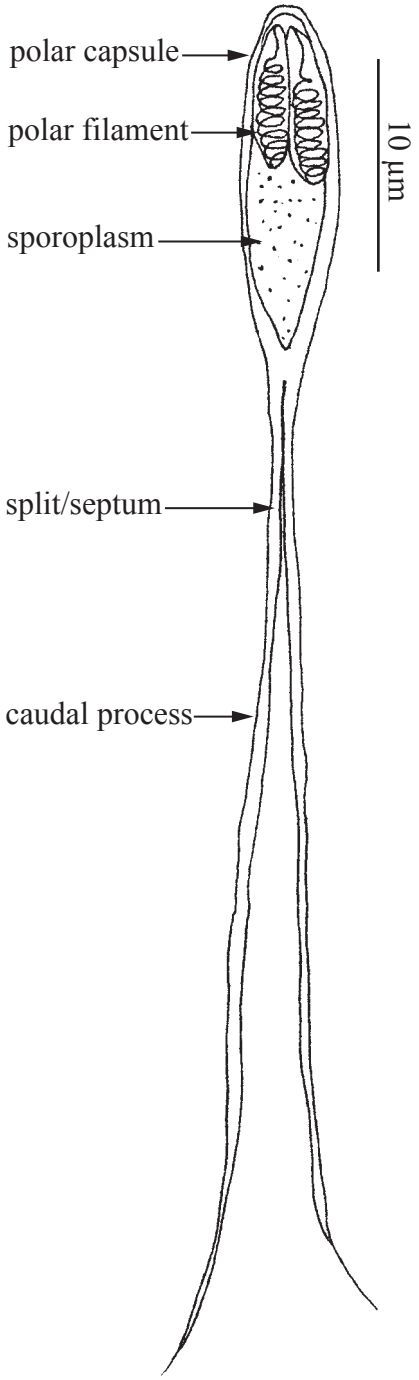

PLATE 5. *Henneguya* cf. *adiposa* Minchew, 1977 from adipose fin of channel catfish studied herein, line illustrations from light microscopy. Scale bar = 10µm.

(57–68; n=10) long in hybrid catfish (Table 5). Spore body ellipsoid, elongate, more than 4 × longer than wide; spore body length 18.45 (12–22; n=22) in channel catfish and 7.09 (4–9; n=10) in hybrid catfish; spore body width widest medially, 4.18 (3–5; n=22) in channel catfish and 4.10 (4–5; n=10) in hybrid catfish (Plate 5; Table 5). Polar capsule in pair, elongate, equal or unequal, anterior in spore body, usually close together, less than half of spore body length; longer polar capsule 7.32 (6–8; n=22) in channel catfish and 8.30 (8–9; n=10) in hybrid catfish, shorter polar capsule 7.05 (5–8; n=22) in channel catfish and 7.90 (6–9; n=10) in hybrid catfish; polar capsule relatively consistent in width, 2 in both channel catfish (n=22) and hybrid catfish (n=10) (Plate 5; Table 5). Polar filament coils present in each capsule, 8 turns each, infrequently extruded; turns present medially and posteriorly in polar capsule. Sporoplasm in posterior end of spore body, slightly longer or shorter than polar capsule, 8.50 (7–10; n=22) in channel catfish and 8.20 (7–10; n=10) in hybrid catfish (Figs. 3.4−11; Plate 5; Table 5).

Caudal processes slender, bifurcating, more than twice longer than spore body, 39.55 (30–51; n=22) in channel catfish and 45.30 (38–53; n=10) in hybrid catfish; septum always present, anterior to caudal process, right next to posterior end of spore body; caudal process splitting anterior, medial, posterior, or not in wet-mounted slides; caudal process branches equal or unequal, tapered posteriorly (Figs. 3.4−11; Plate 5; Table 5).

Taxonomic summary

Type host: Ictalurus punctatus.

Other previously-reported hosts: None.

New host records for this species: Hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Between the connective tissue bands of the adipose fin.

Prevalence and mean intensity: 1 of 112 individual channel catfish (*Ictalurus punctatus*) (0.9%), 0 of 74 individual blue catfish (*Ictalurus furcatus*) (0%), and 5 of 209 individual hybrid

catfish (*Ictalurus punctatus* × *Ictalurus furcatus*) (2.4%) infected *Henneguya* spp. Mean intensity is 3−6 cysts/fish.

Type locality: Private cultured ponds in Lee Co., Mississippi, U.S.A.

Other localities: Alabama, present study.

Remarks

Henneguya adiposa was originally described from channel catfish (*Ictalurus punctatus*) by Minchew (1977). In present study, this species was showed to also infect hybrid catfish additionally to channel catfish. None of examined blue catfish were infected *H. adiposa*. Although slightly higher on hybrid catfish than on channel catfish, low prevalence of *H. adiposa* infection was observed on both catfishes.

Morphological measurements of examined spores between two catfishes inconsistently show larger spores on channel catfish than on hybrid catfish. Notably, almost all average measurements on channel catfish and hybrid catfish in present study are primarily higher than those measurements from Minchew (1977) and Griffin et al. (2009a), especially in spore body length. Possible explanations have been discussed in previous sections.

Repeatedly, splitting feature of caudal process is still doubtable in published literature as compared with this study. *H. adiposa* has been known to have posterior split in their caudal processes when wet-mounted on microscopic slides, which is inconsistent with observations in this study. As already been discussed, splitting character of the caudal process of ictalurid-infecting *Henneguya* spp. seem to be under-evaluated as the findings in this study. Griffin et al. (2009a) was inconsistent in their line drawings and statements of the caudal process splitting characters of *H. adiposa* infecting channel catfish, staying that it is posterior but illustrating as slightly medial or even anterior in their line drawing.

Information on prevalence of *H. adiposa* is provided herein with small numbers of infected adipose fins of catfishes (all cysts infected adipose fins of catfishes). Additionally, *H. adiposa* is currently the only *Henneguya* species known infecting adipose fins of Southeastern United States catfishes (Griffin et al., 2009b).

***Henneguya* cf. *ictaluri* Pote, Hanson, and Shivaji, 2000** (Plate 3, 6)

Supplemental observations based on 12 plasmodia and 7 and 22 wet-mounted spores in channel and blue catfishes, respectively, with all measurements in microns: Cysts elongate or ovoid, small, polysporous; cyst dimension 419.0 (325–490; n=12) in length and 280.42 (160–365; n=22) in breath (Figs. 3.1, 3.3). Spores with spore body and caudal process; total length shorter than *H. longicauda* and *H. pellis*, but longer than other ictalurid-infecting *Henneguya* species in the Southeastern United States, 74.29 (64–90; n=7) long in channel catfish and 85.73 (70–113; n=22) long in blue catfish (Plate 6; Table 5). Spore body elongate, roughly 4 × longer than wide; spore body length 17.57 (16–17; n=7) in channel catfish and 17.59 (15–20; n=22) in blue catfish; spore body width 4.14 (4–5; n=7) in channel catfish and 5.32 (4–6; n=22) in blue catfish (Plate 6; Table 5). Polar capsule present in pair, elongate, frequently unequal, anterior in spore body; longer polar capsule 7.57 (7–8; n=7) in channel catfish and 6.73 (6–8; n=22) in blue catfish; shorter capsule 6.27 (5–8; n=7) in channel catfish and 6.71 (6–7; n=22) in blue catfish; polar capsule width consistently similar among different spores infecting catfishes, 2 (n=7) wide in channel catfish and 2 (n=22) in blue catfish (Figs. 3.4−11; Plate 6; Table 5). Polar filament coils present, 9–11 turns; turns present medially and posteriorly in polar capsules. Sporoplasm posterior half in spore body, slightly longer or shorter than polar capsules in length; sporoplasm length 7.43 (5–9; n=7) in channel catfish and 7.59 (6–10; n=22) in blue catfish; sporoplasm width roughly half of its length, 314 (3–4; n=7) in channel catfish and 4.23 (3–5; n=22) in blue catfish (Figs. 3.4−11; Plate 6; Table 5).

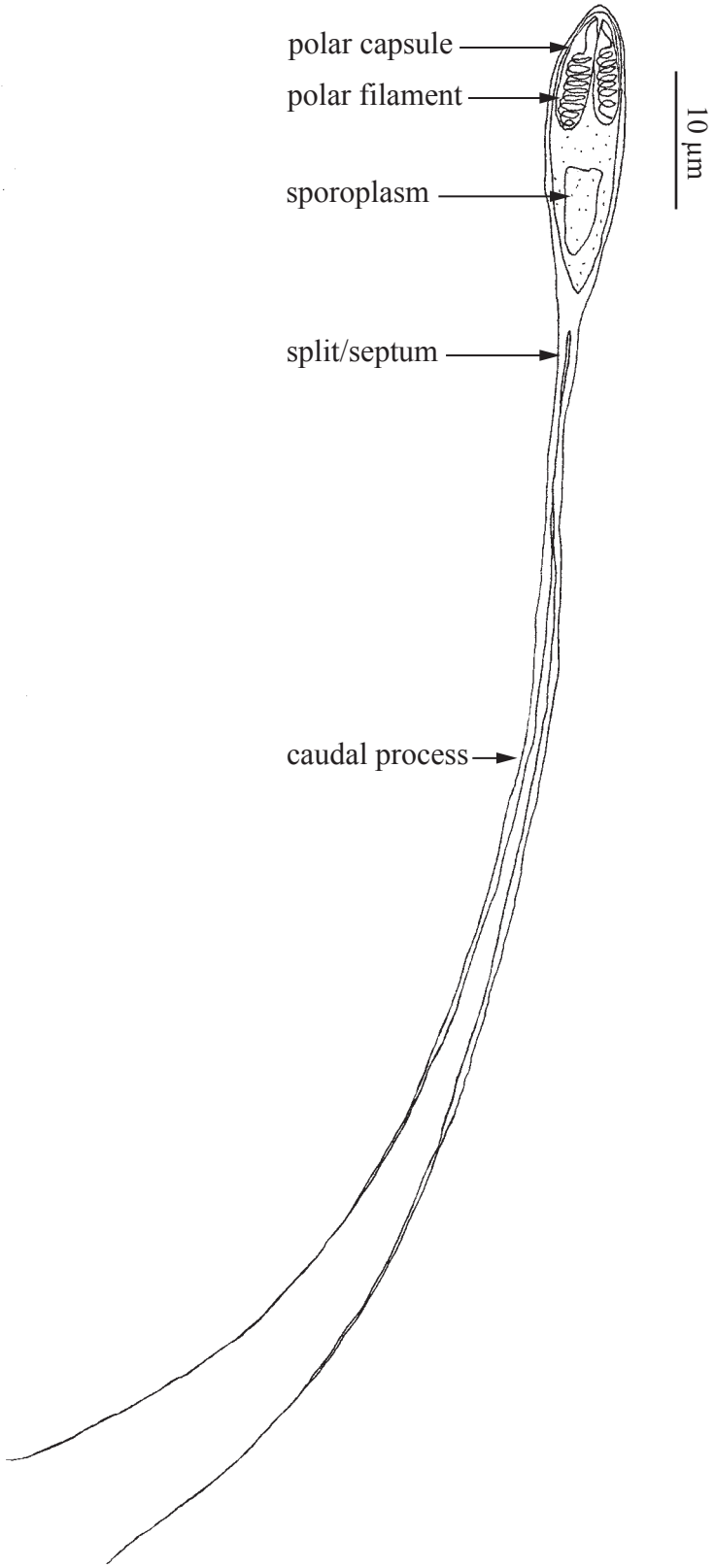

PLATE 6. *Henneguya* cf. *ictaluri* Pote, Hanson, and Shivaji, 2000 from gill of blue catfish studied herein, line illustrations from light microscopy. Scale bar = 10µm.

Caudal process tapered posteriorly, bifurcating, 3–4 × longer than spore body, 56.71 (49–73; n=7) in channel catfish and 68.23 (53–93; n=22) in blue catfish; septum always present from anterior to posterior in caudal process; caudal process splitting anterior, medial, posterior, or not in wet-mounted microscopic slides; caudal process branches tapered posteriorly, equal or unequal in length (Figs. 3.4−11; Plate 6; Table 5).

Taxonomic summary

Type host: Ictalurus punctatus.

Other previously-reported hosts: I. furcatus.

New host records for this species: None.

Site of infection: Gill filaments, interlamellar.

Prevalence and mean intensity: Not particularly recorded for *H. ictaluri*. However, this species was found infected channel catfish and blue catfish in this study. Mean intensity of overall *Henneguya* spp. was 2.09 (1.00−3.00) on channel catfish, 1.40 (1.00−3.00) on blue catfish.

Type locality: Experimental infection and commercial catfish pond, Brooksville, Mississippi

Other localities: California (Dunhamel et al., 1986, Kent et al., 1987, *I. punctatus*); Georgia (Burtle et al., 1991, *I. punctatus*), and Alabama (Davis, 1994; this present study, *I. punctatus* and *I. furcatus*).

Remarks

Henneguya ictaluri was originally described from *Ictalurus punctatus* by Pote, Hanson, and Shivaji (2000). Subsequently, many comparative studies have been carried out on effects of the parasitic disease and resistance of channel catfish, blue catfish, and hybrid catfish to *H. ictaluri*. As discussed previously in the first chapter, blue catfish was found higher resistant to *H. ictaluri* infection than the other 2 catfishes. In the present study, only channel catfish and blue catfish (low prevalence) were infected while none of hybrid catfish was observed the infection. This

prevalence may not reflect the actual parasite susceptibility among the 3 catfishes as few cysts of *Henneguya ictaluri* were found on each channel catfish and blue catfish.

Morphological measurements of the present specimens are variable in some values to the original description (Pote et al., 2000). Specifically, spore body length and width of present materials are smaller than measurements recorded Pote et al. (2000), but other values are generally consistent. In addition, spores infecting blue catfish appear larger in almost all measurements than those infecting channel catfish. Repeatedly, possible explanations of those variations were discussed previously in the first description of species within the genus.

Splitting feature of the caudal process observed among present specimens was consistent to the original description. Additionally, however, in wet-mounted slides, spores may split medially or posteriorly or not split.

Phylum: Platyhelminthes

Class: Monogenea

Family: Dactylogyridae

Genus: *Ligictaluridus* Beverley-Burton, 1984

Diagnosis: Hamuli in two pairs; pair 1dorsal, pair 2 ventral. Transverse bars not articulating with each other, each with flange; flange median, lightly sclerotized. Marginal hooks of slightly dissimilar shape and size. Copulatory complex comprising penis and base; penis sclerotized, curving, tubular; base inflated; accessory piece of copulatory complex closely attached to penis base, with well-sclerotized, blunt, proximal projection and elongate limb, bearing hook-like projection(s) distally. Vagina sclerotized or not, opening on left side of body, leading to seminal receptacle. Vitellaria coextensive with intestine, extending laterally to body margin and filling all available intercaecal space. On gills of North American freshwater fishes (Ictaluridae).

Taxonomic summary

Type species: Ligictaluridus pricei (Mueller, 1936) Beverley-Burton, 1984 (Monopisthocotylea: Dactylogyridae).

Other species: L. mirabilis (Mueller, 1937) Klassen and Beverley-Burton, 1985 (Monopisthocotylea: Dactylogyridae); *L. monticellii* (Cognetti and Martiis) Beverley-Burton, 1985 (Monopisthocotylea: Dactylogyridae); *L. floridanus* (Mueller, 1936) Beverley-Burton, 1984 (Monopisthocotylea: Dactylogyridae); *L. bychowskyi* (Price and Mura, 1969) Klassen and Beverley-Burton, 1985 (Monopisthocotylea: Dactylogyridae).

Host family: Ictaluridae.

***Ligictaluridus mirabilis* (Mueller, 1937) Klassen and Beverley-Burton, 1985** (Plates 7–8)

Supplemental observations based on 9, 3, and 8 whole-mounted specimens on channel, blue, and hybrid catfishes, respectively, with all measurements in microns: Body elongate with length much longer than width (length/width ratios 10.77, 6.22, and 9.90 averagely in channel catfish, blue catfish, and hybrid catfish, respectively); body length 527 (450–610; n=9) in channel catfish, 470 (430–540, n=3) in blue catfish, and 608 (410–770; n=8) in hybrid catfish; medium body width 122 (73–215; n=9) in channel catfish, 107 (102–108, n=3) in blue catfish, and 121 (61–165; n=8) in hybrid catfish (Figs. 7.1; 8.1; Table 3). Cephalic glands lateral near anterior region of head and above pharynx, stretching posteriorly and connecting to vitellaria via small ducts (Fig. 7.1). Eye spot present in two pairs; anterior pair smaller than posterior pair (Figs. 7.1, 8.1). Pharynx subspherical to round with strong musculature, 40 (29–65; n=9) in diameter in channel catfish, 32 (28–38, n=3) in blue catfish, and 44 (25–65; n=8) in hybrid catfish (Figs. 7.1, 8.1; Table 3). Intestine bifurcated, starting from pharynx, developing laterally to posterior body end and joining together in loop-like structure (Fig. 7.1). Vitellaria extensive, distributing almost

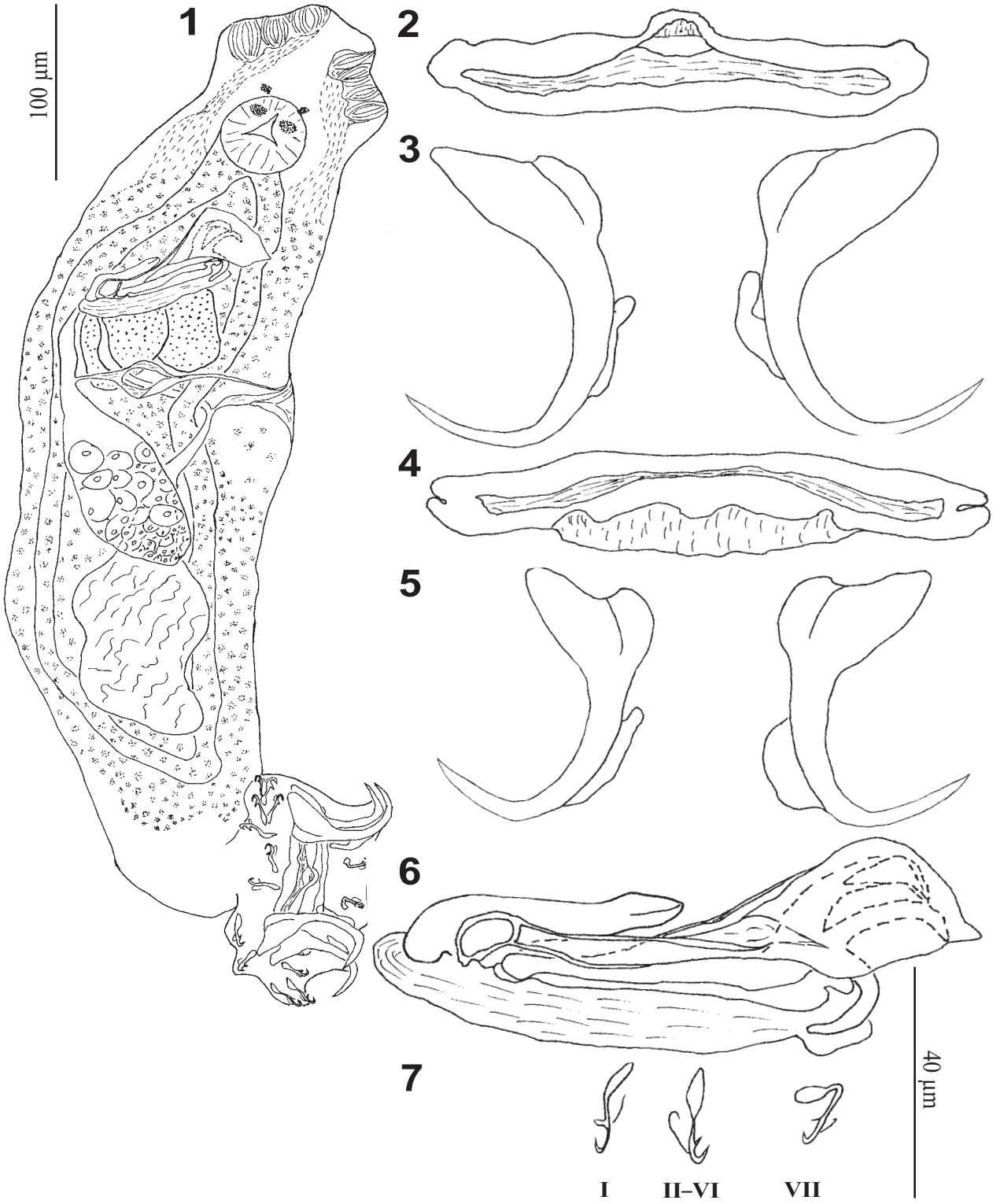

PLATE 7. *Ligictaluridus mirabilis* (Mueller, 1937) Beverley-Burton, 1984 from gill of hybrid catfish studied herein, line illustrations from light microscopy. 1. Whole body, ventral view. 2. Ventral bar. 3. Ventral hamulus. 4. Dorsal bar. 5. Dorsal hamulus. 6. Penis apparatus. 7. Hooklet pairs I, II, III–VII. Scale bars: Figure 1 = 100µm, Figures 2–7 = 40µm.

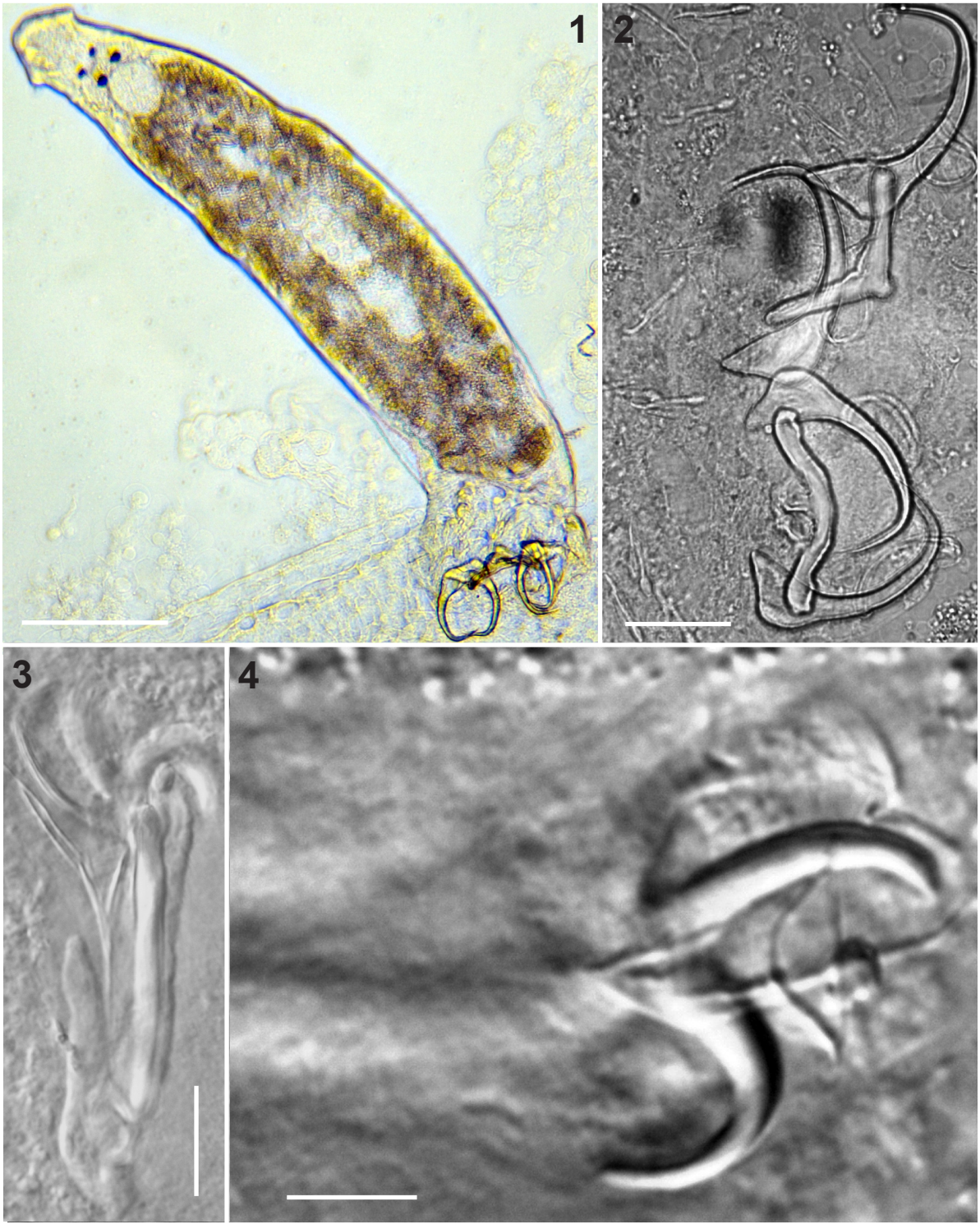

PLATE 8. *Ligictaluridus mirabilis* (Mueller 1937) Klassen and Beverley-Burton, 1985 from gill of channel and blue catfishes studied herein, photograph illustrations. 1. Gill-attached specimens. 2. Hamuli and hooklets. 3, 4. Anterior and posterior ends (2 recurved hook-like structure) of penis apparatus. Scale bars: Figure 1 = 100µm, Figure 2 = 25µm, Figure 3 = 10µm, Figure 4 = 5µm.

all available body space, leaving limited space for reproductive system and intestine (Figs. 7.1, 8.1).

Haptor variable in length and width, with 2 hamuli pairs and 7 hooklets pairs; haptor generally broader than long with length 58 (42–115; n=9) in channel catfish, 53 (50–58, n=3) in blue catfish, and 63 (49–84; n=8) in hybrid catfish; and width 119 (90–210; n=9) in channel catfish, 122 (113–133, n=3) in blue catfish, and 120 (92–148; n=8) in hybrid catfish (Figs. 7.1−5, 7.7, 8.1−2; Tables 3). Hamuli large, slender, well-clerotized, sharp curved, quite robust at base, gradually narrow, and sharp at posterior end; ventral hamuli usually larger and longer than dorsal; both hamuli associating with delicate hamulus wings; dorsal hamulus length 48 (38–55; n=9) in channel catfish, 44 (37–50, n=3) in blue catfish, and 49 (40–55; n=8) in hybrid catfish; ventral hamulus 51 (44–62; n=9) in channel catfish, 44 (38–47, n=3) in blue catfish, and 50 (43–55; n=8) in hybrid catfish in length (Figs. 7.1−5, 7.7, 8.1−2). Transverse bars variable in shape among different specimens; dorsal bar 76 (58–88; n=9) in channel catfish, 67 (50–78, n=3) in blue catfish, and 74 (50–85; n=8) in hybrid catfish in length; dorsal bar median width 15 (8–23; n=9) in channel catfish, 14 (12–18, n=3) in blue catfish, and 15 (5–30; n=8) in hybrid catfish; ventral bar length 74 (65–84; n=9) in channel catfish, 71 (66–77, n=3) in blue catfish, and 78 (64–89; n=8) in hybrid catfish; ventral bar median width 17 (8–19; n=9) in channel catfish, 15 (12–18, n=3) in blue catfish, and 16 (2–23; n=8) in hybrid catfish (Figs. 7.1−5, 7.7, 8.1−2). Hooklets quite dissimilar in shapes (between pairs I, II−VI, and VII) and length with average length 19 (16–23; n=9) in channel catfish, 16 (11–19, n=3) in blue catfish, and 18 (17–22; n=8) in hybrid catfish (Figs. 7.1, 7.7, 8.2; Table 3).

Copulatory organs complex with 1 penis and 4-component accessory piece. Penis, 61 (43–68; n=9) long in specimens from channel catfish, 57 (54–61, n=3) in specimens from blue catfish,

and 64 (46–72; n=8) in specimens from hybrid catfish, slightly clerotized, delicate, complex, tube-like proximally, containing multiple thin crossing layers with complete opening at distal end; distal end sometimes flaring and covering other parts of penis (Figs. 7.6, 8.3−4; Table 3). Accessory piece, 73 (60–85; n=9) long in specimens from channel catfish, 74 (70–77, n=3) in blue catfish, and 73 (67–79; n=8) in hybrid catfish, also complex with 4 substructures; first component short, clerotized, underneath, and connected with penis at its anterior base; second part articulate with penis base proximally and divided into 3 branches, 1 opening and 2 tapering as 2 recurved hook-like structure; third part right under and parallel to previous part; last substructure delicate, largest, locating underneath all other structures as buffering base (Figs. 7.6, 8.3−4; Table 3). Vagina on left side, situating at about medial part of body (Fig. 7.1).

Ovary ovoid, stretching anteriorly and connecting to penis base at left side of body. Testes irregular, single-lobed, extending dextrally and looping around intestine via vas deferens before connecting to penis base. Seminal receptacles, containing 2 large reservoirs and connecting to penis base, dorsal to ovary. Genital pore, connecting to both ovary and testes, on left side and about median of body (Fig. 7.1).

Taxonomic summary

Type hosts: Flathead catfish, *Pylodictis olivaris* (Rafinesque, 1818), (Siluriformes: Ictaluridae).

Other previously-reported hosts: Ictalurus punctatus, *I. furcatus*, *Ameiurus melas*.

New host records for this species: Hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Gill filaments.

Prevalence and mean intensity: 111 of 112 individual channel catfish (*Ictalurus punctatus*) (99.1%), 69 of 74 individual blue catfish (*Ictalurus furcatus*) (93.2%), and 189 of 209 individual hybrid catfish (*Ictalurus punctatus* × *Ictalurus furcatus*) (90.4%) infected *Ligictaluridus* spp. (*L. mirabilis* and *L. pricei*). Specifically, *L. mirabilis* infected all of the

three catfishes during the study period. Mean intensity of *Ligictaluridus* spp. infection was 1.66 (1.00−3.00) on channel catfish, 2.07 (1.00−2.80) on blue catfish, and 2.00 (1.00−2.70) on hybrid catfish.

Type locality: Mississippi River, Mississippi, U.S.A.

Other localities: Ontario, Canada (Klassen and Beverley-Burton, 1985, *Ictalurus punctatus*); Tennessee, U.S.A. (Mizelle and Cronin, 1943; Brown, 1953); Alabama, U.S.A. (this study, *I. punctatus*, *I. furcatus*, hybrid *I. punctatus* × *I. furcatus*).

Remarks

This monogenetic trematode was originally described by Mueller (1937), on the gills of mud cat, *Pylodictis olivaris* in Mississippi River, as *Cleidodiscus mirabilis*, and later reclassified as *Ligictaluridus mirabilis* by Beverley-Burton (1984). This species was distinguished from other *Ligictaluridus* species by the morphology of the complex accessory piece with four terminal components, which include two recurved hooks (Mueller, 1937; Klassen and Beverley-Burton, 1985), especially with *L. floridanus* (1 recurved hook in the accessory piece) (Klassen and Beverley-Burton, 1985). This character is consistent among specimens in this study (Figs. 7.6, 8.3−4). However, morphology of the hamuli, accessory piece, especially the two recurved hooks, is variable among published works. Mueller (1937) first described the penis as a tube with largely expanded, folded, irregular margins and the absence of the hamulus wings. Mizelle and Cronin (1943) were in agreement with absence of the humulus wings in their illustrations and described variations of the accessory piece among observed monogenean individuals with the presence (less or well-developed) or absence of a knob structure and 2 relatively slender, sharp and long recurved hooks. Meanwhile, Klassen and Beverley-Burton (1985) observed hamulus wings in their illustrations, describing the funnel-liked opening structure of distal end of the

penis. They further observed variation of transverse bars under pressure and suggested it as a minor taxonomic character in differentiating *Ligictaluridus* spp.

In present specimens, morphology of the two recurved hooks, which are quite long, slender, and tapered, are mostly close to the illustrations of Mizelle and Cronin (1943) (Figs. 7.6, 8.3−4). However, presence of the hamulus wings (Figs. 7.3, 7.5, 8.2) and the funnel-like structure of the distal opening (Fig. 7.6), which consistent to Klassen and Beverley-Burton (1985), were observed among present materials. Transverse bar structure (Figs. 7.2, 7.4, 8.2) is mostly matched Mueller (1937) although the less reliability of this structure in separation *Ligictaluridu*s spp. (Klassen and Beverley-Burton, 1985). Moreover, although the relative consistence in length measurements, dissimilarities in shapes among hooklets were also observed. Specifically, hooklet pairs I−VI are straight and quite identical, while pair VII is sharply curved at its base and quite smaller than the others (Figs. 7.7, 8.2).

The measurements reported herein for these specimens are generally within those reported for *L. mirabilis*; however, among the 3 catfishes it is noted that specimens infecting hybrid catfish are larger in size than those infecting the other 2 catfishes. On the other hand, those infecting blue catfish generally have the smallest sizes relatively to those parasitizing channel catfish and hybrid catfish (Table 3).

Specific values for prevalence and mean intensity of *L. mirabilis* were not recorded in this study because in many instances hundreds of worms infected the gill of catfish and time constraints did not allow for an exact count. Reported data above is for the prevalence and mean intensity of the genus *Ligictaluridus,* including both *L. mirabilis* and *L. pricei* together.

***Ligictaluridus pricei* (Mueller, 1936) Beverley-Burton, 1984** (Plates 9−11)

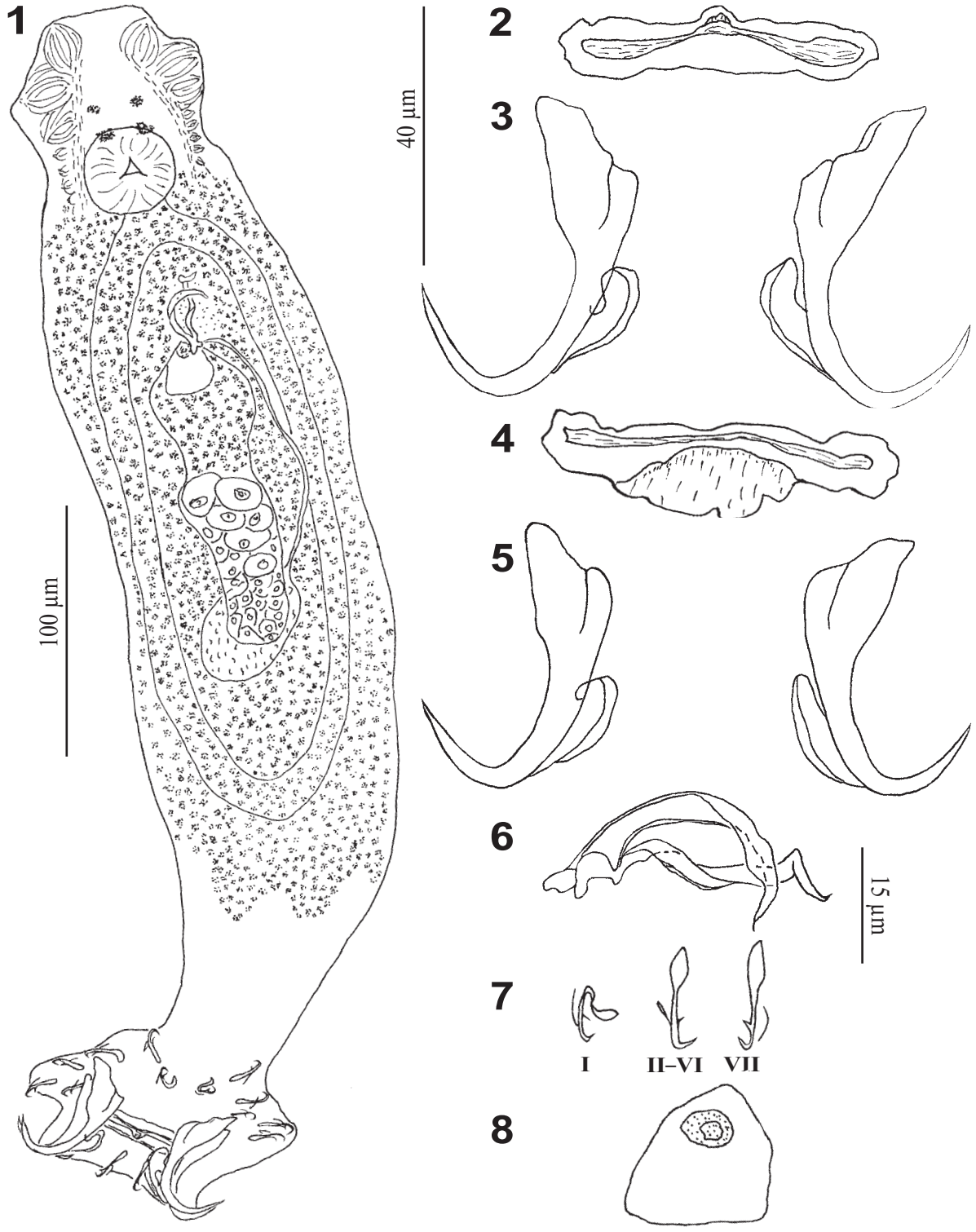

PLATE 9. *Ligictaluridus pricei* (Mueller, 1936) Beverley-Burton, 1984, from gill of hybrid catfish studied herein, line illustraions from light microscopy. 1. Whole body, ventral view. 2. Ventral bar. 3. Ventral hamulus. 4. Dorsal bar. 5. Dorsal hamulus. 6. Penis apparatus. 7. Hooklets pairs I, II, III–VII. 8. Egg. Scale bars: Figure 1 = 100µm, Figures 2–5, 8 = 40µm, Figures 6–7 = 15µm.

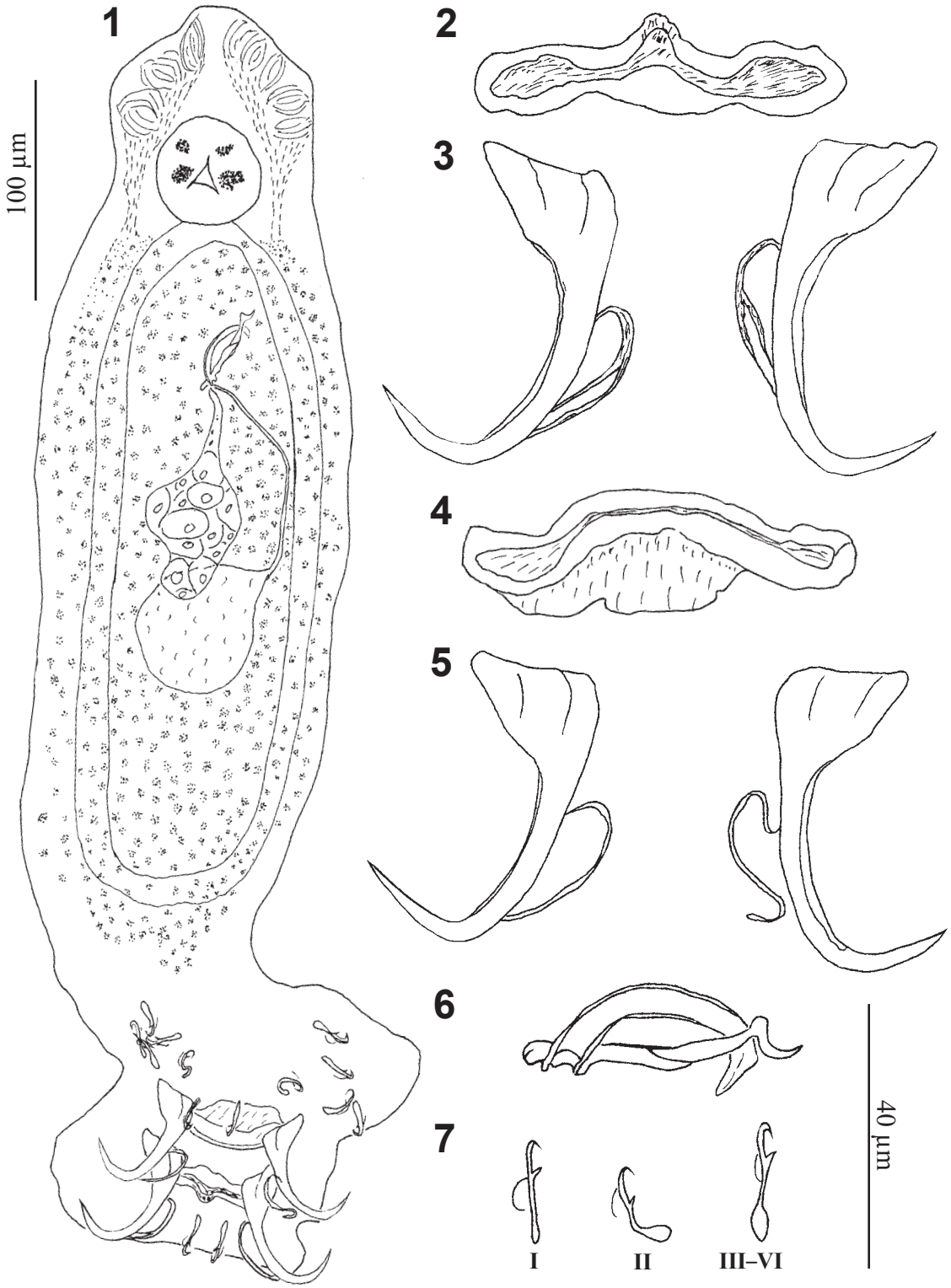

PLATE 10. *Ligictaluridus pricei* (Mueller, 1936) Beverley-Burton, 1984 from gill of hybrid catfish studied herein, shows variations in morphology of hamuli and hooklets, line illustrations from light microscopy. 1. Whole body, ventral view. 2. Ventral bar. 3. Ventral hamulus. 4. Dorsal bar. 5. Dorsal hamulus. 6. Penis apparatus. 7. Hooklet pairs I, II, III–VII. Scale bars: Figure 1 = 100µm, Figures 2–7 = 40µm.

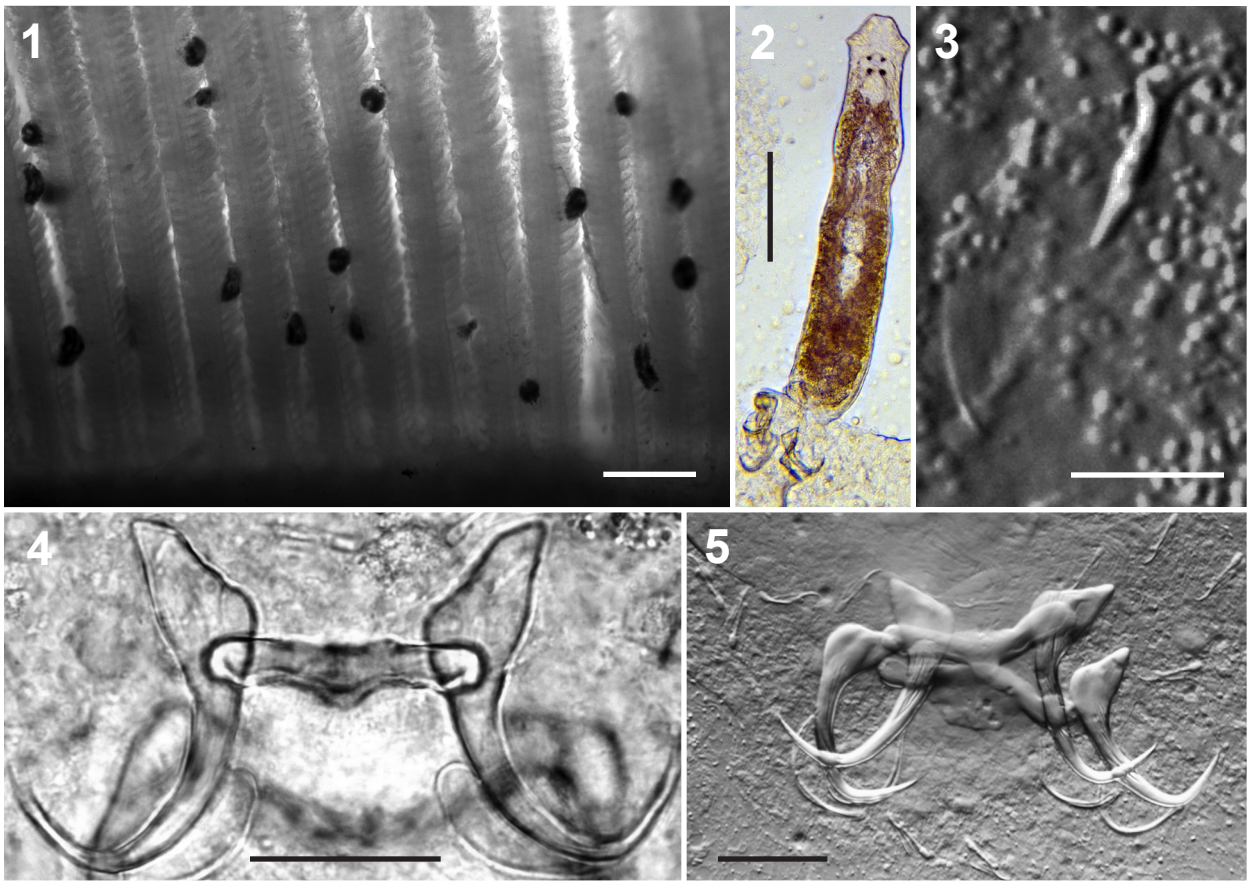

PLATE 11. *Ligictaluridus pricei* (Mueller 1936) Beverley-Burton, 1984 from gill of channel and blue catfishes studied herein, photograph illustrations. 1, 2. Gill-attached specimens. 3. Penis apparatus. 4, 5. Variations in structures of hamuli and hooklets. Scale bars: Figure 1 = 500µm, Figure 2 = 100µm, Figure 3 = 10µm, Figures 4–5 = 25µm.

Supplemental observations based on 6, 7, and 7 whole-mounted specimens on channel, blue, and hybrid catfishes, respectively, with all measurements in microns: Body elongate, body length much longer than width (length/width ratios 4.56, 4.89, and 4.27 averagely in specimens from channel catfish, blue catfish, and hybrid catfish, respectively); body length 438 (400–490; n=6) in specimens from channel catfish, 381 (310–430; n=7) in specimens from blue catfish, and 490 (430–580; n=7) in specimens from hybrid catfish; medium body width 98 (77–120; n=6) in specimens from channel catfish, 97 (68–108; n=7) in specimens from blue catfish, and 118 (88–148; n=7) in specimens from hybrid catfish (Figs. 9.1, 10.1, 11.2; Table 4). Cephalic glands well-developed, lateral around anterior head, and gradually less developed until vitellaria; cephalic gland connected with vitellaria via small ducts (Figs. 9.1, 10.1). Eye spot present in 2 pairs, posterior pair larger and closer together than anterior pair (Figs. 9.1, 10.1, 11.2). Pharynx diameter 32 (29–37; n=6) in channel catfish, 28 (20–40; n=7) in blue catfish, and 34 (28–41; n=7) in hybrid catfish, generally round with strong musculature (Figs. 9.1, 10.1, 11.2; Table 4). Vitellaria well-developed in several layers, filling up almost available body space from pharynx to posterior body end; condense vitellarium layers sometimes making other internal organs opaque for observing (Figs. 9.1, 10.1, 11.2). Intestine laterally bifurcated, connected with pharynx in short, single tube, extended posteriorly and joined together at posterior end in loop-like structure (Figs. 9.1, 10.1).

Haptor with 2 hook pairs and 7 hooklet pairs, usually irregular, wider than long, 61 (49–71; n=6) in channel catfish, 52 (47–60; n=7) in blue catfish, and 63 (38–100; n=7) in hybrid catfish in length and 91 (70–112; n=6) in channel catfish, 85 (65–98; n=7) in blue catfish, and 87 (38–104; n=7) in hybrid catfish in width (Figs. 9.1−5, 9.7, 10.1−5, 10.7, 11.4−5; Table 4). Hamuli well-clerotized, slender, sharply curved, tapered; ventral hamuli usually larger than dorsal;

hamulus bases grooved with reduced superficial roots relatively to deep roots, especially more obvious in ventral hooks; ventral hamulus length 45 (43–49; n=6) in channel catfish, 42 (35–46; n=7) in blue catfish, and 46 (44–48; n=7) in hybrid catfish; dorsal hamulus 40 (34–44; n=6) in channel catfish, 40 (32–51; n=7) in blue catfish, and 42 (37–49; n=7) in hybrid catfish; hamulus wings present, associating to all ventral and dorsal hamuli (Figs. 9.1−5, 10.1−5, 11.4−5; Table 4). Transverse bars different both in sizes and shapes; dorsal bars usually wider, longer than ventral; ventral bar length 52 (47–56; n=6) in channel catfish, 47 (43–52; n=7) in blue catfish, and 48 (42–52; n=7) in hybrid catfish; dorsal bar length 53 (46–58; n=6) in channel catfish, 49 (44–55; n=7) in blue catfish, and 54 (50–58; n=7) in hybrid catfish; ventral bar median width 9 (8–11; n=6) in channel catfish, 9 (7–12, n=3) in blue catfish, and 9 (7–14; n=7) in hybrid catfish; dorsal median width 13 (10–16; n=6) in channel catfish, 11 (8–13; n=7) in blue catfish, and 15 (12–18; n=7) in hybrid catfish (Figs. 9.2, 9.4, 10.2, 10.4, 11.4−5; Table 4). Hooklet pairs less variable in length but more in shape; average hooklet length 16 (14–17; n=6) in channel catfish, 15 (13–18; n=7) in blue catfish, and 14 (13–16; n=7) in hybrid catfish; hooklet pairs II-VII generally straight; pair I sharply bent at base (Figs. 9.1, 9.7, 10.1, 10.7, 11.5; Table 4).

Copulatory organs quite simple with single accessory piece and penis; penis small, thin, chitinous, tube-like with opening base and tapered distal end, curved to roughly perpendicular at distal end; accessory piece clerotized, curved and slightly wavy, connecting to penis base and crossing with penis distal end; penis and accessory piece together making arc-like structure; penis generally equal or longer than accessory piece; penis 29 (23–38; n=6) in channel catfish, 29 (22–36; n=7) in blue catfish, and 31 (23–36; n=7) in hybrid catfish; accessory length 26 (19–31; n=6) in channel catfish, 26 (19–35; n=7) in blue catfish, and 31 (20–43; n=7) in hybrid catfish (Figs. 9.1, 9.6, 10.1, 10.6, 11.3; Table 4). Vagina not observed among present specimens.

Ovary elongate, about in middle of body, connecting to penis base; more mature eggs anterior and younger eggs posterior within ovary; young eggs ovoid and more mature eggs pentagonal (Figs. 9.1, 9.8, 10.1). Testes ovoid, posterior, dorsal to ovary, also connecting to penis base via delicate vas deferens (Figs. 9.1, 10.1); seminal receptacles not observed among present materials.

Taxonomic summary

Type hosts: Not specified but initial hosts reported were *Ictalurus punctatus* (Rafinesque, 1818), (Siluriformes: Ictaluridae) channel catfish; *Ameiurus nebulosus* (Lesueur, 1819), (Siluriformes: Ictaluridae), brown bullhead; and *A. natalis* (Lesueur, 1819), (Siluriformes: Ictaluridae) yellow bullhead.

Other previously-reported hosts: White catfish, *I. catus* (Linnaeus, 1758) (Siluriformes: Ictaluridae), *I. furcatus*, *A. melas,* flat bullhead, *I. platycephalus* (Girard, 1859) (Siluriformes: Ictaluridae), green sunfish, *Lepomis cyanellus* (Rafinesque, 1819) (Perciformes: Centrarchidae), warmouth, *L. gulosus* (Cuvier, 1829) (Perciformes: Centrarchidae), striped bass, *Morone saxatilis* (Walbaum, 1792) (Perciformes: Moronidae), slender madtom, *Noturus exilis* (Nelson, 1876) (Siluriformes: Ictaluridae), tadpole madtom, *N. gyrinus* (Mitchill, 1817) (Siluriformes: Ictaluridae), *Pylodictis olivaris*.

New host records for this species: Hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Gill filaments.

Prevalence and mean intensity: 111 of 112 individual channel catfish (*Ictalurus punctatus*) (99.1%), 69 of 74 individual blue catfish (*Ictalurus furcatus*) (93.2%), and 189 of 209 individual hybrid catfish (*Ictalurus punctatus* × *Ictalurus furcatus*) (90.4%) infected *Ligictaluridus* spp. *(L. mirabilis* and *L. pricei*). Specifically, *L. pricei* infected all of the three catfishes during the study period. Mean intensity of *Ligictaluridus* spp. infection is 1.66

(1.00−3.00) on channel catfish, 2.07 (1.00−2.80) on blue catfish, and 2.00 (1.00−2.70) on hybrid catfish.

Type locality: Myakka River, Lake Okeechobee, Florida, U.S.A.

Other localities: Ontario (Mizelle and Donahue, 1944, *Ictalurus melas*, *I. punctatus*; Dechtiar, 1972, Hanek and Fernando, 1972, Molnar et al., 1974, *I. nebulosus*, *I. punctatus*, *Noturus flavus*, *N. gyrinus*; Klassen and Beverley-Burton, 1985, *I. nebulosus* and *Notorus gyrinus*); New York (Mueller, 1973, *I. nebulosus*); Oklahoma (Seamster, 1938, *I. melas*, *I. punctatus*); Louisiana (Summers and Bennett, 1938, Seamster, 1948, *I. melas*, *I. punctatus*); Tennessee (Mizelle and Cronin, 1943, *I. natalis*, *I. punctatus*¸ *I. melas*, *I. furcatus*); Wisconsin (Mizelle and Regensberger, 1945, *I. nebulosus*; Mizelle and Klucka, 1953, Mizelle and Webb, 1953, *I. platycephalus*); Virginia (Hargis, 1952, 1953, *I. nebulosus*); Ohio (Krueger, 1954, *I. melas, I. nebulosus*); North Carolina (Cloutman, 1978, *I. platycephalus*); California (Mizelle et al., 1961, Hensley and Nahhas, 1975, *I. catus*, *I. melas*, *Morone saxatilis, Lepomis gulosus*; Miller et al., 1972, Miller et al., 1973, *I. nebulosus, I. natalis*; *I. punctatus*, *I. melas*); Texas (Nowlin et al., 1967, *I. natalis;* Lawrence and Murphy, 1967, Clayton and Schlueter, 1970, Meade and Bidinger, 1972, *I. punctatus*); Pennsylvania (Torres and Price, 1971, *I. nebulosus*); Kansas (Cloutman, 1974, *I. melas*, *I. punctatus*); Georgia (Rawson and Fox, 1974, *I. punctatus*); Florida (Riley, 1978, *I. natalis, I. nebulosus*); Lake Erie (Baker and Crites, 1976, *I. punctatus*); New Brunswick (Cone, 1980, *I. nebulosus*); Manitoba (Lubinsky and Loch, 1979, *I. nebulosus*); North Dakota (Sutherland and Holloway, 1979, *I. melas*), Arkansas (Cloutman, unpublished data, *Noturus exilis*); Alabama (Allison, 1963, *I. punctatus*; Allison and Rogers, 1970, *Ictalurus catus*, *I. furcatus*, *I. punctatus*, *I. nebulosus*, *Lepomis cyanellus*, *Pylodictis olivaris*; present study, *I. punctatus*, *I. furcatus*, hybrid *I.*

punctatus × *I. furcatus*); Czechoslovakia (Zitnan, 1965, *I. nebulosus*); Hungary (Molnar, 1968, *I. nebulosus*); Poland (Adamczyk, 1973, Prost, 1973, *I. nebulosus*); Yugoslavia (Kiskaroly, 1977, *I. nebulosus*); France (Lambert, 1977, *I. melas*); U.S.S.R (Mirzoyeva, 1977, *I. platycephalus*).

Remarks

This species was originally described by Mueller (1937) on the gill filaments of *I. punctatus*, *A. nebulosus*, and *A. natalis* in Myakka River, Lake Okeechobee, Florida. It was then reclassified to *Ligictaluridus pricei* by Beverley-Burton (1984). Another *Ligictaluridus* species, namely *L. monticellii*, has a very similar copulatory organ with *L. pricei*, but *L. pricei* differs from *L. monticelli* by having relatively enlarged superficial roots and clear deep roots on the hamuli. Moreover, *L. pricei* generally infect on host gills whereas *L. monticellii* is specifically infects the host nasal cavities of its fish hosts (Klassen and Beverley-Burton, 1985).

Morphology of the ventral and dorsal hamuli among the present materials is generally consistent to the original descriptions of Mueller (1936) in which they have long deep roots (Figs. 9.3, 9.5, 11.4). However, the present specimens have vestigially bifurcated and sized-different hamuli, which are characters that are in agreement with observations of Mizelle and Cronin (1943). Moreover, Klassen and Beverley-Burton (1985) illustrated *L. pricei* specimens that had slightly different hamuli shape (short deep root) from the original description of Mueller (1936).Those differences can be explained as previously insufficient observations or morphological variations among individuals of this species. The short deep root character of the hamuli was observed in some other specimens from this study (Figs.10.1, 10.3, 10.5, 11.5). This variation has been noted by Seamster (1938) and Mizelle and Cronin (1943), and variation in transverse bars described by Klassen and Beverley-Burton (1985) resulted from different

pressures when preparing the specimens on microscopic slides. Moreover, the presence of associated hamulus wings, which is described above among the present specimens, is not mentioned in previous studies, until descriptions of Klassen and Beverley-Burton (1985). Hooklet pair size seeingly varies intraspecifically in this species. Prost (1973) and Klassen and Beverley-Burton (1985) described the difference in size (smaller) of seventh pair relatively to the other pairs. However, in present materials, the first or sometimes the second pair is consistently different in size as it is bent at its base and quite smaller than other pairs (Figs. 9.7, 10.7). In addition, egg morphology was also found inconsistent with those from the original description. Mueller (1936) observed the eggs as triangular pyramid or tetraheron, while they seem ovoid among young eggs and become pentagon as they are more mature in present specimens (Figs. 9.1, 9.8). The vagina was not observed among the present materials, which is in agreement with observations of Mizelle and Cronin (1943)

In term of variation of *L. pricei* infecting the three catfishes, individuals infecting hybrid catfish seem to have larger sizes than those on channel catfish and blue catfish although the average measurements across catfishes stay within the range reported in previous observations. On the other hand, those infecting blue catfish are consistently equal or smaller than their congeners that infect channel catfish and hybrid catfish (Table 4).

Class: Cestoda

Family: Proteocephalidae

Genus: *Corallobothrium* (Fritsch, 1886) Freze, 1965

Diagnosis: Suckers without muscular sphincter. Strobila with numerous segments. Gravid and mature segments broader than long. Posterior edge of vitelline bands turning toward median of proglottid and extents parallel to posterior wall of each segment. Testes lateral to uterus and extended in several layers. Parasites of silurid fishes of North Africa and North America.

Taxonomic summary

Type species: Corallobothrium solidum Fritsch, 1886 (Proteocephalidea: Proteocephalidae).

Other species: C. fimbriatum Essex, 1928 (Proteocephalidea: Proteocephalidae), *C. parafimbriatum* Befus and Freeman, 1973 (Proteocephalidea: Proteocephalidae).

Host family: Malapteruridae and Ictaluridae.

***Corallobothrium fimbriatum* Essex, 1928** (Plates 12−13)

Supplemental observations based on seven whole-mounted specimens with all measurements in microns unless stated; measurements based on five whole-mounted specimen: Worms medium-sized, dorsoventrally flattened, 24mm (16–33; n=7) in total length (Figs. 13.1−3). Scolex irregular with four suckers; scolex length 1,985 (1,800–2,200; n=4); scolex width 632.5 (380–800; n=4); metascolex, mainly marginal in scolex, highly developed with deep grooves; suckers without musculature sphincters, ovoid to round depending on contraction status, 485 (410–620; n=10) in diameter; apical organ and all hook types absent (Figs. 12.1, 13.4). Neck present with condense musculature fibers, short, usually broader than long, 632.5 (380–800; n=4) in length and 852.5 (680–1,050; n=4) in width. Vitellaria bilateral, follicular, highly developed, internal to musculature fibers; vitelline bands fewer and less developed as proglottids more mature and little space remaining in fully mature segments (Figs. 12.2, 12.4, 13.5−8).

Strobila with numerous segments, 35–64 in whole mature specimens; tegument thick, irregularly developed grooves along body; musculature powerfully developed, longitudinal, bilateral from neck to posterior end of proglottid; proglottids gradually larger from scolex, both in width and length, as mature and gravid. Immature proglottids about 7 × wider than long, 12–24 in number, averagely 1,145 (940–1,240; n=10) wide and 170 (130–260; n=10) long. Mature proglottids roughly 3 × wider than long, 16–24 in whole worms, 1,142 (950–1,320; n=10) in width and 407 (260–560; n=10) in length (Figs. 12.2, 13.5). Gravid proglottids variable from

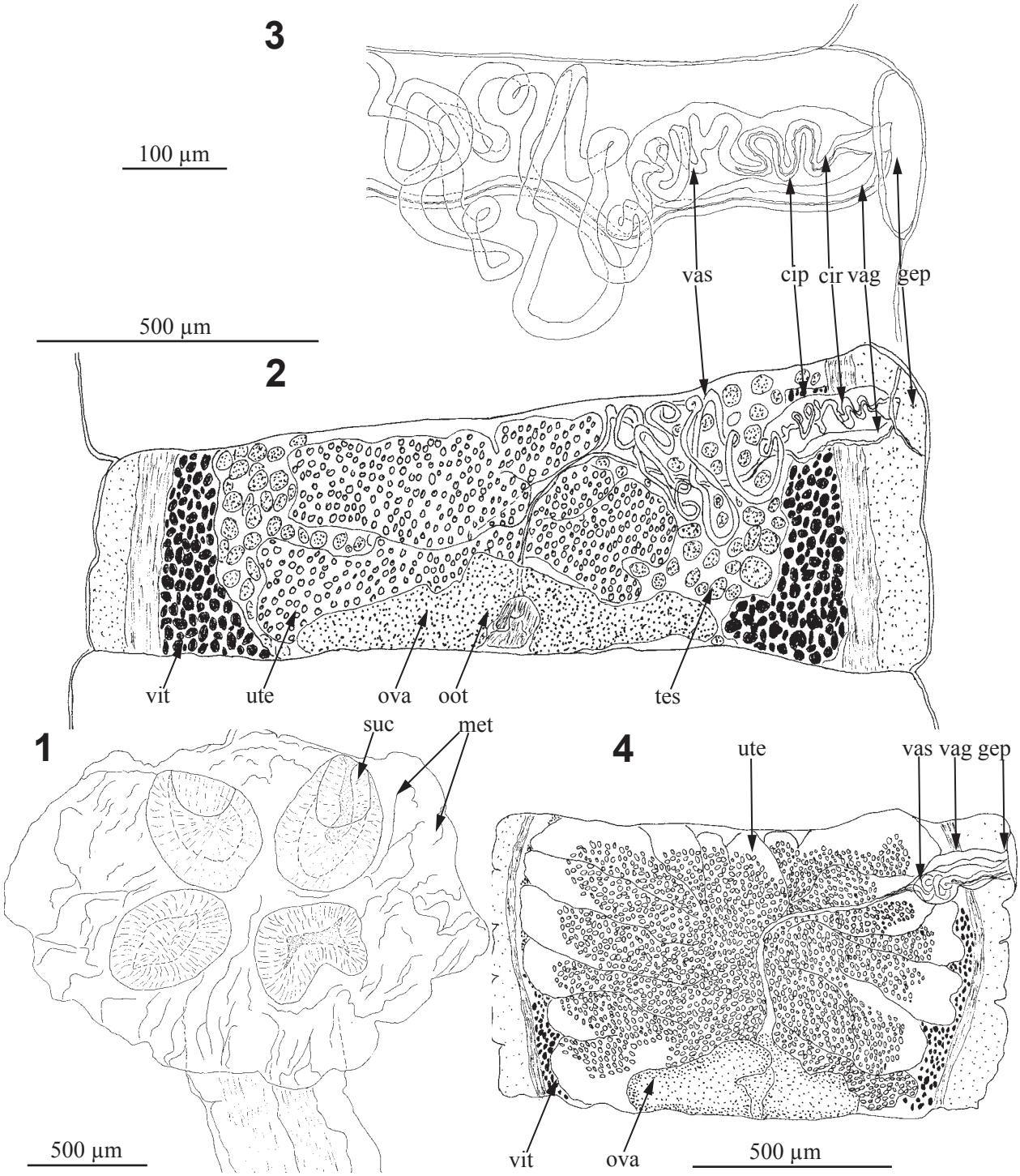

PLATE 12. *Corallobothrium fimbriatum* Essex, 1928, from intestine of blue and hybrid catfishes studied herein, line illustrations from light microscopy. 1. Scolex from mature specimens. 2. Mature proglottid. 3. Higher magnification of the terminal genitalia from Figure 2. 4. Gravid proglottid. 5. Abbreviations: suc, sucker; met, metascolex; vit, vitellaria; tes, testes; ute, uterus; cip, cirrus pouch; cir, cirrus; ova, ovary; oot, ootype; vas, vas deferens; gep, genital pouch; vag, vagina. Scale bars: Figures 1–2, 4 = 500µm, Figure 3 = 100µm.

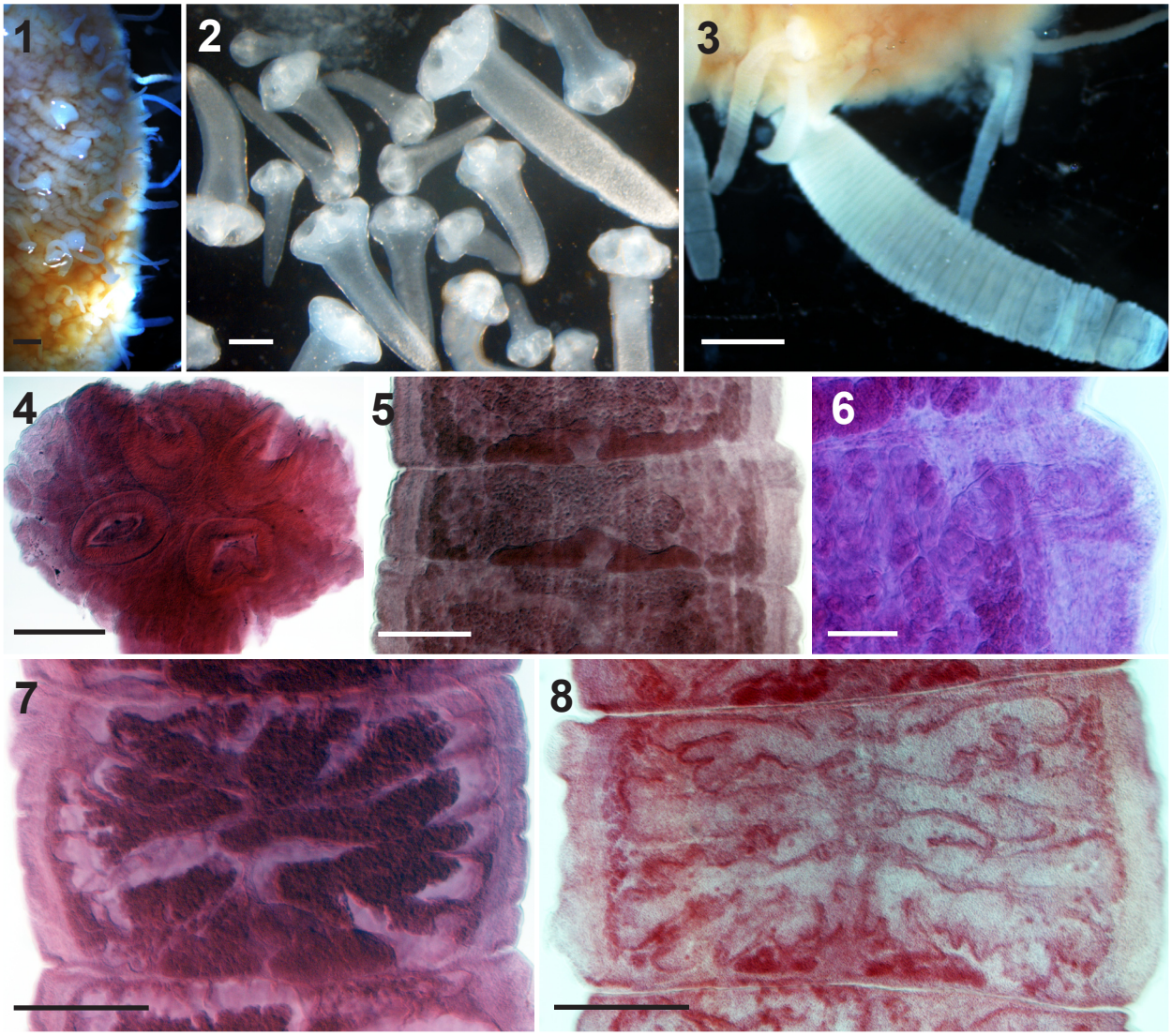

PLATE 13. *Corallobothrium fimbriatum* Essex, 1928 from intestine of blue and hybrid catfishes studied herein, photograph illustrations. 1, 3. Intestine-attached specimens. 2. Released juveniles. 4. Scolex. 5. Fully mature proglottid. 6. High magnification of mature proglottid shows cirrus pore and vagina. 7. Gravid proglottid. 8. Spent proglottid. Scale bars: Figure 1 = 2mm, Figures 2, 4, 7, 8 = 500µm, Figure 3 = 1 mm, Figure 5 = 250µm, Figure 6 = 200µm.

quadrate to 3 × wider than long, 1,915 (1,010–2,220; n=10) in width and 640 (340–880; n=10) in length (Figs. 12.4, 13.7).

Genital pore 3/4 to 1/7 anterior of mature and gravid proglottids, irregularly alternative from dextrally to sinistrally (Figs. 12.2, 12.4). Cirrus pouch generally pyriform, slightly medially constrictive at lower or both sides, averagely 472 (450–490; n=10) long and 190 (160–220; n=10) wide; cirrus coiled within cirrus pouch, connective with vas deferens (Figs. 12.2−4, 13.6). Vas deferens very long, irregularly coiled, vertically expansible almost half of mature proglottids; vas deferens less developed, less competitive to uterus in gravid proglottids (Figs. 12.3, 13.6). Vagina thin-walled, connective to ovary, frequently anterior to cirrus sac or sometimes posterior; vaginal canal opening in genital pouch (Figs. 12.2-3, 13.6).

Testis numer 85–100, several layers, evenly and fully distributed in proglottid space between vitellaria lines in mature proglottids, ovoid to round, 55.3 (50–61; n=10) in diameter; testes less developed in number and size as proglottids more mature and almost disappeared in fully mature proglottids (Fig. 12.2). Ovary in two lobes, posterior, medial, roughly marginal in mature and gravid proglottids; ovary sac less developed in gravid proglottids; lobes generally symmetrical, equal in size; total ovary width in mature 834 (740–900; n=10) (Figs. 12.2, 12.4, 13.5, 13.7−8). Uterus not visible in immature and early mature proglottids; uterus lobulate as proglottids more mature, dividing into 5–7 branches with full eggs in completely gravid proglottids; eggs spherical, 20.3 (17–22; n=10) in diameter (Figs. 12.2, 12.4, 13.5, 13.7−8).

Taxonomic summary

Type host: Not specified among channel catfish, *Ictalurus punctatus* (Rafinesque, 1818), (Siluriformes: Ictaluridae); mud cat, *Pylodictis (Leptops) olivaris* (Rafinesque, 1818), (Siluriformes: Ictaluridae); black bullhead, *Ameiurus melas* (Rafinesque, 1820), (Siluriformes: Ictaluridae).

Other previously-reported hosts: Stonecats, *Notorus flavus* (Rafinesque, 1818) (Siluriformes: Ictaluridae), *Ameiurus nebulosus*, *A. natalis*, *N. gyrinus*, brindled madtom, *N. miurus* (Jordan, 1877) (Siluriformes: Ictaluridae), balsas catfish, *Ictalurus balsanus* (Jordan and Snyder, 1899) (Siluriformes: Ictaluridae).

New host records for this species: I. furcatus and hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Anterior intestine.

Prevalence and mean intensity: 64 of 112 individual channel catfish (*Ictalurus punctatus*) (57.1%), 26 of 74 individual blue catfish (*Ictalurus furcatus*) (35.1%), and 100 of 209 individual hybrid catfish *I. punctatus* × *I. furcatus*) (47.8%) were infected with cestode parasites. Particularly, *C. fimbriatum* was found infecting all of the three catfishes during the study period. Mean intensity of overall cestodes in channel catfish is 1.80 (1.00−3.00), in blue catfish is 1.87 (1.00−3.00), and in hybrid catfish is 1.72 (1.00−2.67).

Type locality: Illinois, U.S.A.

Other localities: Alabama, Arkansas, California, Iowa, Indiana, Kansas, Kentucky, Massachusetts, Minnesota, North Dakota, New York, Ohio, Tennessee, Texas, Wisconsin, West Virginia, Ontario.

Remarks

Most of the morphological measurements of present specimens are consistent with those from the original description of Essex (1928). Moreover, overlapping ranges was also found among measurements of tapeworms infecting catfishes. Essex (1928) noted high variation levels of the scolex morphology of this species in different contraction states. Specimens in this study strongly support his observation as the worms were primarily fixed as still attaching tissue and became contracted in their scolices, although heat-killed initially (Fig. 12.1). Moreover, highly

developed metascolex is also a character that makes this tapeworm species more variable in their scolices, which results in multiple specimens are required for confident identification.

In the first description of this species, Essex (1928) gave the features of sucker as absent or weakly developed sphincter. In present materials, no musculature sphincter was observed on the worm suckers (Fig. 12.1). Notably, inconsistency between descriptions and measurements from Essex (1928) were considerably confused the identification of this species. He described the gravid proglottids longer than broad but 7 out of 10 proglottid measurement showed equal values or broader than long. Moreover, the feature of which gravid proglottids longer than broad (in his descriptions) challenges the classification of the species as genus diagnoses generally reveal the opposite characters across all segment types.

Corallobothrium parafimbriatum **Befus and Freeman, 1973** (Plates 14−15)

Supplemental observations based on 8 whole-mounted specimens with all measurements in micronsunless stated; measurements based on 8 whole-mounted specimens: Worms small-sized, dorsoventrally flatten, total length 19.4mm (13–24; n=8) (Figs. 15.1−2). Scolex irregular with four suckers, 1,652 (1,440–1,860; n=6) in length and 1,056 (820–1,260; n=6) in breadth; metascolex present, powerfully developed with deep or shallow grooves; sucker in four without muscular sphincters, generally ovoid or round, 540 (430–680; n=13) in diameter; apical organs and hooks absent (Figs. 14.1, 15.3). Neck present, short with strong internal musculature fibers, 952 (380–1,600; n=6) in length and 860 (490–1,700; n=6). Vitellaria bands bilateral of body, filling almost all length of each proglottid; vitellaria most abundant in mature proglottids, less developed in immature and gravid segments (Figs. 14.2−3, 15.4−5).

Strobila numerous with about 60 segments in complete specimens (Figs. 15.1−2). Tegument thick with irregularly distributed grooves. Internal musculature developed bilaterally across whole body (Fig. 14.3). Immature proglottids usually 6 × broader than long, about 24 segments,

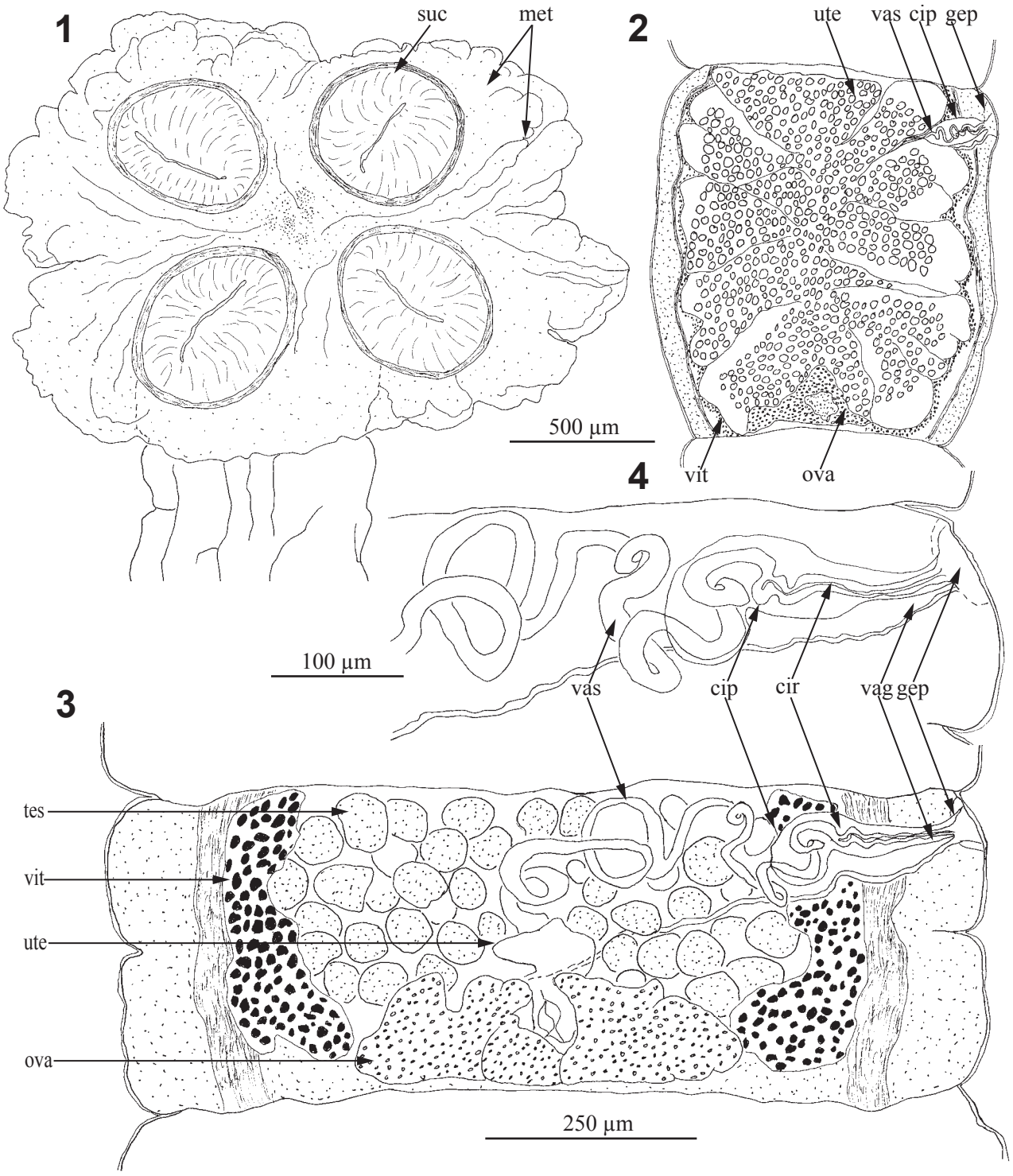

PLATE 14. *Corallobothrium parafimbriatum* Befus and Freeman, 1973, from intestine of channel and hybrid catfishes studied herein, line illustrations from light microscopy. 1. Scolex from mature specimens. 2. Gravid proglottid. 3. Mature proglottid. 4. Higher magnification of the terminal genitalia from Figure 3. Abbreviations: suc, sucker; met, metascolex; vit, vitellaria; tes, testes; ute, uterus; cip, cirrus pouch; cir, cirrus; ova, ovary; vas, vas deferens; gep, genital pouch; vag, vagina. Scale bars: Figures 1–2 = 500µm, Figure 3 = 250µm, Figure 4 = 100µm.

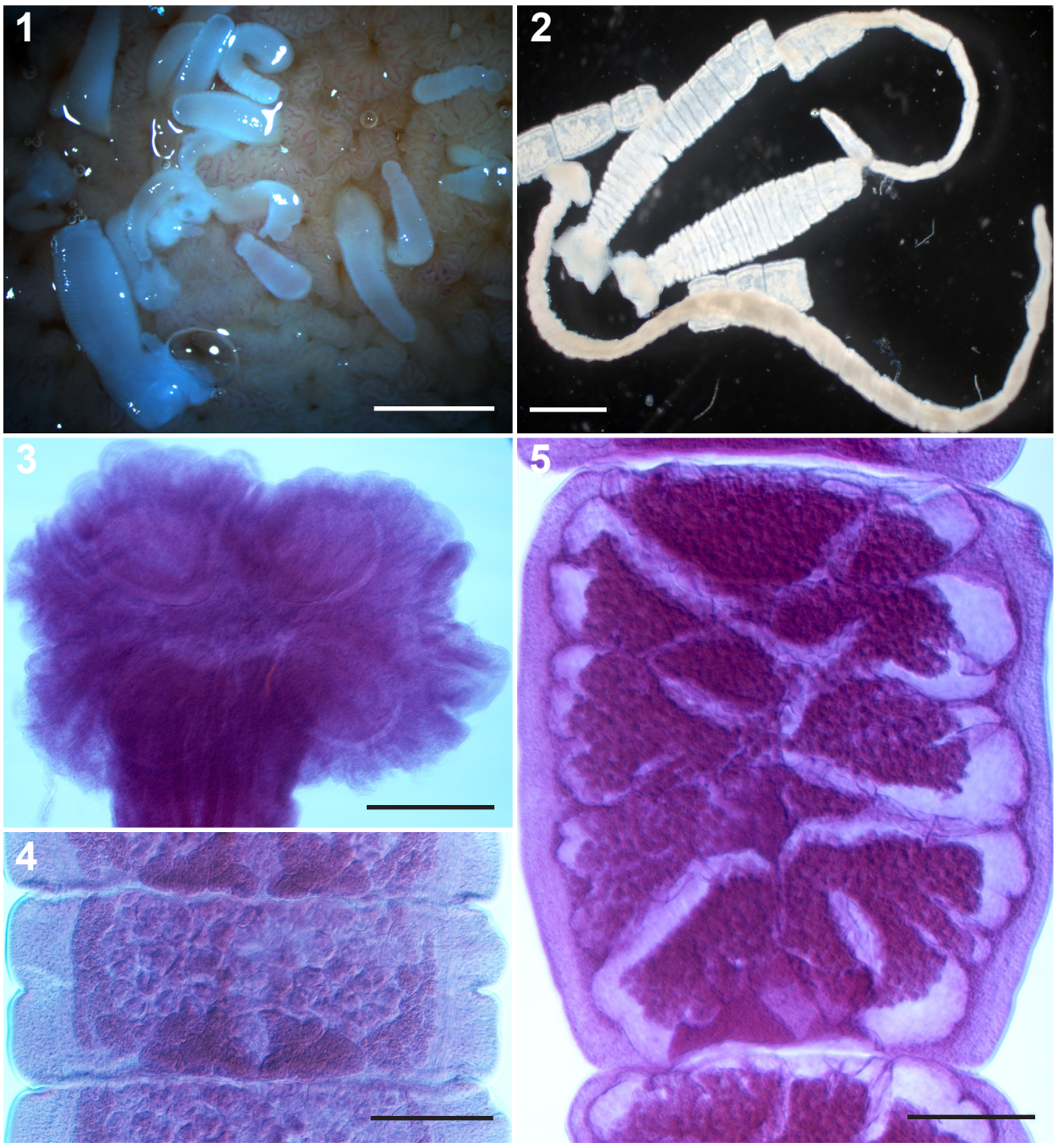

PLATE 15. *Corallobothrium parafimbriatum* Befus and Freeman, 1973 from intestine of channel and hybrid catfishes studied herein, photograph illustrations. 1. Intestine-attached specimens. 2. Released specimens. 3. Scolex. 4. Mature proglottid. 5. Gravid proglottid. Scale bars: Figures 1–2 = 2mm, Figure 3 = 500µm, Figures 4–5 = 250µm.

894 (760–1,160; n=10) in width and 146 (120–190; n=10) in length. Mature proglottids, about 18 in number, roughly 3 × wider than long; more mature progottids larger, both length and width, than less mature ones; average mature proglottids 1,000.5 (910–1,150; n=10) wide and 329 (190–440; n=10) long (Figs.14.3, 15.4). Gravid proglottids also wider than long in early stages and gradually longer than wide in more gravid ones, about 18 in number; average proglottid length 1,265 (780–1,620; n=16) and proglottid width 1,256.3 (600–1,880; n=16) (Figs. 14.2, 15.5).

Genital pore approximately 1/7 to 1/8 anterior to each proglottid, irregularly alternative dextrally or sinistrally (Figs. 14.2−4, 15.4−5). Cirrus pouch generally elongate, constrictive at lower side, 212 (180–235; n=10) in length and 76 (70–85; n=10) in width; cirrus coiled inside cirrus pouch and connective to vas deferens (Figs. 14.2−4). Vas deferens very long, coiled, thin-tubed, irregularly distributed further to middle, in upper half of each mature proglottid; vas deferens less developed in gravid proglottids, almost disappeared in fully gravid segments (Figs. 14.3−4). Vagina thin-walled, connected with ovary, irregularly upper or lower to cirrus sac; vaginal canal opening in genital pouch (Figs. 14.2–4).

Testes numerous, 45–53 in number, several layers, ovoid or round, completely distributed between vitellaria bands in each mature proglottids, 57.8 (45–65; n=16) in diameter in mature proglottids; testes less developed in number and size, appeared laterally to uterus, as proglottids more mature and almost disappeared in gravid segments (Figs. 14.3, 15.4). Ovary bi-lobed, posterior and medial in each mature and gravid proglottid; ovary equal in 2 lobes with total width in mature proglottids 510.6 (380–620; n=16); ovary less developed in fully gravid segments (Figs. 14.2−3, 15.4). Uterus primarily in fully mature and gravid proglottids; uterus medial to mature proglottids in early stages, expanding bilaterally in gravid segments; uterine branches 3–4

in number, unequally in size, filling with eggs in fully gravid proglottids; eggs generally spherical, 19.7 (15–25; n=16) in diameter (Figs. 14.2, 15.5).

Taxonomic summary

Type hosts: Ictalurus nebulosus.

Other previously-reported hosts: Ictalurus melas.

New host records for this species: I. punctatus, *I. furcatus*, hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Intestine.

Prevalence and mean intensity: 64 of 112 individual channel catfish (57.1%), 26 of 74 individual blue catfish (*I. furcatus*) (35.1%), and 100 of 209 individual hybrid catfish (*I. punctatus* × *I. furcatus*) (47.8%) infected cestode parasites. As previously discussed, no information on prevalence and intensity of *C. parafimbriatum* was found infecting all of the three catfishes during the study period. Mean intensity of overall cestodes is 1.80 (1.00−3.00) on channel catfish, is 1.87 (1.00−3.00) on blue catfish, and 1.72 (1.00−2.20) on hybrid catfish.

Type locality: Algonquin Park, Ontario, Canada.

Other localities: Fish farm near Ferrara, Italy (Scholz and Cappellaro, 1993; *Ictalurus melas*), Alabama, U.S.A. (present study; *I. punctatus, I. furcatus,* hybrid *I. punctatus* × *I. furcatus*).

Remarks

Corallobothrium parafimbriatum was first discovered and described by Befus and Freeman (1973) when examining the life cycle of corallobothriins on brown bullhead, *Ictalurus nebulosus*, in Algonquin Park, Ontario. Although some overlapping morphological measurements exist, those authors distinguished this species from *C. fimbriatum* because *C. parafimbriatum* have generally smaller sizes, fewer segments, testes, medially unterine branches, and the fourth layer of egg structure (see Befus and Freeman, 1973 for more details of comparative measurements between the two species). In present study, *C. parafimbriatum* was found infecting channel

catfish, blue catfish, and hybrid catfish. Most measurements of the present materials are consistent with those from the original descriptions, except for the larger sucker and scolex dimensions. However, since those values are very dependable to contraction status of the worms at fixing, so they could be considered negligible (Essex, 1928).

Uterine branches were counted 2–4 in the holotype of *C. parafimbriatum* (Befus and Freeman), which is consistent with specimens from this study (Figs. 14.2, 15.5). Scholz and Cappellaro (1993) reported the new host record of this tapeworm, which possesses 5–7 uterine branches, on *Ictalurus melas* in Europe. This character is consistent to *C. fimbriatum*, which is closely related to this species. Moreover, specimens from those authors also have very close segment number (60–80 versus 40–90) and testes numbers (60–80 versus 100–125) with *C. fimbriatum*, respectively, which described by Freze, 1965. Those variations significantly challenge the identification of the 2 mentioned species as they have very close characteristics. Misidentification between *C. fimbriatum* and *C. parafimbriatum*, therefore, can be very likely for current and later studies. Better distinct characters may be needed to eliminate the problems.

In a phylogenetic analysis of 28S rRNA gene of the genera Corallobothriinae, Rosas-Valdez et al. (2004) suggested a pending reclassification of this species to *Corallotaenia parafimbriatum* as it shares principal phylogenetic features (99% bootstrap support) with species of the genus *Corallotaenia* (Rosas-Valdez et al., 2004).

Genus: *Corallotaenia* (Freze, 1965) Befus and Freeman, 1973

Diagnosis: Corallobothriinae, without muscular sphincters on suckers, gravid segments longer than wide; testes in several layers; vitellaria follicular, in straight lateral fields; ovary follicular; in ictalurids from North America.

Taxonomic summary

Type species: Corallotaenia parva (Larsh, 1941) Freze, 1965 (Proteocephalidea: Proteocephalidae).

Other species: C. intermedia (Proteocephalidea: Proteocephalidae), *C. minutium* (Proteocephalidea: Proteocephalidae).

Host family: Ictaluridae.

***Corallotaenia intermedia* (Fritts, 1959) Freze, 1965** (Plates 16−17)

Supplemental observations based on four whole-mounted specimens with all measurements in microns unless stated; measurements based on four whole-mounted specimens: Worms small-sized, dorsoventrally flatten, total length 5.1mm (4.0–7.0; n=4). Scolex irregular with four suckers, 827.5 (690–980; n=4) in length and 537.5 (420–650; n=4) in width; metascolex present, developed with parallelly deep grooves on scolex surface; suckers relatively equal in size, without muscular sphincter, round or oval, 221 (200–275; n=10) in diameter; apical organs and hooks are absent (Figs. 16.1, 17.1). Neck present with internal longitudinal musculature, short, variable with contraction state of scolex, 166.3 (110–220; n=4) in length and 258.8 (175–320; n=4) in width (Fig. 16.1). Vitellaria bands bilaterally developed, in almost whole length of each proglottid, most abundant in mature proglottids (Figs. 16.2, 17.3).

Strobila segmented with 17–20 immature and mature proglottids. Tegument thin with irregularly distributed grooves. Internal longitudinal musculature relatively developed along whole worm body. Immature proglottids more than 3 × wider than long, 12–13 in number, 474.2 (300–590; n=12) in width, 133.3 (90–220; n=12) in length. Mature proglottids usually 5 × longer than wide when fully mature but wider than long in early mature ones; average width 451.3 (260–620; n=16); average length 710.6 (270–1,200; n=16); last mature proglottids in mature

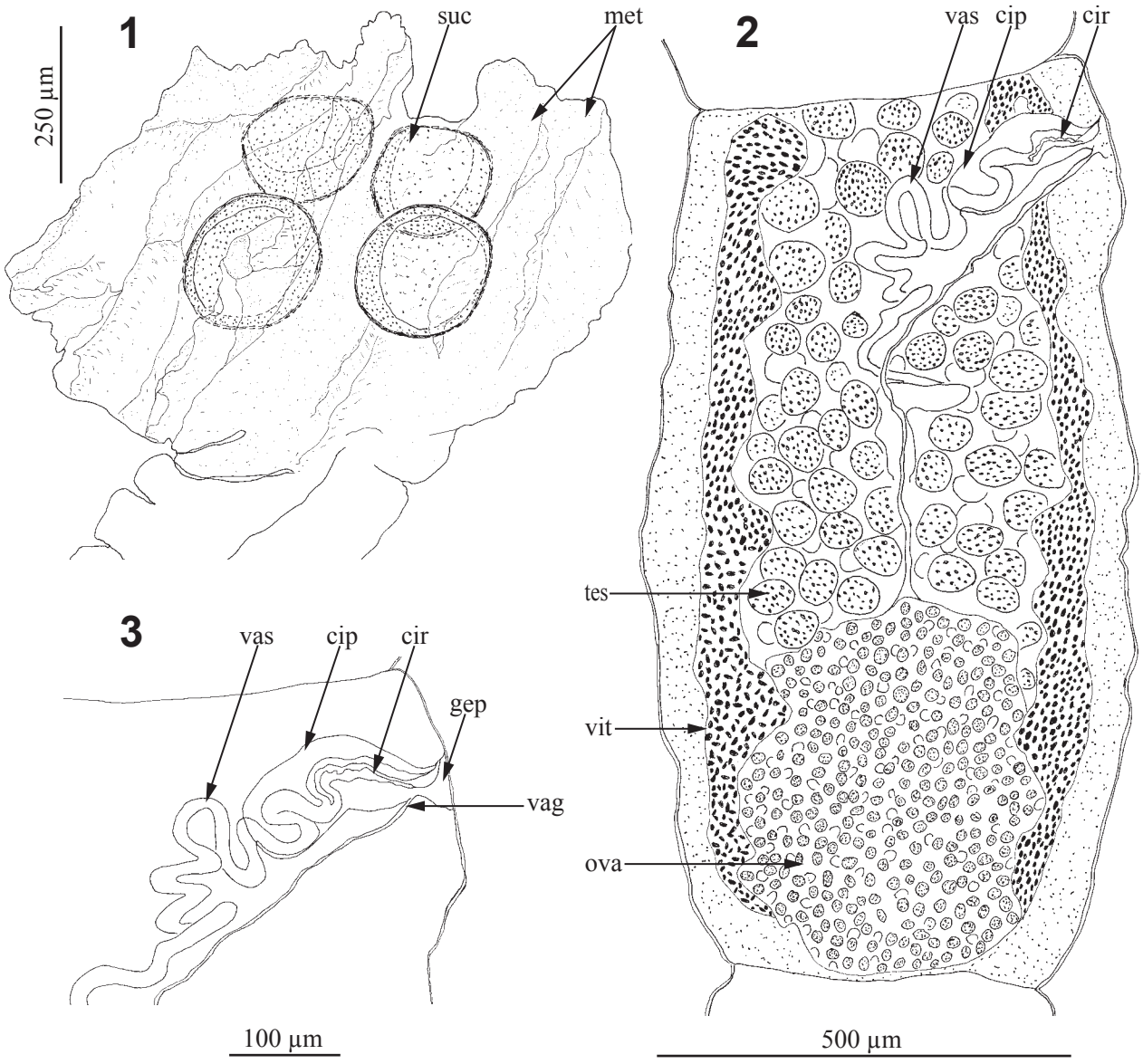

PLATE 16. *Corallotaenia intermedia* (Fritts, 1959) Freze, 1965, from intestine of channel and hybrid catfishes studied herein, line illustrations from light microscopy. 1. Scolex from mature specimens. 2. Mature proglottid. 3. Higher magnification of the terminal genitalia from Figure 2. Abbreviations: suc, sucker; met, metascolex; vit, vitellaria; tes, testes; cip, cirrus pouch; cir, cirrus; ova, ovary; vas, vas deferens; gep, genital pouch; vag, vagina. Scale bars: Figure 1 = 250µm, Figure 2 = 500µm, Figure 3 = 100µm.

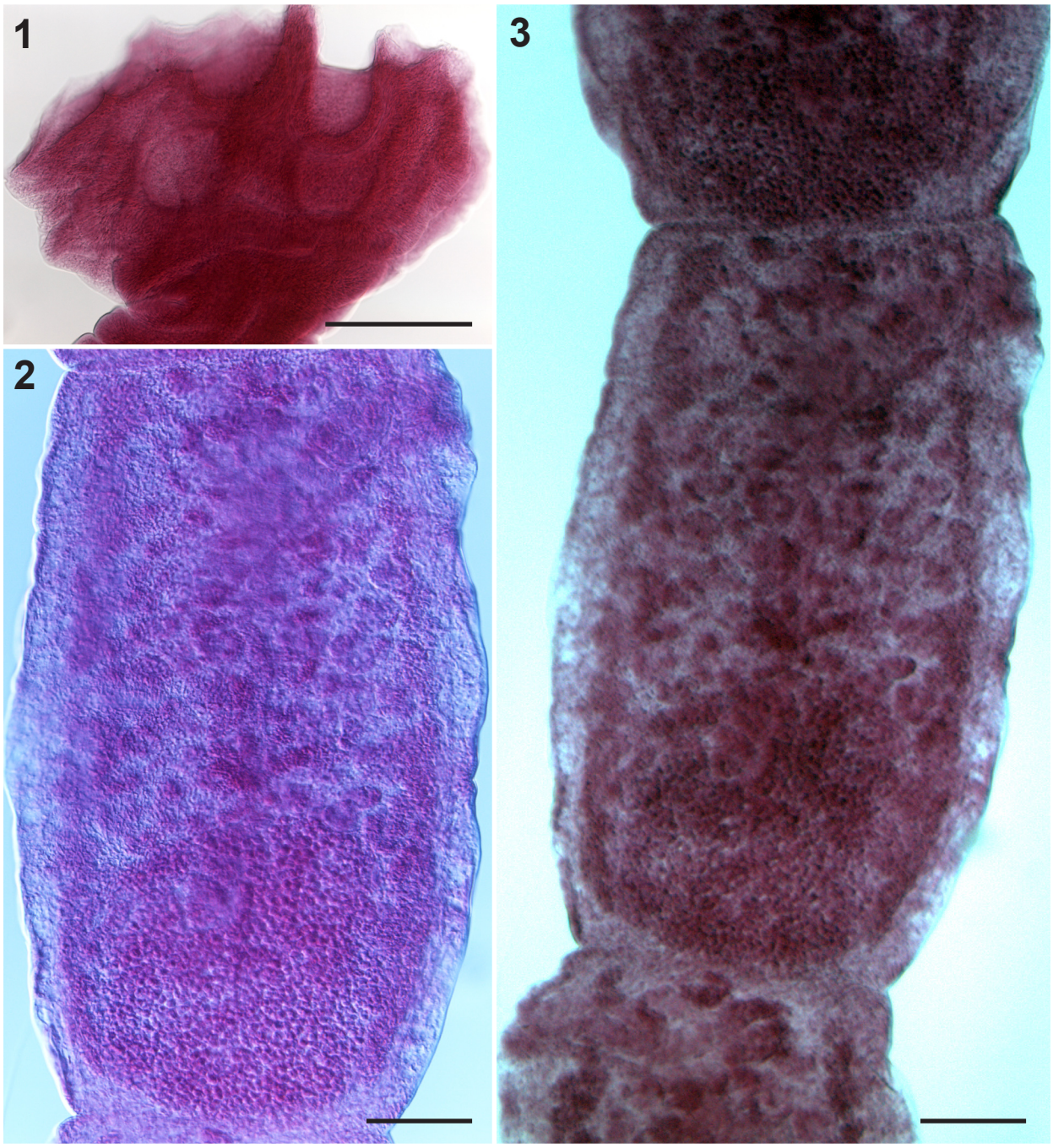

PLATE 17. *Corallotaenia intermedia* (Fritts, 1959) Freze, 1965 from intestine of channel and hybrid catfishes studied herein, photograph illustrations. 1. Scolex. 2, 3. Mature proglottid in different light views. Scale bars: Figure 1 = 250µm, Figures 2–3 = 100µm.

worms usually oval or pointed posteriorly (Figs. 16.2, 17.2−3). No observed gravid proglottid among specimens in this study.

Genital pore of 1/10 anterior, irregularly alternative dextrally or sinistrally in each mature proglottid (Figs. 16.2, 17.2−3). Cirrus pouch elongate, slightly constrictive medially, 171.7 (170–175; n=3) in length and 73.3 (65–80; n=3) in width; cirrus also coiled, connective to vas deferens (Figs. 16.2−3). Vas deferens long, coiled, anterior, extending to middle in each mature proglottid (Figs. 16.2−3). Vagina thin-wall, connective to ovary, frequently in lower side relatively to cirrus pouch; vaginal canal opening to cirrus pore (Figs. 16.2−3, 17.2−3).

Testes round or oval, 36–58 in number, single-layered, evenly distributed within space between 2 vitelline bands, 56.9 (45–61; n=20) in diameter (Figs. 16.2, 17.2−3). Ovary relatively ellipsoid, single-lobed, posterior, medial to almost marginal edge in each mature proglottid (Figs. 16.2, 17.2−3). Unknown uterus and egg characters (no observed gravid proglottid among present materials).

Taxonomic summary

Type hosts: Ameiurus nebulosus.

Other previously-reported hosts: Ictalurus melas.

New host records for this species: I. punctatus, hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Intestine.

Prevalence and mean intensity: Similar to the previous discussions, no information on particular prevalence and intensity of *Corallotaenia intermedia*. However, this species was found infecting channel and hybrid catfishes during the study period. No blue catfish was infected by this tapeworm. Mean intensity of overall cestodes was 1.80 (1.00−3.00) in channel catfish and 1.72 (1.00−2.67) in hybrid catfish.

Type locality: Robinson Lake, Idaho, U.S.A.

Other localities: Ontario, Canada; Alabama, U.S.A. (present study; *I. punctatus*, hybrid *I. punctatus* × *I. furcatus*).

Remarks

This tapeworm was first described on *Ameiurus nebulosus* by Fritts, 1959 as *Corallobothrium intermedium*. Freze (1965) then reclassified it as *Corallotaenia intermedia.* Subsequently, Befus and Freeman (1973) suggested reassigning this species to *Megathylacoides intermedium*. However, this new combination was not supported by some other authors (Scholz et al., 2003; Rosas-Valdez et al., 2004) as they still kept the former combination, *Corallotaenia intermedia*, for this species and considered *Megathylacoides intermedium* as a synonym in their reports.

In present study, this tapeworm species was found infecting *I. punctatus* and hybrid *I. punctatus* × *I. furcatus* while no blue catfish was infected. Most of the morphological measurements of the present specimens are consistent with those from the original descriptions of Fritts (1959).

Genus: *Megathylacoides* (Jones, Kerley, and Sneed, 1956) Freze, 1965

Diagnosis: Corallobothriinae with features of family. Suckers with musculature sphincter which particularly surrounding aperture of each sucker. Mature proglottids longer than broad. Testes in single layer. Vitellaria lateral. Parasites of silurid fishes of North America.

Taxonomic summary

Type species: Megathylacoides giganteum (Essex, 1928) Freze, 1965 (Proteocephalidea: Proteocephalidae).

Other species: M. procerum (Proteocephalidea: Proteocephalidae), *M. tva* (Proteocephalidea: Proteocephalidae), *M. thompsoni* (Proteocephalidea: Proteocephalidae).

Host families: Ictaluridae.

***Megathylacoides* cf. *giganteum* (Essex, 1928) Freze, 1965 (**Plate 18)

Supplemental observations based one whole-mounted immature specimen with all measurements in microns unless stated: Body medium-sized, dorsoventrally flatten, ~ 10mm in total length. Scolex irregularly shaped, having four suckers, 1,960 long, 500 broad with meatascolex weakly developed, having few grooves on marginal scolex surface (Fig. 18.1). Suckers oval or rounded, lacking muscular sphincter, 436.7 (350–500; n=3) in diameter (Fig. 18.1). Apical organ or hooks not evident. Neck present, short, 430 long and 1,020 wide. Vitellaria bilateral, thick-banded, most developed in mature proglottids (Fig. 18.2).

Strobila numerous segments, about 38 in number in immature specimens. Tegument thick with irregularly and deeply distributed groove on strobila surface. Internal longitudinal weakly developed as thin lines along whole strobilation in immature worm. Proglottids gradually larger in length and width, from immature to early mature segments. Immature proglottids wider than long, 16 in number, 500 (470–530; n=6) in width and 295 (230–370; n=6) in length. Early mature segments relatively quadrate or wider than long, 12 in number, averagely 650 (620–680; n=6) wide and 520 (430–650; n=6) long (Fig. 18.2). Because of only observed immature specimens, no fully mature or gravid segments described.

Genital pore 1/6 of anterior, irregularly alternative as dextrally or sinistrally in each early mature proglottids (Figs. 18.2−3). Cirrus pouch generally elongate, opening end smaller than other end, 166.3 (143–178; n=3) in length and 62 (60–63; n=3) in width; cirrus coiled within cirrus pouch and connected with vas deferens (Figs. 18.2−3). Vas deferens very long, coiled, extended posteriorly and medially in early mature proglottids; vas deferens gradually larger posteriorly, frequently ventrally to oviduct and uterus (Figs. 18.2−3). Vagina thin-walled, irregularly upper or lower to cirrus sac, connected with anterior end or medial uterus (Figs. 18.2−3).

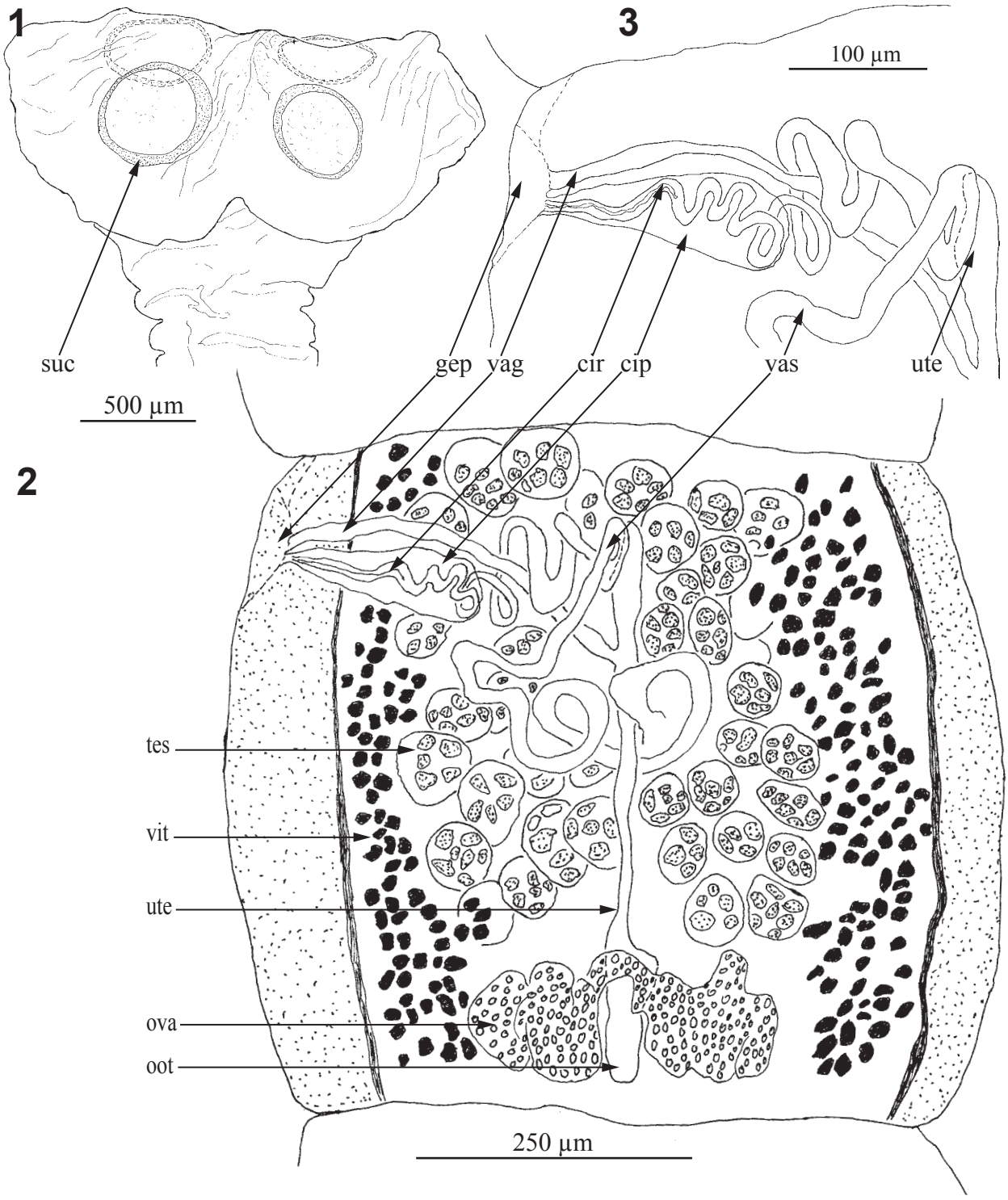

PLATE 18. *Megathylacoides* cf. *giganteum* (Essex, 1928) Freze, 1965, from intestine of channel catfish studied herein, line illustrations from light microscopy. 1. Scolex from mature specimens. 2. Mature proglottid. 3. Higher magnification of the terminal genitalia from Figure 2. Abbreviations: suc, sucker; met, metascolex; vit, vitellaria; tes, testes; ute, uterus; cip, cirrus pouch; cir, cirrus; ova, ovary; oot, ootype; vas, vas deferens; gep, genital pouch; vag, vagina. Scale bars: Figure 1 = 500µm, Figure 2 = 250µm, Figure 3 = 100µm.

Testes oval or round, cortical, generally in 2 layers, 55–70, 55 (40–65; n=20) in diameter; testis divided into 4–7 granular components (Fig. 18.2). Ovary bilobed, relatively equal, posterior and medial in each mature proglottid; each lobe incompletely lobulate; total ovary width 270 (250–295; n=7) (Fig. 18.2). Repeatedly, no fully mature eggs observed because of immature specimens. Uterus thin-tubed, generally medial, connective to ovary and extended anteriorly to almost whole length in early mature proglottids (Fig. 18.2).

Taxonomic summary

Type host: Not specified among *Ictalurus punctatus*, *Pylodictis olivaris*, and *Ameiurus melas*.

Other previously-reported hosts: I. natalis, *I. catus*.

New host records for this species: None.

Site of infection: Intestine.

Prevalence and mean intensity: 1 of 99 individual channel catfish (*Ictalurus punctatus*) (1.0%) was found infected *Megathylacoides giganteum* larvae. Mean intensity is 1 tapeworm/fish.

Type localities: Illinois and Mississippi, U.S.A.

Other localities: Ohio (Bangham, 1941, Baker and Crites, 1976, *I. punctatus*); Lake Huron (Bangham, 1955, *I. punctatus*); Kentucky (Edwards et al., 1977, *I. punctatus*); California (Haderlie, 1953, *I. catus*; Miller et al., 1973, *I. punctatus*; Hensley and Nahhas, 1975, *I. catus*, *I. punctatus*, *I. melas*; Edwards and Nahhas, 1986, *I. punctatus*); Wisconsin (Fischthal, 1952, *Pylodictis olivaris*); Kansas (Harms, 1959, *I. punctatus*, *I. melas*, *I. natalis*; Wilson, 1957, *I. punctatus*); Arkansas (Hoffman et al., 1974, *I. punctatus*); South Dakota (Hugghins, 1959, *I. melas*); Texas (Lawrence and Murphy, 1967, *I. punctatus*); North Dakota (Woods, 1971, *I. melas*); Alabama (present study, *I. punctatus*); Manitoba, Canada (Scholz et al., 2003, from GenBank, accession number AY307118, *Ictalurus punctatus*).

Remarks

This species was first described as *Corallobothrium giganteum* on *Ictalurus punctatus* and *I. oivaris* by Essex (1928). It then was reclassified to *Megathylacoides giganteum* by Freze (1965). The genus *Megathylacoides* (Freze, 1965) was erected for species with musculature sphincters on the sucker. In present study, since very limited and immature material was available for study (single observed cestode), characteristics of the genus and species cannot fully be described. The only immature specimen infected channel catfish. The present immature specimen has similar characters to previous description of Essex (1928): cortical testes, counting 55–70, lying on two layers; uterus thin-tubed, connected to oviduct anteriorly or medially; and ovary incompletely lobulate in each lobe (Fig. 18.2).

***Megathylacoides thompsoni* Jones, Kerley, and Sneed, 1956** (Plates 19−20)

Supplemental observations based on two whole-mounted mature specimens with all measurements in microns unless stated: Worms large-sized, dorsoventrally flatten, total length 116.5cm (97–136; n=2, contracted specimens). Scolex large, generally oval, 1,490 (1,340–1,640; n=2) in length and 1,050 (1,040–1,060; n=2) in width; metascolex present, powerfully developed on scolex surface as deep and irregular grooves; suckers in four with strong musculature sphincters, oval or round, partially circular over half of each sucker; sucker diameter 593.8 (500–690; n=8); suckers sometimes opaque by metascolex folds (Plate 19; Figs. 20.1−3). Apical organ present in middle of four suckers in scolex. All hook types absent. Neck absent. Vitellaria strongly developed, bilateral from anterior to posterior ends of each mature and gravid proglottid; vitelline bands most abundant in mature proglottids.

Strobila distinctly segmented with about 195 proglottids in whole specimens. Tegument very thick with both irregularly horizontally and vertically deep grooves along whole body. Internal longitudinal musculature powerfully developed as fibers within whole length of each segment. Proglottids larger in size as more mature and gravid. Immature and mature proglottids broader

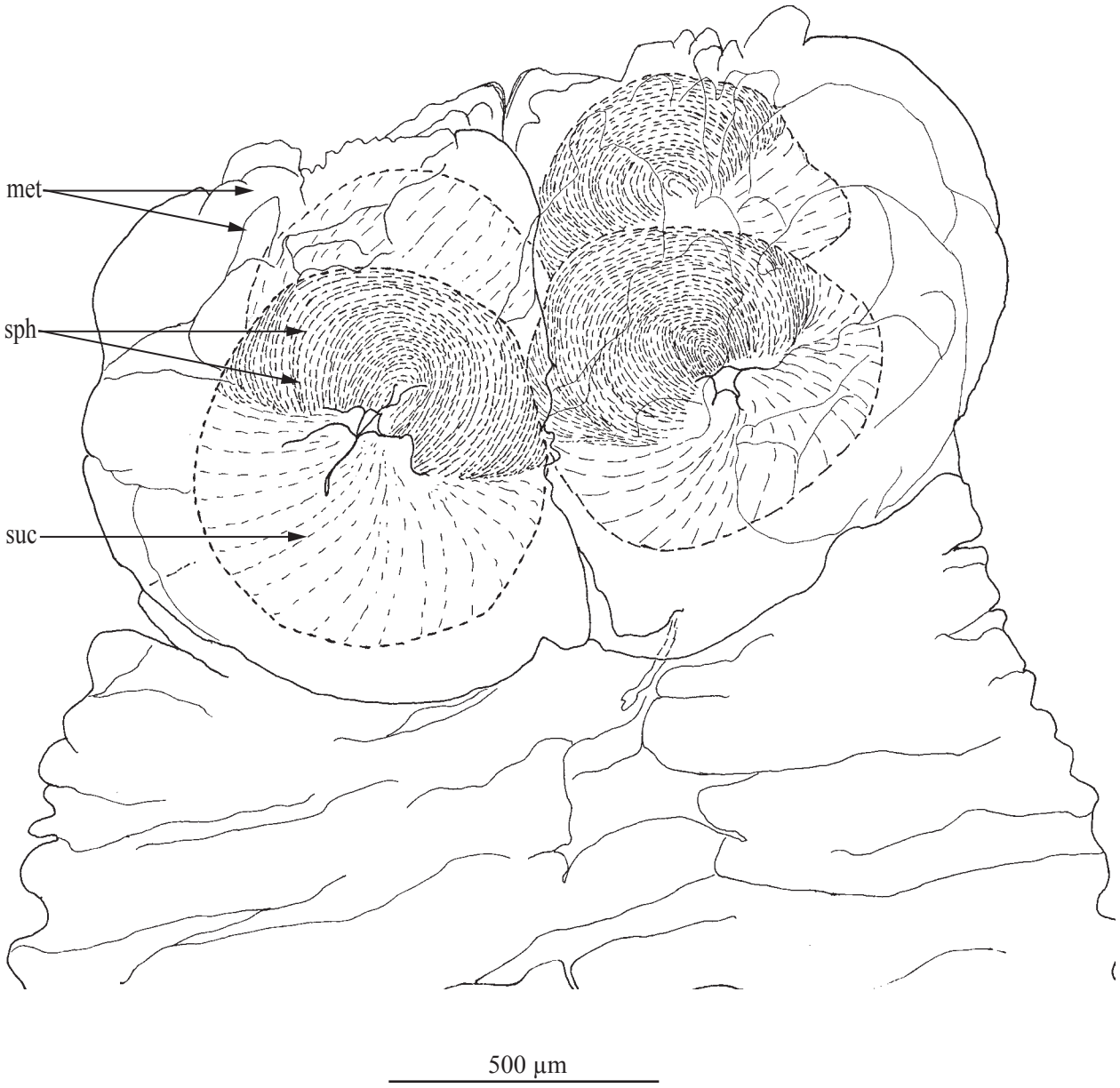

PLATE 19. *Megathylacoides* cf. *thompsoni* Jones, Kerley, and Sneed, 1956, from intestine of channel catfish studied herein, line illustration from light microscopy. Scolex from mature specimens shows the robust musculature sphincter on its four suckers. Abbreviations: suc, sucker; met, metascolex; sph, sphincter. Scale bar = 500µm.

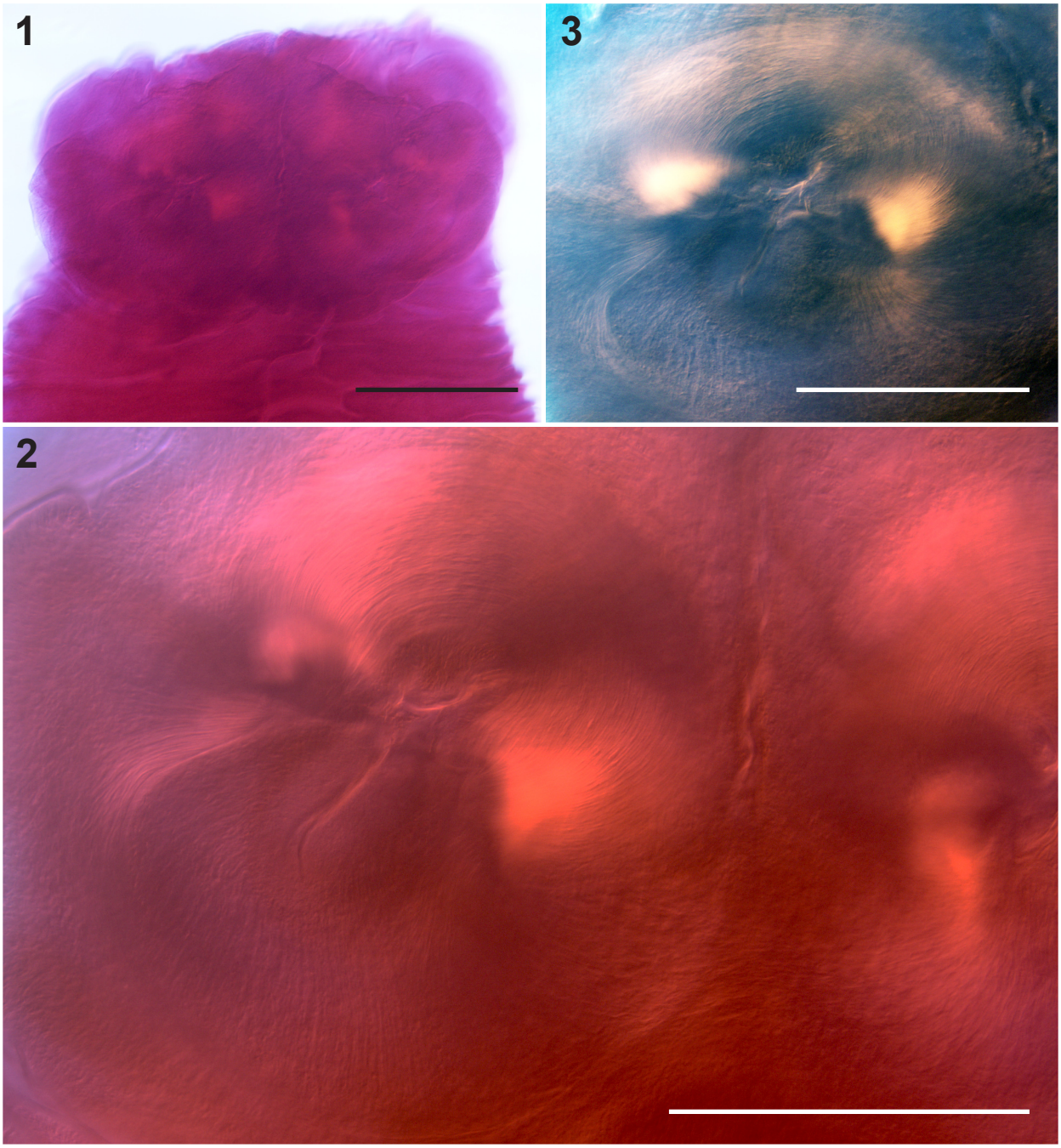

PLATE 20. *Megathylacoides* cf. *thompsoni* Jones, Kerley, and Sneed, 1956 from intestine of channel catfish studied herein, photograph illustrations. 1. Scolex. 2. Sucker with musculature sphincter. 3. Same, different light view. Scale bars: Figure 1 = 500µm, Figures 2–3 = 250µm.

than long, width 2,280 (1,640–2,980; n=12) and 3,156.7 (2,740–3,500; n=12), respectively. Gravid proglottids quadrate or longer than broad, 3,429.2 (2,620–4,440; n=12) in width. Length of different proglottid types not observed as badly fixed specimens (no heat-killed fixation, specimens went straightly into 10% NBF at fixing time).

Cirrus pouches elongate, smaller at genital pore opening end, 36.7 (32–45; n=22) in length and 13.1 (12–15; n=12) in width. Testes oval or round, numerous with 173 (163–188; n=5) in each segments; testes in 2 layers, 72.4 (63–82; n=22) in diameter. Ovary bilobed. Uterine branches 6–9 in gravid proglottids. Eggs round, biggest sizes in gravid proglottids, 18.2 (16–21; n=22).

Taxonomic summary

Type host: Ictalurus punctatus.

Other previously-reported hosts: None.

New host records for this species: None.

Site of infection: Small intestine.

Prevalence and mean intensity: two individual worms infecting two channel catfish in other ponds, not the three experimental ponds of this study. Prevalence: 100%; mean intensity: 1 tapeworm/fish.

Type localities: Lake Texoma, Oklahoma.

Other localities: Alabama (present study, *I. punctatus*).

Remarks

This species was first described as *Corallobothrium thompsoni* on *Ictalurus punctatus* (= *I. lacustris*) from Lake Texoma, Oklahoma in an unpublished thesis of Sneed (1950). This species was first published by Jones, Kerley, and Sneed (1956) under the same genus with the note on subgenus *Megathylacoides*. Freze (1965) officially separated the species of this subgenus to a

new genus *Megathylacoides*. Although I had poor specimens to study (segments shrunk and unobservable ovaries), the two specimens I studied still have sufficient important characteristics for identification to *Megathylacoides*: the presence of an apical organ, four robust suckers which are very close together and strongly musculature sphincters on each sucker, powerfully developed metascolex folds, very long and thick tapeworms, and number of testes in each mature proglottid (Plate 19; Figs. 20.1−3). The comparative examinations of specimens descriptions and illustrations of species in this genus from Sneed (1950); Jones, Kerley, and Sneed (1956); Freze (1965); and Hoffman (1999) and data from present specimens showed the best match to species *M. thompsoni*.

The two specimens were not from the three experimental ponds of this study. Two channel catfishes were donated from other ponds at the E. W. Shell Fishery Center, North Auburn Unit as extra materials in this study. The examination of those 2 fish intestines showed infection of this tapeworm species.

Phylum: Nematoda

Order: Spirurida

Family: Gnathostomatidae

Genus: S*piroxys* Schneider, 1886

Diagnosis: (according to Hoffman, 1999) Adult in stomach of turtles and intestines of amphibians. Larvae of medium size, red; mouth with large, distinctly trilobed lips, giving head a triangular appearance. In mesenteries of fishes, amphibians, dragonfly nymphs, and snails.

Taxonomic summary

Type species: Spiroxys contortus (Rudolphi, 1819) (Spirurida: Gnathostomatidae).

Other species: Spiroxys hanzaki (Hasegawa, Miyata, and Doi, 1998) (Spirurida: Gnathostomatidae), *S. amydae* (Cob, 1929) (Spirurida: Gnathostomatidae), *S. annulata*

(Baylis and Daubney, 1922) (Spirurida: Gnathostomatidae), *S. chelodinae* (Berry, 1985) (Spirurida: Gnathostomatidae), *S. constricta* (Leidy, 1856) (Spirurida: Gnathostomatidae), *S. corti* (Caballero, 1935) (Spirurida: Gnathostomatidae), *S. gangetica* (Baylis and Lane, 1920) (Spirurida: Gnathostomatidae), *S. gubernae* (Spirurida: Gnathostomatidae), *S. hectographi* (Chakravarty and Majumdar, 1959) (Spirurida: Gnathostomatidae), *S. japonica* (Morishita, 1926) (Spirurida: Gnathostomatidae), *S. susanae* (Caballero, 1941) (Spirurida: Gnathostomatidae), *S. torquata* (Karve, 1938)(Spirurida: Gnathostomatidae), *S. triretrodens* (Caballero and Zerecero, 1943) (Spirurida: Gnathostomatidae), *S. ankarafantsika* (Roca and Garcia, 2008) (Spirurida: Gnathostomatidae).

Host family: Adults: freshwater turtles, amphibians; larvae: variety of fishes, copepods, mollusk, tadpoles, aquatic insects, newts, and reptiles.

***Spiroxys* cf. *contortus* (Rudolphi, 1819)** (Plates 21−22)

Supplemental observations based on two 3rd larval specimens with all measurements in microns: Worms small, rounded, threadlike, tapering at both ends, 2,360. 5 (2,151–2,570; n=2) in length and 86.5 (80–93; n=2) maximum width (Figs. 22.1−3). Cuticle present, fine, and thin with relatively evenly distributed striations almost whole body surface. Anterior extremity particularly subtriangular with two large, apically tapering pseudolabia (probolae) in mouth; two marginal lobe-like papillae connected with pseudolabia at bases; pseudolabium 25.5 (23–28; n=2) (Figs. 21.1, 21.3, 22.4−5).

Esophagus large, strongly developed, medial to body, vertically symmetrical buccal capsule and esophagus tube axis, reaching almost half of body width, 37 (35–39; n=2) in width and 778.5 (737–820; n=2) in length; staring from base of pseudolabia to almost middle of body (Figs.

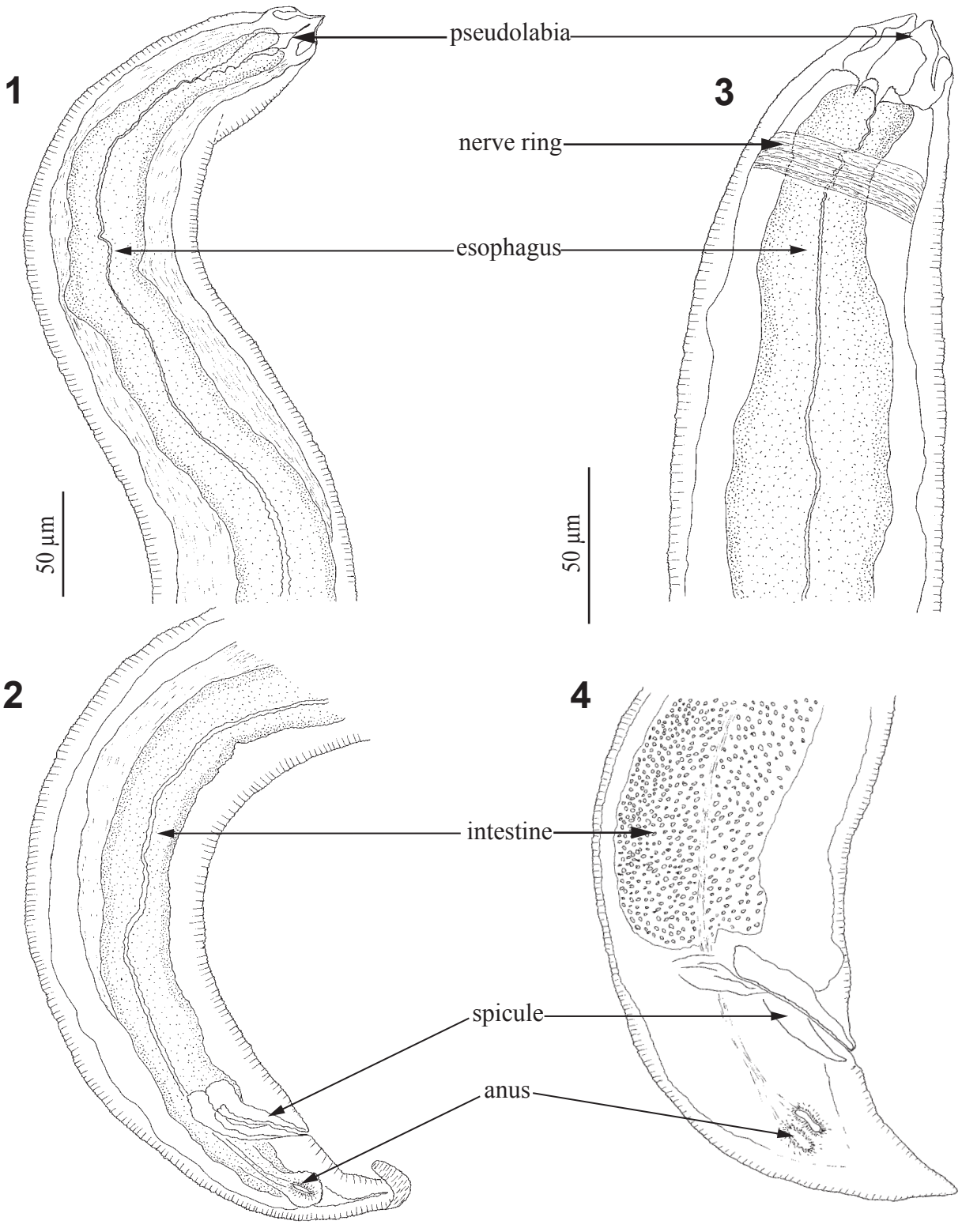

PLATE 21. *Spiroxy* cf. *contortus* (Rudolphi, 1819), third larval stage, two distinct specimens, from mesentery and liver of channel and hybrid catfishes studied herein, line illustrations from light microscopy. 1. Larvae I, anterior end. 2. Same, posterior end. 3. Larvae II, anterior end. 4. Same, posterior end. Scale bars: Figures 1–2 = 50µm, Figures 3–4 = 50µm.

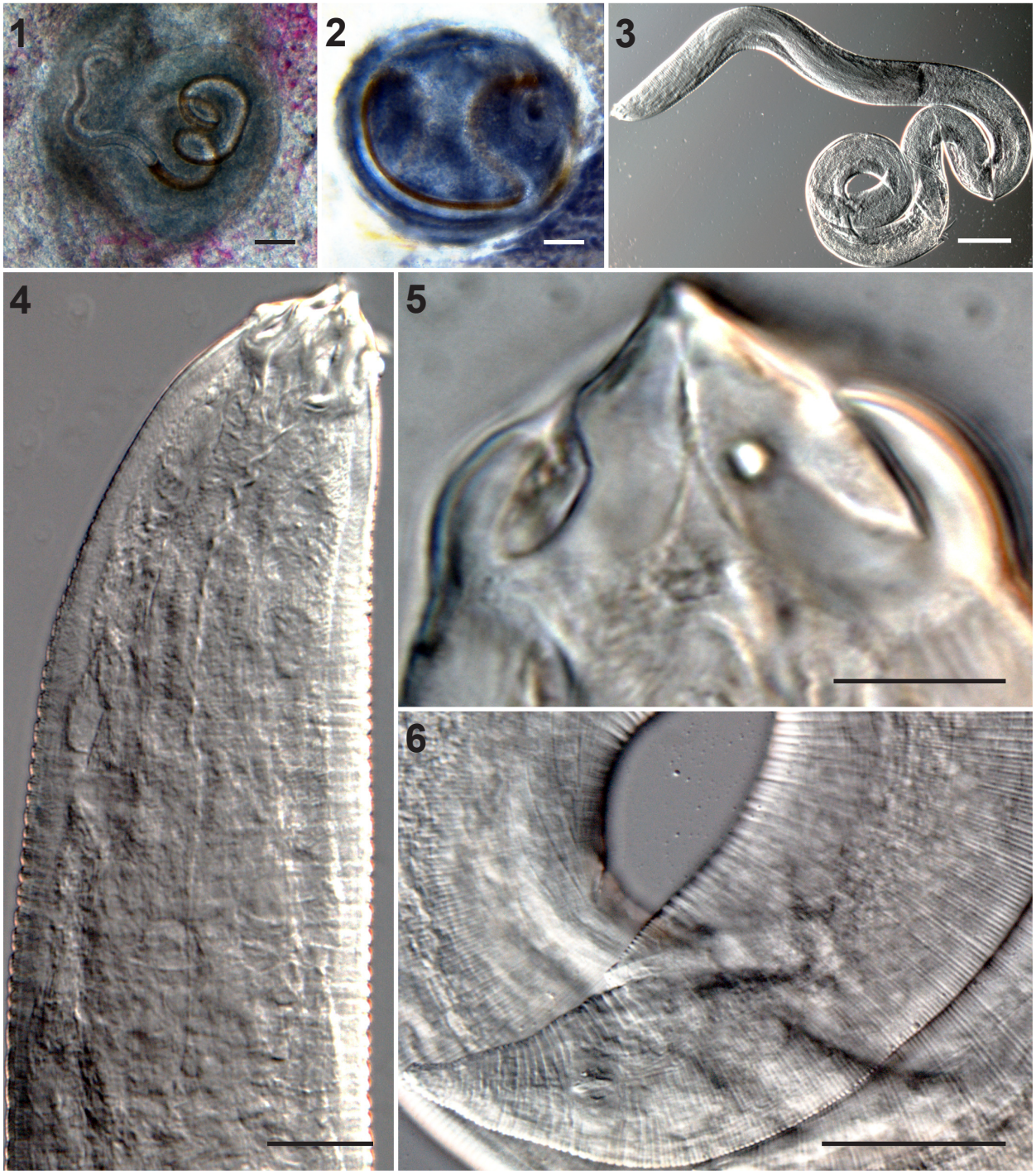

PLATE 22. *Spiroxys* cf. *contortus* (Rudolphi, 1819), third larval stage, from mesentery and liver of channel and hybrid catfishes studied herein, photograph illustrations. 1. Encysted form, in liver. 2. Same, in mesentery. 3. Relseased specimens from the cyst. 4. Low magnification of the anterior end. 5. higher magnification of the anterior end. 6. posterior end. Scale bars: Figures 1–2 = 200µm, Figure 3 = 100µm, Figure 4 = 25µm, Figure 5 = 10µm, Figure 6 = 50µm.

21.1−2, 22.3−4). Nerve ring fiber thick, poorly visible, encircling to esophagus at body anterior end (21.3). No observed excretory pore and deirids among present specimens.

Intestine brownish, about size of esophagus, connecting to posterior end of esophagus and ending at opening anus pore (Fig. 21.2, 21.4, 22.1−3). Spicule present, robust at base and tapering at distal end; opening genital pore present at spicule distal end, 53 (52–54; n=2) long (Figs. 21.2, 21.4, 22.6). Tail conical or tapering slightly posteriorly sometimes, 60.5 (48–73; n=2) long from medial anus to posterior end (Figs. 21.2, 21.4, 22.6).

Taxonomic summary

Type host: European pond turtle, *Emys orbicularis* (Linnaeus, 1758), (Testudines: Emydidae).

Other previously-reported hosts: Cyprinus spp., *Leuciscus* spp., *Rhodeus* spp., *Cobitis* ssp., *Misgusrnus* spp., *Umbra* spp., *Anguilla* spp., *Salmo* spp., *Ictalurus* spp., *Perca* spp.

New host records for this species: I. punctatus, hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Mesentery, intestinal wall, and liver.

Prevalence and mean intensity: 1 of 112 individual channel catfish (*I. punctatus*) (0.9%) and 2 of 209 individual hybrid catfish (*I. punctatus* × *I. furcatus*) (1%) infected *Spiroxys contortus*. Mean intensity was 1 individuals/fish.

Type locality: Unknown.

Other locality: Central and North America, Europe, Trans-Caucasia, Middle East, North Africa (Moravec, 1998, review).

Remarks

Fishes as intermediate or paratenic hosts for this parasite genus; adults are not found in certain infected fishes. Other intermediate or paratenic hosts include copepods, aquatic insects, snails, frog tadpoles, newts, and reptiles (Moravec, 1998). Definitive hosts are fish-eating

vertebrates, piscivorous fishes, reptiles, birds, and mammals (Moravec, 1998). In present study, only channel catfish and hybrid catfish were found infected third-stage larvae of *Spiroxys*.

Of the total 15 described species of *Spiroxys*, seven have been known from Central and North America to infect stomaches of freshwater turtiles as definitive hosts. However, since most of diagnostic characters of species within the genus are only exhibited in adult individuals, it is not possible to identify larval specimens to species levels (Moravec, 1998). Most of the known larval stages of this genus infecting fishes belong to the species *S. contortus* with low prevalence and intensity (1−30 larvae/fish) (Moravec, 1998). Moravec (1998) further described two types of third-stage *Spiroxys* larvae, namely *S. contortus* Rudolphi, 1819 and *Spiroxys* sp. Moravec, Vivas-Rodriguez, Scholz, Vargas-Vazquez, Mendonza-Franco, Schmitter-Soto, and Gonzalez-Soliz, 1995. The former infects many fish genera, including *Ictalurus* spp. in Central and North America, Trans-Caucasia, Middle East, and North Africa, while the latter is found parasitizing variety of fishes, excluding ictalurids, in Mexico and Cuba. Additionally, most of morphological characters and measurements from present specimens of this study are consistent with those reviewed descriptions of Moravec (1998). Those references suggested a higher possibility that present specimens belonging to the first *Spiroxys* larval type by Moravec (1998), *Spiroxys contortus*.

Phylum: Mollusca

Class: Bivalvia

Family: Unionidae

Genus: ***Pyganodon* Fischer and Crosse, 1894**

Diagnosis: (according to Williams et al., 2008) Shell inflated; thin to moderately thick; elliptical to oval; without hinge teeth, umbo sculpture double looped rigdes; umbo inflated, elevated above

hinge line. Inner lamellae of inner gills connected with visceral mass only anteriorly; outer gills marsupial; marsupium well-paddled across entire gill, not extended beyond original gill ventral edge when gravid, glochidium with styliform hooks.

Taxonomic summary

Type species: Pyganodon globosa Lea, 1841 (Unionoida: Unionidae).

Other species: Eastern floater, *P. cataracta* (Say, 1817) (Unionoida: Unionidae), Newfoundland floater, *P. fragilis* (Lamarck, 1819) (Unionoida: Unionidae), inflated floater, *P. gibbosa* (Say, 1824) (Unionoida: Unionidae), lake floater, *P. lacustris* (Lea, 1852) (Unionoida: Unionidae), giant floater, *P. grandis* (Say, 1829) (Unionoida: Unionidae).

Host family: Ictaluridae, Sciaenidae, Atherinopsidae, Centrarchidae, Cichlidae, Cyprinidae, Gasterosteidae, Lepisosteidae, Percidae, Fundulidae, Gobiidae, Clupeidae, Poeciliidae, Moronidae, and Catostomidae.

***Pyganodon* cf. *grandis* (Say, 1829)** (Plates 23−24)

Supplemental observation based on 4 unionid specimens, unionid dimensions followed Kennedy and Haag (2005) (all measurements in microns) Unionid subtriangular, inflated at base and more flattened at apical area; shell thin-walled with delicate denticles covering almost whole body surface; lateral margins slightly curved (Figs. 23.1, 24.1−3). Marginal edge rimmed, especially more powerful at hinge and apical areas (Figs. 23.1, 24.1−2). Body length and height roughly equal and consistent among different individuals, 322.5 (315–325; n=4) long and 321.5 (320–325; n=4) high, respectively (Figs. 23.1, 24.2). Hinge line generally straight and robust, 251.3 (240–260; n=4) (Figs. 23.1, 24.2).

Apical teeth present in two types of distribution and sizes; 15 robust and sharp teeth (hooks) roughly equal in size, inward, locating in two slant lines at about middle apical area of each

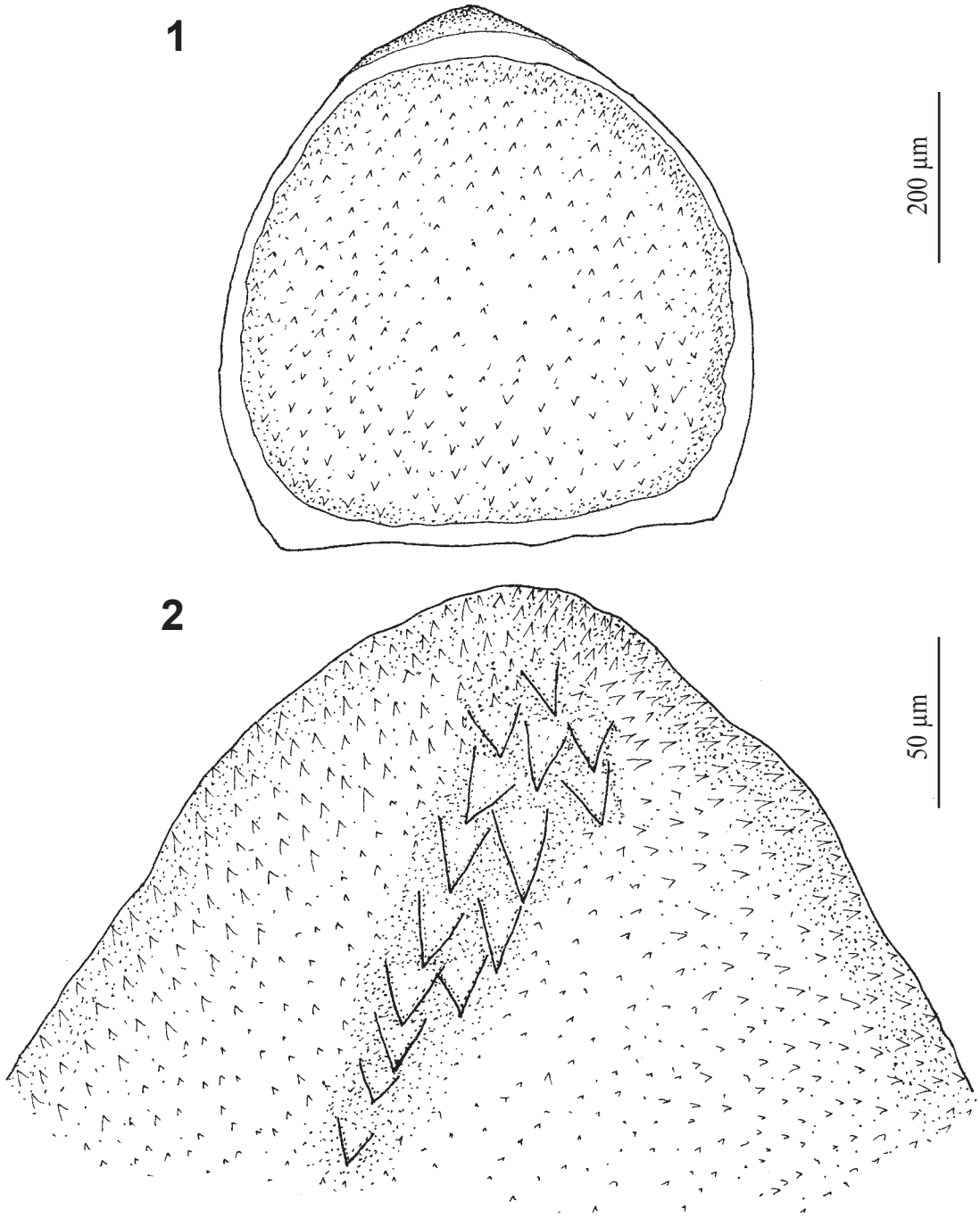

PLATE 23. *Pyganodon* cf. *grandis* (Say, 1829), glochidium, from gill of hybrid catfish studied herein, line illustrations from light micrscopy. 1. Whole body. 2. Apical teeth. Scale bars: Figure 1 = 200µm. Figure 2 = 50µm.

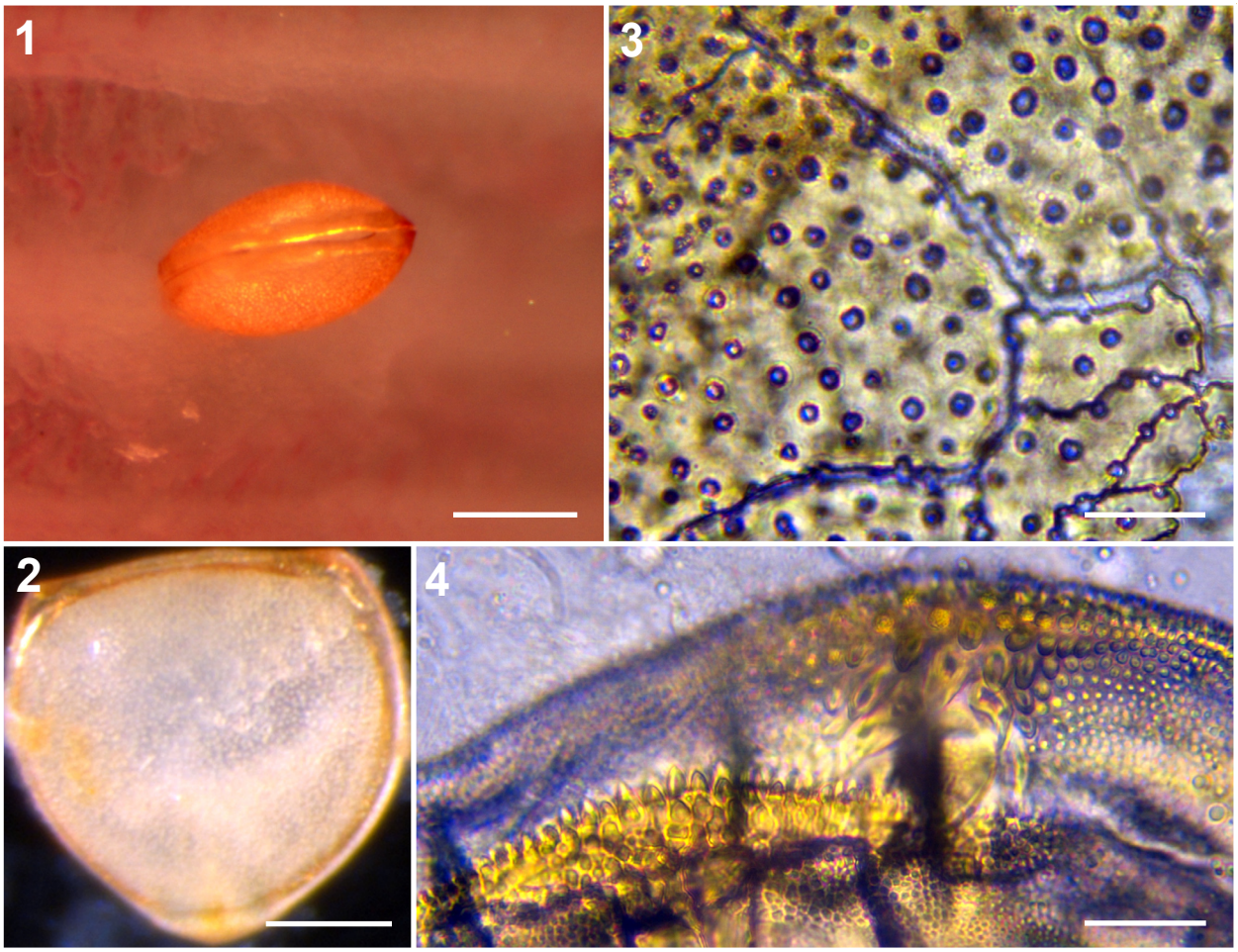

PLATE 24. *Pyganodon* cf. *grandis* (Say, 1829), glochidium, from gill of hybrid catfish studied herein, photograph illustrations. 1. Gill filament-attached glochidium. 2. Released glochidium. 3. Body surface shows multiple denticles. 4. Apical area shows tooth distribution. Scale bars : Figure 1 = 150µm, Figure 2 = 100µm, Figures 3–4 = 50µm.

glochidial shell; much smaller denticles numerous, lateral to larger teeth and marginal to apical area of each glochidial shell (Fig. 23.2, 24.4).

Taxonomic summary

Type host: First described as adult shells.

Other previously-reported hosts: P. grandis has very general glochidial stages, infecting numerous fishes from different families (Williams et al., 2008), including *Ictalurus* sp., *Lepisosteus* sp., freshwater drum, *Aplodinotus grunniens* (Rafinesque, 1819) (Perciformes: Sciaenidae), brook silverside, *Labidesthes sicculus* (Cope, 1865) (Atheriniformes: Atherinopsidae), rock bass, *Ambloplites rupestris* (Rafinesque, 1817) (Perciformes: Centrarchidae), *Lepomis cyanellus*, bluegill, *L. macrochirus* (Rafinesque, 1819) (Perciformes: Centrarchidae), largemouth bass, *Micropterus salmoides* (Lacepede, 1802) (Perciformes: Centrarchidae), black crappie, *Pomoxis nigromaculatus* (Lesueur, 1829) (Perciformes: Centrarchidae), white crappie, *P. annularis*) (Rafinesque, 1818) (Perciformes: Centrarchidae), Texas cichlid, *Cichlasoma cyanoguttatum* (Baird and Girard, 1854) (Perciformes; Cichlidae), central stoneroller, *Campostoma anomalum* (Rafinesque, 1820) (Cypriniformes: Cyprinidae), common shiner, *Luxilus cornutus* (Mitchill, 1817) (Cypriniformes: Cyprinidae), redfin shiner, *Lythrurus umbratilis* (Girard, 1856) (Cypriniformes: Cyprinidae), golden shiner, *Notemigonus crysoleucas* (Mitchill, 1814) (Cypriniformes: Cyprinidae), blackchin shiner, *Notropis heterodon* (Cope, 1865) (Cypriniformes: Cyprinidae), blacknose shiner, *N. heterolepis* (Eigenmann & Eigenmann, 1893) (Cypriniformes: Cyprinidae), bluntnose mannose, *Pimephales notatus* (Rafinesque, 1820) (Cypriniformes: Cyprinidae), western blacknose dace, *Rhinichthys obtusus* (Agassiz, 1854) (Cypriniformes: Cyprinidae), common creek chub, *Semotilus atromaculatus* (Mitchill, 1818) (Cypriniformes: Cyprinidae), banded killifish, *Fundulus diaphanous* (Lesueur, 1817)

(Cyprinodontiformes: Fundulidae), brook stickleback, *Culaea inconstans* (Kirtland, 1840) (Gasterosteiformes: Gasterosteidae), longnose gar, *Lepisosteus osseus* (Linnaeus, 1758) (Lepisosteiformes: Lepisosteidae), rainbow darter, *Etheostoma caeruleum* (Storer, 1845) (Perciformes: Percidae), Iowa darter, *E. exile* (Winn, 1958) (Perciformes: Percidae), Johnny darter, *E. nigrum* (Rafinesque, 1820) (Perciformes: Percidae), yellow perch, *Perca flavescens* (Mitchill, 1814) (Perciformes: Percidae), goldfish, *Carassius auratus* (Linnaeus, 1758) (Cypriniformes: Cyprinidae), round goby, *Neogobius melanostomus* (Pallas, 1814) (Gobioidei: Gobiidae), guppy, *Poecilia reticulate* (Peters, 1859) (Cyprinodontiformes: Poeciliidae), longear sunfish, *Lepomis megalotis* (Rafinesque, 1820) (Perciformes: Centrarchidae), skipjack shad, *Alosa chrysochloris* (Rafinesque, 1820) (Clupeiformes: Clupeidae), pearl dace, *Margariscus margarita* (Cope, 1867) (Cypriniformes: Cyprinidae), golden topminnow, *Fundulus chrysotus* (Gunther, 1866) (Cyprinodontiformes: Fundulidae), *Ameiurus nebulosus*, mosquitofish, *Gambusia affinis* (Baird and Girard, 1853) (Cyprinodontiformes: Poeciliidae), orangespotted sunfish, *Lepomis humilis* (Perciformes: Centrarchidae), common carp, *Cyprinus carpio* (Linnaeus, 1758) (Cypriniformes: Cyprinidae), American gizzard shad, *Dorosoma cepedianum* (Lesueur, 1818) (Clupeiformes: Clupeidae), *Ameiurus natalis*, white bass, *Morone chrysops* (Rafinesque, 1820) (Perciformes: Moronidae), *Aplodinotus grunniens*, and river carpsucker, *Carpiodes carpio* (Rafinesque, 1820) (Cypriniformes: Catostomidae).

New host records for this species: Hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Gill filaments.

Prevalence and mean intensity: 6 of 184 individual hybrid catfish (*I. punctatus* × *I. furcatus*) (3.3%) infected glochidia of *Pyganodon grandis*. Mean intensity was 1–2 individuals/fish.

Type locality: Fox River, Wabash, Indiana.

Other localities: Southern Canada; Minnesota; North Dakota; Great Lakes drainage; Mississippi basin; New York; Montana; Cumberland Falls, Southeastern Kentucky, Tennessee River drainage, Apalachicola basin to lower Rio Grande, Arizona, New Mexico, Alabama, Mobile basin (all above records from the review of Williams et al., 2008).

Remarks

As it has a very low host specificity*, P. grandis* is the most widespread freshwater mussel in North America; ranging in ponds, lakes, reservoirs, pools, creeks, and rivers of Alabama, excluding Yellow, Blackwater, and Perdido River drainages; frequently found in cultured fishes, including Ictaluridae (Williams et al., 2008). In present study, *P. grandis* glochidia attached their host in low prevalence (3%) and mean intensity (1−2 glochidia/fish). Only hybrid catfish were infected, whereas channel catfish and blue catfish infections were not observed in this study.

Pyganodon grandis is the only known freshwater mussel that has a glochidial stage infecting fishes in study area (E.W. Shell Fishery Center, North Auburn Unit, Auburn, Alabama) (J. Stoeckel, 2011, personal communication). Measurements of the present specimens are all slightly smaller than those of Wiliams et al. (2008). Those variations can be explained as the earlier developmental stages or ages of present glochidia than those of Wiliams et al. (2008).

Phylum: Arthropoda

Class: Maxillopoda

Familiy: Ergasilidae

Genus: *Neoergasilus* Yin, 1956

Diagnosis: Females with first swimming leg prolonged, reaching fourth or fifth thoracic segment at ventral surface. First leg with large spatulate spine on outer margin of exopodal segment 2;

spatulate spine parallel, longer or shorter than third segment. Triangular spinous process present on basis between exo- and endopodite of first swimming leg.

Males slightly smaller than females. Maxillipeds similar to species of genus *Ergasilus*. Triangular spinous process also present, less obvious than those on females.

Taxonomic summary

Type species: Neoergasilus japonicus Yin, 1956 (Poecilostomatoida: Ergasilidae).

Other species: N. longispinosus Yin, 1956 (Poecilostomatoida: Ergasilidae), *N. inflatus* Yin, 1956 (Poecilostomatoida: Ergasilidae).

Host family: Cyprinidae, Siluridae, Bagridae, Percichthyidae, Centrarchidae, Percidae, Cichlidae.

***Neoergasilus japonicus* (Harada, 1930) Yin, 1956** (Plates 25−27)

Supplemental observations based on three wet-mounted specimens with all measurements in microns: Adult females: Overall body pyriform, segmented; total body length longer than width; total length (excluding setae) 740 (680–800, n=3); largest body width posterior head or medial first thoracic segment, 317 (280–335, n=3) (Figs. 25.1, 27.1−2). Head subtriangular, 260 (240–280, n=2) long (Fig.25.1). Eye spot single, visible or not on different individuals (Figs. 25.1, 27.1−2). Thoracic segment five in number, diminished posteriorly; first segment approximately as wide as head, but slightly shorter in length; second segment narrow, about 1/6 of head length, length greatly reduced; third segment barrel-shaped, longer than second segment but length diminish to roughly half; fourth and fifth segment greatly slender and shorter than other thoracic segments (Fig. 25.1). Genital segment barrel-shaped, 59 (55–63, n=2) in length and 81 (78–84, n=2) in width, with/without 2 lateral egg sacs (Fig. 25.5, 27.6). Egg sacs equal with 2–3 eggs rows, 574 (450–630, n=5) long and 139 (125–160, n=5) wide (Figs. 25.1, 27.2). Abdomen 4-segmented with small row of denticle in posterior end of each segment; first and second segments subcylindrical, smaller than genital segment, roughly equal in size; third segment

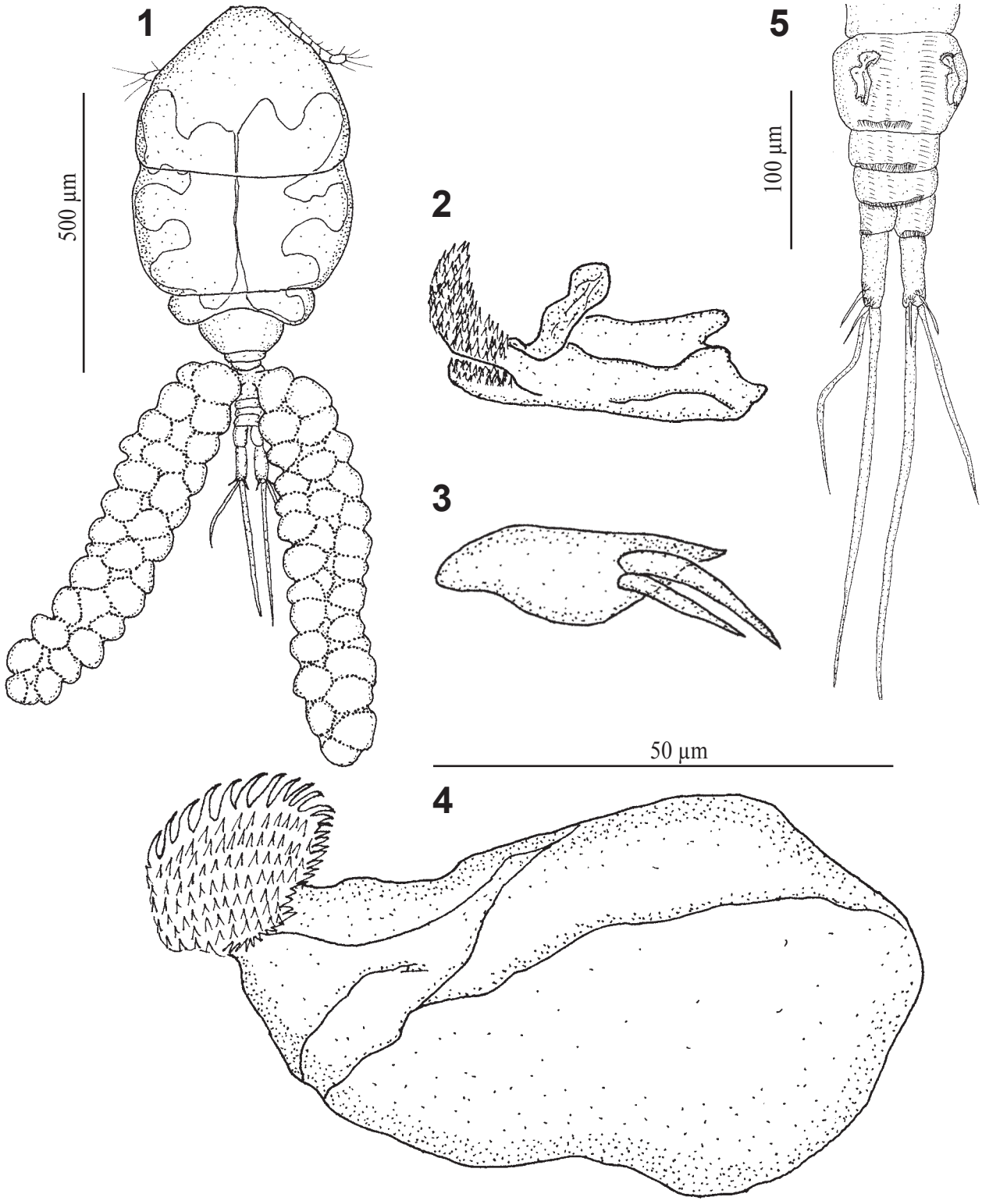

PLATE 25. *Neoergasilus japonicus* (Harada, 1930) Yin, 1956, female, from anal fin of blue catfish studied herein, line illustrations from light microscopy. 1. Whole body, ventral view, 2. Mandible. 3. First maxilla. 4. Second maxilla. 5. Abdomen, dorsal view. Scale bars: Figure 1 = 500µm, Figures 2–4 = 50µm, Figure 5 = 100µm.

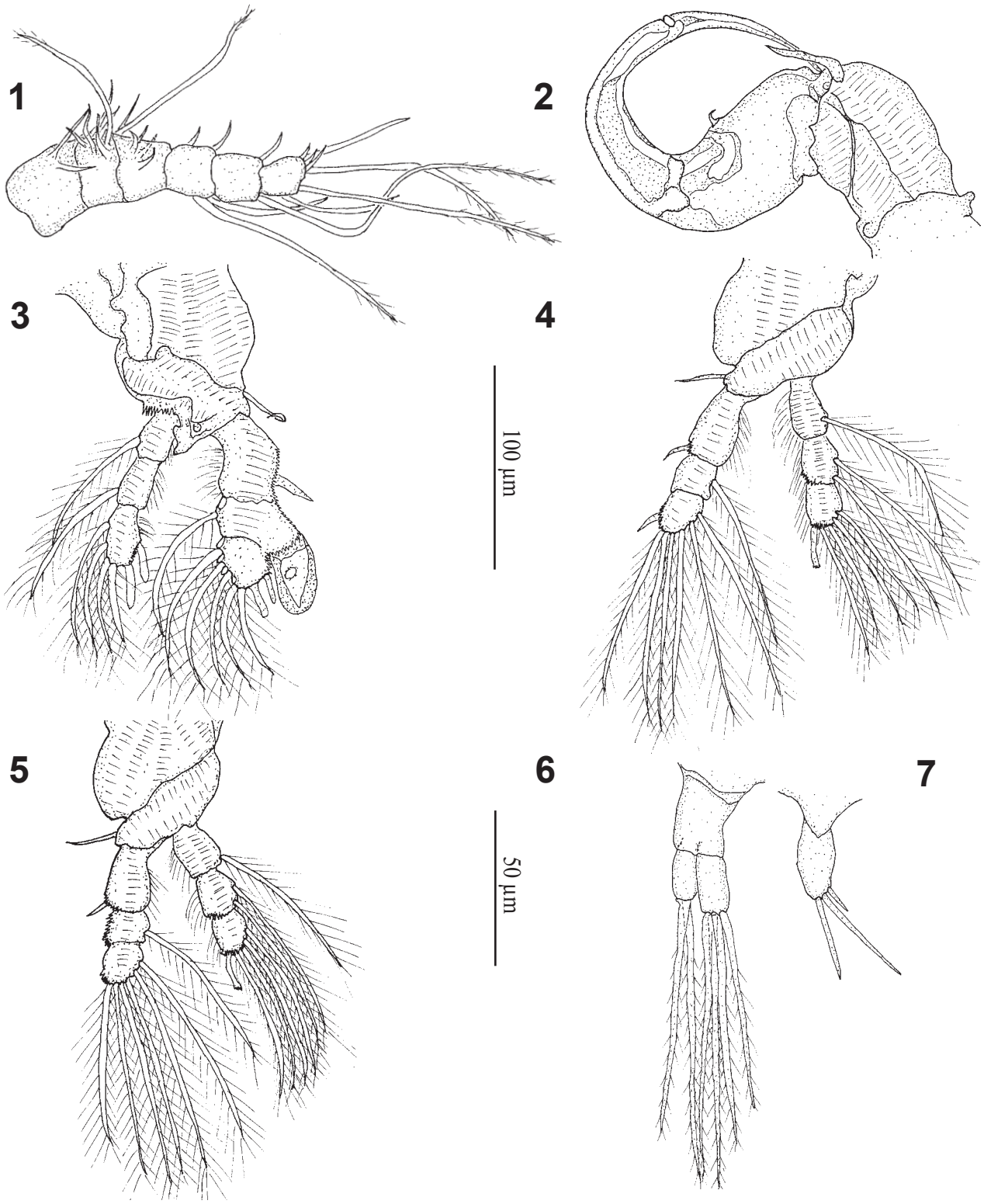

PLATE 26. *Neoergasilus japonicus* (Harada, 1930), Yin 1956, from anal fin of blue catfish studied herein, line illustrations from light microscopy. 1. First antenna. 2. Second antenna. 3. First leg. 4. Second leg. 5. Third leg. 6. Fourth leg. 7. Fifth leg. Scale bars: Figure 1–5 = 100µm, Figures 6–7 = 50µm.

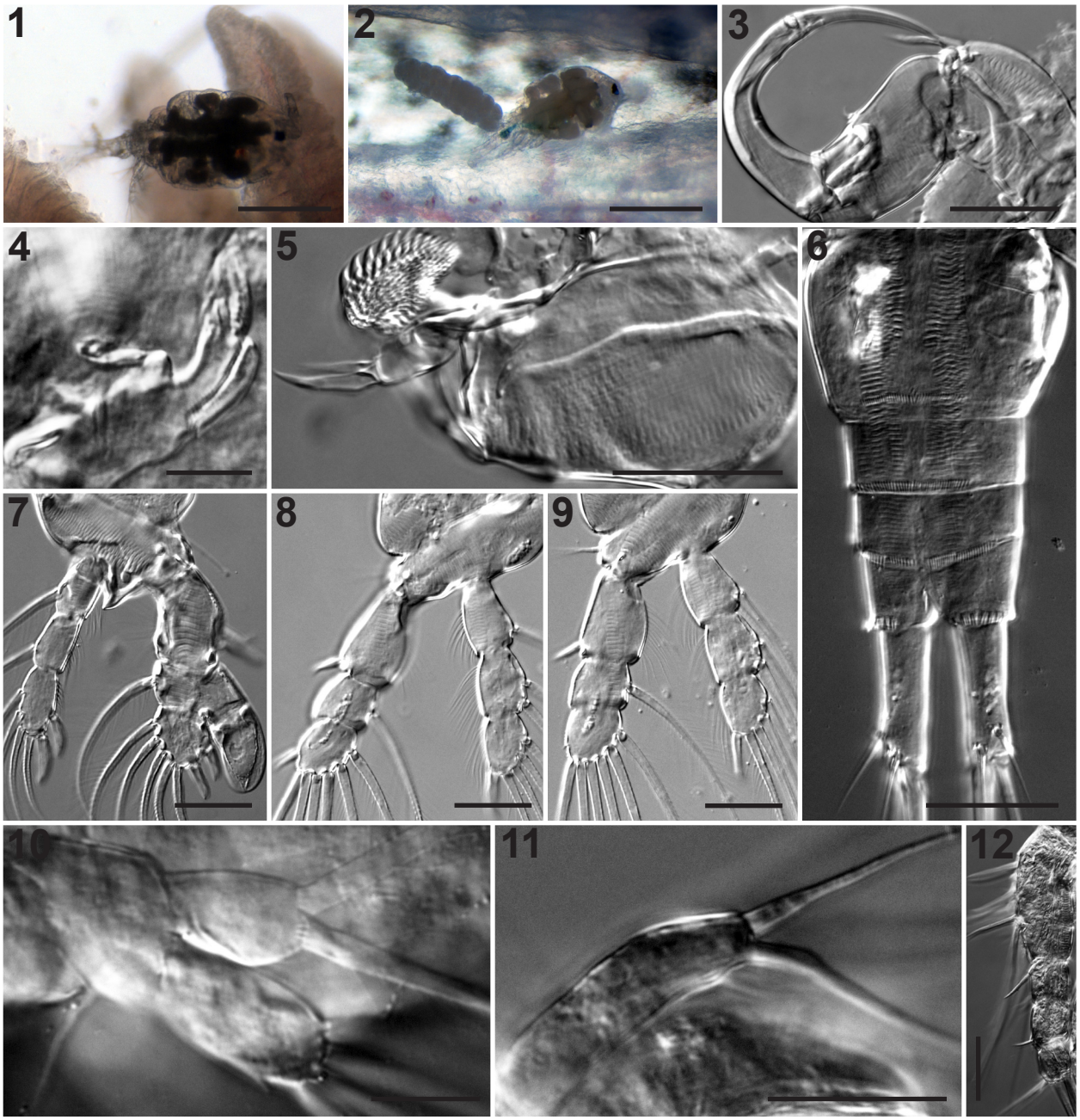

PLATE 27. *Neoergasilus japonicus* (Harada, 1930) Yin 1956 , females, from gill and anal fin of channel and blue catfishes studied herein, photograph illustrations. 1. Gill-attached soecimens. 2. Fin-attached specimens. 3. Second antenna. 4. Mandible. 5. First (left, smaller) and second (right, bigger) maxilla. 5. Abdomen. 7. First leg. 8. Second leg. 9. Third leg. 10. Fourth leg. 11. Fifth leg. 12. First antenna. Scale bars: Figures 1–2 = 300µm, Figures 3, 12 = 50µm, Figures 4, 10–11 = 15µm, Figures 5–9 = 30µm.

bifurcated, equal in size; last segment (uropod) slender, equal in size with two short naked setae front side and another two long naked setae back side at posterior end in each uropod; front setae with 3–4 small spines at base; back setae pair unequal with internal setae more robust and longer than external setae (Figs.25.5, 27.6).

First antenna in six segments, diminished posteriorly; first segment robust with two short setae; second and third segment with five short setae and one pinnate seta; fourth segment with two short setae and two long setae, one pinnate; fifth segment with one short and one long pinnate setae; last segment with four long (two pinnate, two naked) and three short setae (Figs. 26.1, 27.12). Second antenna in four segments, unequal; first segment short, robust with sharp spine at distal end; second segment also robust, roughly equal to first segment with small, medial, inward curved spine; third segment slender, inward curved with large groove dorsally; fourth segment more slender and taper at distal end (Figs. 26.2, 27.3). Mouth parts ventral to head segment with one modified mandible and two maxilla; mandible in three pieces, first robust, second upper first piece, slender, and wavy, third bifurcate with numerous denticles; first maxilla elongate, tapered at two ends with three unequal spines; second maxilla robust, diminished posteriorly with multiple rows of small and enlarge denticles (Figs. 25.2−4, 27.4−5). Maxilliped absent in all observed specimens.

Swimming legs 1–4 biramous with associated spines, setules, and pinnate setae (Figs. 26.3−6, 27.7−10). First leg with two segmented robust sympod ending by triangular spine between two rami and marginal denticles; second sympodial segment with one marginal spine; exopod 3-segmented, first segment with numerous setules sinistrally and several denticles and one spine dextrally, second segment modified with one pinnate setae sinistrally, denticles dextrally and distally, marginal spine expanded into flatten paddle-like structure parallel and

over third segment, third segment with five marginal pinnate setae, two short and dull spines, and dextral denticles; endopod with first and second segment bearing one pinnate setae on marginal left and setules on marginal right, third segment with four marginal pinnate setae, two marginal dull spines, setules and posterior denticles (Figs. 26.3, 27.7). Second leg also 2-segmented in sympod and marginal spine on second sympodial segment; exopod denticulated laterally and one spine in first and second segments, second segment with one pinnate setae and without modified spine, third segment additional with six pinnate setae; endopod with one, two, and four pinnate setae on segment 1, 2, 3, respectively, distally denticulated on second and third segment, third segment also with one short spine distally (Figs. 26.4, 27.8). Third leg generally similar to leg 2 with minor differences of additional marginal denticles on segment 2 and absence of third segment spine of exopod (Figs. 26.5, 27.9). Leg 4 not segmented in both sympod and rami; exopod withfour pinnate setae and endopod with two pinate setae (Figs. 26.6, 27.10). Fifth leg only one segment with three unequal naked setae (Figs. 26.7, 27.11).

Taxonomic summary

Type host: Cultriculus knei and stone moroko, *Pseudorasbora parva* (Temminck and Schlegels, 1846) (Cypriniformes: Cyprinidae).

Other previously-reported hosts: Black carp, *Mylopharyngodon piceus* (Richardson, 1846) (Cypriniformes: Cyprinidae), grass carp, *Ctenopharyngodon idella* (Valenciennes in Cuvier and Valenciennes, 1844) (Cypriniformes: Cyprinidae), bighead carp, *Hypophthalmichthys nobilis* (Richardson, 1845) (Cypriniformes: Cyprinidae), silver carp, *H. molitrix* (Richardson, 1845) (Cypriniformes: Cyprinidae), Chinese false gudgeon, *Abbottina rivularis* (Basilewsky 1855) (Cypriniformes: Cyprinidae), spotted steed, *Hemibarbus maculates* (Bleeker, 1871) (Cypriniformes: Cyprinidae), amur catfish, *Parasilurus asotus* (Linnaeus, 1758) (Siluriformes: Siluridae), ussuri catfish, *Pseudobagrus ussuriensis* (Dybowski, 1872)

(Siluriformes: Bagridae), mandarin fish, *Siniperca chuatsi* (Basilewsky, 1855) (Perciformes: Percichthyidae), sharp belly, *Hemiculter lucisculus* (Basilewsky, 1855) (Cypriniformes: Cyprinidae), Moltrecht's minnow, *Pararasbora moltrechti* (Regan, 1908) (Cypriniformes: Cyprinidae), dark chub, *Zacco temminckii* (Temminck and Schlegel, 1846) (Cypriniformes: Cyprinidae), *Lepomis macrochirus*, redear sunfish, *L. microlophus* (Gunther, 1859) (Perciformes: Centrarchidae), pumpkinseed sunfish, *L. gibbosus* (Linnaeus, 1758) (Perciformes: Centrarchidae), *L. cyanellus*, *Micropterus salmoides*, smallmouth bass, *M. dolomilieu* (Lacepede, 1802) (Perciformes: Centrarchidae), fathead minnow, *Pimephales promelas* (Rafinesque, 1820) (Cypriniformes: Cyprinidae), *Perca flavescens*, European perch, *P. fluviatilis* (Linnaeus, 1758) (Perciformes: Percidae), European chub, *Squalius cephalus* (Linnaeus, 1758) (Cypriniformes: Cyprinidae), *Cyprinus carpio*, *Carassius auratus*, *Ambloplites rupestris*, common roach, *Rutilus rutilus* (Linnaeus, 1758) (Cypriniformes: Cyprinidae), tench, *Tinca tinca* (Linnaeus, 1758) (Cypriniformes: Cyprinidae), common bream, *Abramus brama* (Linnaeus, 1758) (Cypriniformes: Cyprinidae), common rudd, *Scardinius erythropthalmus* (Linnaeus, 1758) (Cypriniformes: Cyprinidae), *Esox* sp., tailbar cichlid, *Vieja hartwegi* (Taylor and Miller, 1980) (Perciformes; Cichlidae), Angostura cichlid, *V. breidohri* (Werner and Stawikowski, 1987) (Perciformes; Cichlidae), *Cichlasoma grammodes* (Taylor and Miller, 1980) (Perciformes: Cichlidae), and *Ictalurus punctatus*.

New host records for this species: I. furcatus, hybrid *I. punctatus* × *I. furcatus*.

Site of infection: Gill filaments, gill and nasal cavities, skin, fins.

Prevalence and mean intensity: 18 of 112 individual channel catfish (*I. punctatus*) (16.1%), 16 of 74 individual blue catfish (*I. furcatus*) (21.6%), and 14 of 209 individual hybrid catfish (*I.*

punctatus × *I. furcatus*) (6.7%) infected *Neoergasilus japonicus*. Mean intensity was 1−6 individuals/fish.

Type locality: Lake Jitsugetsutan, Formosa, Taiwan.

Other locality: China (Yin, 1956, *Mylopharyngodon piceus*, *Ctenopharyngodon idella*, *Cyprinus carpio*, *Carassius auratus*, *Hypophthalmichthys nobilis*, *Hypophthalmichthys molitrix*, *Pseudogobio rivularis*, *Hemibarbus maculates*, *Parasilurus asotus*, *Leiocassis ussuriensis*, *Siniperca chautsi*, *Hemiculter lucisculus*, *Pseudorasbora parva*, *Zacco temminckii*, *Pararasbora moltaechti*); former U.S.S.R. (Gusev and Smirnova, 1962); Hungary (Ponyi and Molnar, 1969); Czechoslovakia (Fryer, 1978); Hiroshima, Japan (Urawa et al., 1980a,b, *Lepomis macrochirus*); Britain (Mugridge et al., 1982, *Tinca tinca*, *Cyprinus carpio*, *Abramus brama*, *Rutilus rutilus, Scardinius erythropthalmus, Perca fluviatilus*); India (Kumari et al., 1988); Cuba (Prieto, 1991); Central Finland (Tutuha et al., 1992, *Perca fluviatilis*, *Rutilus rutilus*); Boldmere Lake, near Working, England (Abdelhalim et al., 1993, *Abramis brama*, *Rutilus rutilus, Scardinius erythropthalmus, Esox* sp.*)*; Lake Huron, Michigan, and Superior, U.S.A. (Hudson and Bowen, 2002, *Pimephales promelas*, *Micropterus salmoides*, *L. gibbosus*, *Perca flavescens*; *L. macrochirus*; *Cyprinus carpio*; *Ictalurus punctatus*; *Carassius auratus*; *Lepomis cyanellus*; *Ambloplites rupestris*; *M. dolomilieu*); Korea (Kim and Choi, 2003); Grand Laoucien Lake, Southern France (Baud et al., 2004, *L. gibbosus*, *R. rutilus*, *Perca fluviatilis*, *Leuciscus cephalus*); Lake Dollnsee, near to Berlin, Germany (Knopf and Holker, 2005, *Rutilus rutilus*); State of Chiapas, Mexico (Suarez-Morales et al., 2010, *Vieja hartwegi*, *V. breidohri*, *Cichlasoma grammodes*); Lee County, Alabama, U.S.A. (Hayden and Rogers, 1998, *L. macrochirus*, *L. microlophus*, *M. salmoides*, *I. punctatus*; this study, *I. punctatus*, *I. furcatus*, hybrid *I. punctatus* × *I. furcatus*).

Remarks

Harada (1930) first described this species as *Ergasilus japonicus*. Yin (1956) moved the species to a new genus *Neoergasilus* with two new species *N. longispinosus*, *N. inflatus*. *Neoergasilus japonicus* has very low host specificity and the widest geographic distribution, including Alabama (U.S.A, North America), relative to other two species of *Neoergasilus* (Urawa et al., 1991; Hayden and Rogers, 1998). Only adult females are parasitic (free-swimmers at early stages), males are free-swimmers (Harada, 1930; Kabata, 1979; Urawa et al., 1980; Abdelhalim et al., 1993; Hayden and Rogers, 1998; Baud et al., 2004). In this study, since we did not collect free-swimming individuals, examined specimens showed all parasitic females. Three catfishes were infected with *N. japonicus* but blue catfish appear to be more susceptible (21.6% prevalence) than the other two catfishes, followed by channel catfish (16.1%), while hybrid catfish is the least susceptible species (6.7%). All of the known infection sites, including gills, skin, and fins, were infected by this copepod species. Although having almost the same study location (Auburn, Alabama), prevalence of infection of *N. japonicus* on catfishes in this present study is much lower than fish species from Hayden and Rogers (1998) (all of their fishes infected in100% of prevalence).

Most key characteristics of the species are observed among present specimens, except for some minor variations. Particularly, the second, fifth, and sixth segment of first antenna in the present specimens bear six, two, and six setae (Figs. 26.1, 27.12) instead of seven, three, and even, respectively in the descriptions of Hayden and Rogers (1998) (setules were not observed). Other morphological characters are generally consistent with Hayden and Rogers (1998). Those authors further noted possible explanations for variations at subspecies or species levels or even

imply observation errors. In some cases, differences in the use of terminologies rather than real structures also contribute to inconsistent descriptions among publications.

Family: Lernaeopodidae

Genus: *Achtheres* von Nordmann, 1832

Diagnosis: (according to Kabata, 1979) Females: Cephalothorax much shorter than trunk, dorsoventrally flattened, inclined obliquely from long axis of trunk towards ventral side, anteriorly tapering, posteriorly rounded or transversely truncated, separated from trunk by distinct constriction. Trunk dorsoventrally slightly flattened, its extremity conical and protruding markedly beyond level of oviduct orfices. First antenna three- or four-segmented, with well-developed apical armature. Second antenna prehensile. Labrum with transversely truncated tip provided with marginal fringe of setae. Mandible with one secondary tooth, third from tip. First maxilla with vestigial exopod on lateral side and with three well-developed terminal papillae. Second maxilla separate from each other, slightly shorter than, or as long as, trunk. Bullae usually plano-convex, circular, with moderately large anchors and short manuria. Medial margin of corpus maxillipeds armed with spinulated pad and papilliform process, its subchela distally armed with barb and additional structures at base of claw. No thoracic legs or uropods.

Males: Cephalothorax constituting about half of total length, in line with trunk and separated from it by shallow constriction posterior to bases of maxillipeds. Trunk with reduced uropods. First antenna long, clearly segmented, with well-developed apical armature. Second antenna and mouth parts similar to those of female. Second maxilla and maxillaped short, subchelate. Meditative process present. No thoracic legs.

Taxonomic summary

Type species: Achtheres percarum Nordmann, 1832 (Siphonostomatoida: Lernaeopodidae).

Other species: A. ambloplitis, *A. coregoni*, *A. coregonorum*, *A. corpulentus*, *A. lacae* Kroyer, 1863 (Siphonostomatoida: Lernaeopodidae), *A. micropteri*, *A. pimelodi* Kroyer, 1863 (Siphonostomatoida: Lernaeopodidae), *A. pseudobasanites*, *A. sandrae* Gadd, 1901 (Siphonostomatoida: Lernaeopodidae), *A. sibirica*, *A. strigatus*, *A. extensus*.

Taxonomic notes of the genus: Kabata (1979) considered *A. sandrae*, *A. percarum*, and *A. sibirica* are synonyms. Kabata (1988) considered *A. ambloplitis*, *A. pimelodi*, and *A. micropteri* are synonyms. Kabata (1969, 1979), Hoffman (1999), and Piasecki et al. (2006) reviewed the presence of six valid species, including *A. ambloplitis*, *A. coregoni*, *A. corpulentus*, *A. lacae*, *A. micropteri*, *A. pimelodi*. Kabata (1969) revised the genus *Salmincola* and transferred four species *A. coregonorum*, *A. extensus*, *A. strigatus*, and *A. corpulentus* to the genus. Kabata (1988) and Boxshall and Halsey (2004) provided only three valid species belonging to the genus *Achtheres*: *A. percarum*, *A. pimelodi*, and *A. lacae*. Recent studies from Kempter et al. (2006) and Piasecki et al. (2006) reported morphological and genetic differences between *A. percarum* and *A. sandrae* and concluded they are distinct species, making four current valid species into the genus.

Host family: Freshwater teleosts.

***Achtheres* cf. *percarum* von Nordmann, 1883 or *A.* cf. *sandrae* Gadd, 1901** (Plates 28-30)

Supplemental observations based on five wet-mounted specimens: Male: Body ant-like shaped, elongate, slightly dorsoventrally flattened, 1.96 mm in total length; body in two parts, anterior cephalothorax and posterior genital trunk; cephalothorax unsegmented, slightly shorter than trunk, bearing antennae, mandible, maxillae, and maxillaped; trunk 4-segmented with vestigial legs and caudal rami posteriorly (Figs. 28.1, 30.1).

First antenna slender 4-segmented with marginal rims; first segment without spine, slightly shorter than others; other segment equal in size, second segments provided with short spine

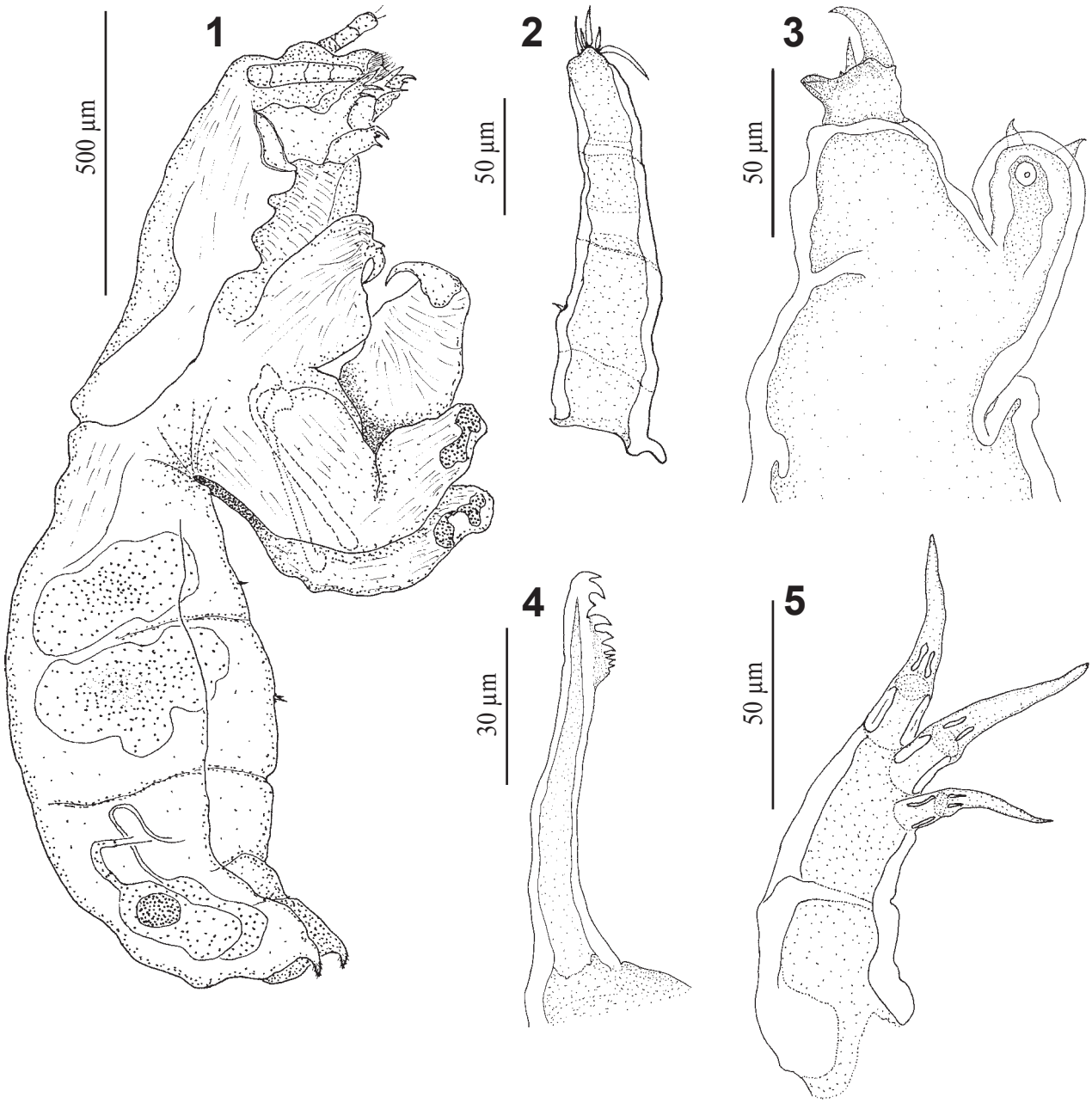

PLATE 28. *Achtheres* cf. *percarum* Nordmann, 1883/ *A.* cf. *sandrae* Gadd, 1901, male, from gill of channel catfish studied herein, line illustrations from light microscopy. 1. Whole body, ventral view. 2. First antenna. 3. Second antenna. 4. Mandible. 5. First maxilla. Scale bars: Figure 1 = 500µm, Figures 2–3, 5 = 50µm, Figure 4 = 30µm.

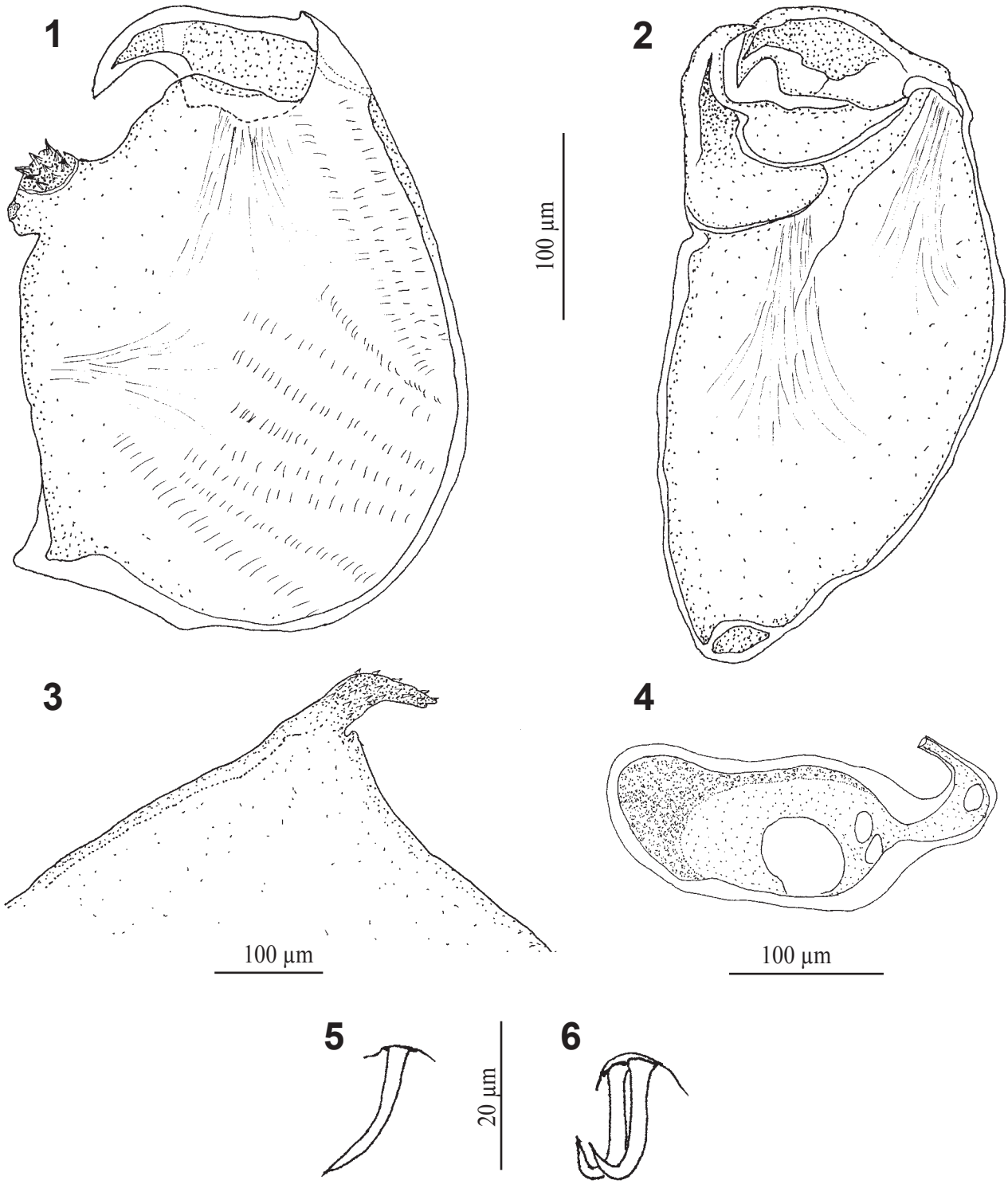

PLATE 29. *Achtheres* cf. *percarum* Nordmann, 1883/ *A.* cf. *sandrae* Gadd, 1901, male, from gill of channel catfish studied herein, line illustrations from light microscopy. 1. Second maxilla. 2. Maxilliped. 3. Caudal ramus. 4. Spermatophore. 5. First leg. 6. Second leg. Scale bars: Figures 1–4 = 100µm, Figures 5–6 = 20µm.

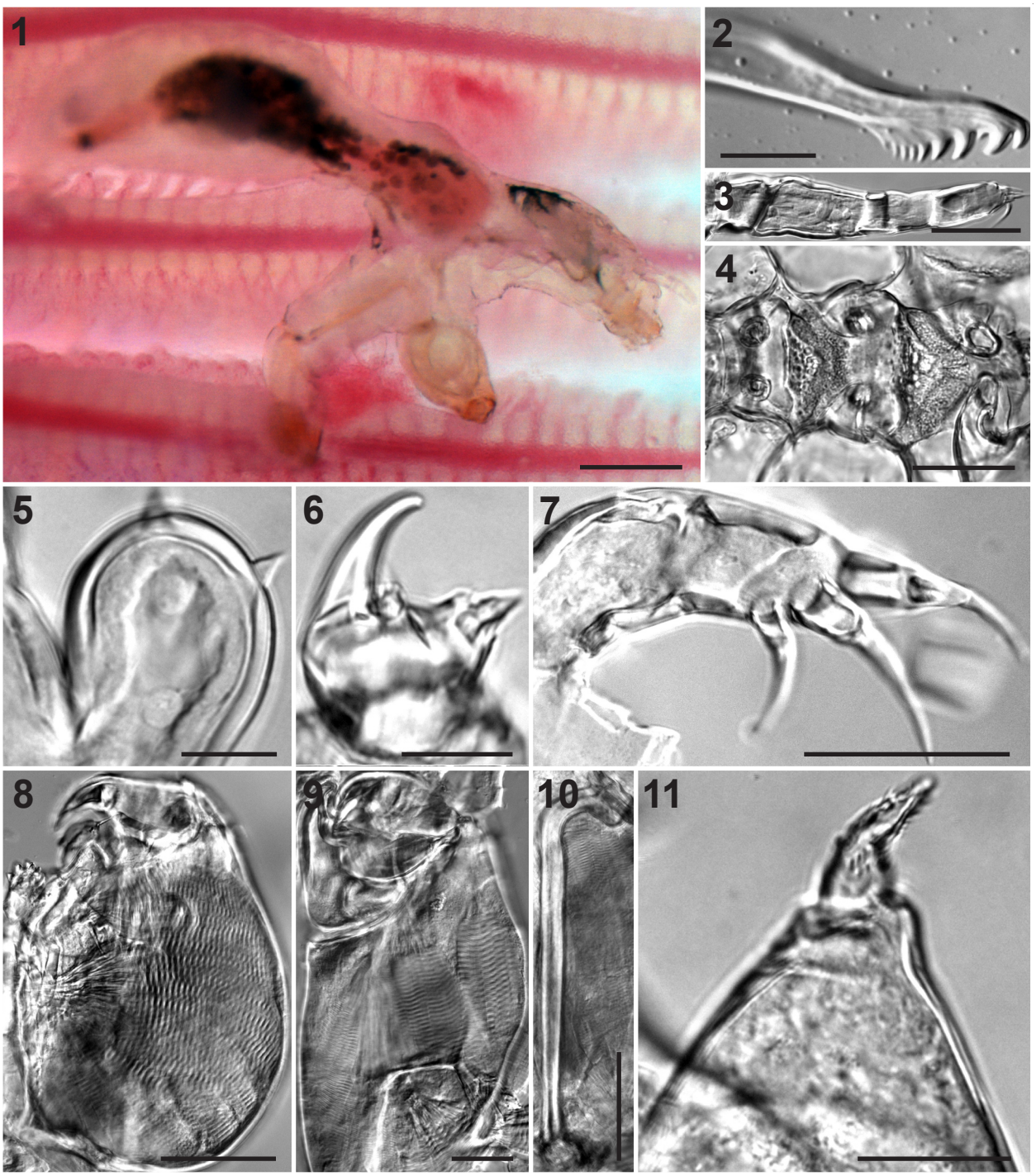

PLATE 30. *Achtheres* cf. *precarum* Nordmann, 1883/ *A.* cf. *sandrae* Gadd, 1901, male, from gill of channel and hybrid catfishes studied herein, photograph illustrations. 1. Gill filament-attached specimens. 2. Mandible. 3. First antenna. 4. Bulla. 5. Second antenna, exopod. 6. Same, enodopod. 7. First maxilla. 8. Second maxilla, posterior end. 9. Maxilliped, posterior end. 10. Internal clerite in maxilliped. 11. Caudal ramus. Scale bars: Figure 1 = 300µm, Figures 2, 5–6 = 15µm, Figures 3, 7, 9 = 50µm, Figures 4, 8, 10–11 = 100µm.

medially, last segment ending with five observed setae, two shorter than others (Figs. 28.2, 30.3). Second antenna more robust but shorter than first antenna, biramous posteriorly; exopod unsegmented, flattened paddle-like and oval, armed with two equal robust apical spines; endopod fist-like structure, 2-segmented, almost double size of exopod, second segment much shorter than first segment, posterior end with two, one long one short, spines marginally, one short seta and two tubercle medially (Figs. 28.3, 30.5−6). Mandible in mouth part, slender, flattened, and marginally rimmed; distal end with marginal denticulated blade; blade with nine teeth, generally posteriorly diminished, third tooth from distal end reduced and much smaller than adjacent teeth (Figs. 28.4, 30.2). Mouth rounded, covering with several setules (Fig. 28.1). First maxilla equally 2-segmented, strongly marginal rimmed; second terminating with three long setae, third seta smaller than other, each seta provided with one larger marginal pair of elongate hump-like structure anteriorly and one smaller pair almost medially (Figs. 28.5, 30.7).

Second maxilla robust, 2-segmented, weakly covering with armature; second segment generally oval, terminating with well-clerotized recurved subchela and ventral 9-to-10-denticle bearing plate (Figs. 29.1, 30.8). Maxilliped 3-segmented, longer than second maxilla; first segment longer than other, robust with internal stick-like clerite; third segment (chela) short, robust, and marginal rimmed (Figs. 29.2, 30.9−10).

First leg short, vestigial, ventral to first segment of genital trunk (Fig. 29.5). Second leg in paired, equal in length, ventral to second segment of genital trunk, also vestigial and as long as first leg (Fig. 29.6). Caudal rami in pair, posterior to genital trunk; caudal ramus elongate, dorsally curved, and surrounded with numerous denticles (Figs. 28.1, 29.3, 30.11). Spermatophore sac in pair, equal in size, ellipsoid, internal in both third and last segment of genital trunk (Fig. 29.4).

Taxonomic summary

Type host: European perch, *Perca fluviatilis* (*A. percarum*) (Linnaeus, 1758), (Perciformes: Percidae); zander, pike perch, *Sander lucioperca* (*A. sandrae*), (Linnaeus, 1758), (Perciformes: Percidae).

Other previously-reported hosts: Northern pike, *Esox lucidus* (Linnaeus, 1758) (Esociformes: Esocidae), *S. marina* (Cuvier, 1828) (Perciformes: Percidae), Volga pike perch, *S. volgensis* (Gmelin, 1789) (Perciformes: Percidae), Eurasian ruffe, *Gymnocephalus cernua* (Linnaeus, 1758) (Perciformes: Percidae).

New host records for this species: Ictalurus punctatus, hybrid *I. punctatus* × *I. furcatus*

Site of infection: Gill filaments.

Prevalence and mean intensity: 3 of 112 individual channel catfish (*I. punctatus*) (2.68%) and 1 of 209 individual hybrid catfish (*I. punctatus* × *I. furcatus*) (0.5%) infected *Achtheres* cf. *percarum/sandrae*. Mean intensity: 1–2 individuals/fish.

Type locality: Europe (?)

Other localities: England (Harding and Gervers, 1956, Fryers, 1969, *Perca fluviatilis*); U.S.S.R (Markewitsch, 1976, *Perca fluviatilis*, *Lucioperca lucioperca*, *L. marina*, *L. volgensis*); Germany, Szechoslovikia, North Italy, Turkey (Markewitsch, review, 1976); Kazakhstan, Uzbekistan, Far East, Black Sea, Aral Sea, Sea of Azov (Kabata, 1979, review); Central Finland (Valtonen et al., 1993, *Perca fluviatilis*, *Stizostedion lucioperca*); Lake Balaton, Hungary (Molnar and Szekely, 1995, *Stizostedion lucioperca, Stizostedion volgense*); Lake Dabie, North-Western Poland (Piasecki, 1993; Piasecki et al., 2006, Kempter et al., 2006, Piaseki and Kuzminska, 2007, *Perca fluviatilis*, *Sander lucioperca*); and Alabama (this study, *I. punctatus*, hybrid *I. punctatus* × *I. furcatus*).

Remarks

In present study, only males of *Actheres* sp. were found infecting gill filaments of channel catfish and hybrid catfish in the last sampling (February 2011) during the study period. Considerable injuries (epithelial hypertrophy) associated with infections were found on host tissue. The only reported *Achtheres* species on ictalurid fishes from North America is currently known as *A. pimelodi*, although 3 other species: *A. lacae, A. ambloplitis*, and *A. micropteri* were reported as synonyms or misidentifications (G. Benz, 2011, personal communication).

Currently, since only males of *A. percarum* and *A. sandrae* (Piasecki et al., 2006) were well-described, it is uncertain for sufficient identification of present specimens. Close examinations of present specimens (five males) showed very close characters with descriptions of *A. percarum* and *A. sandrae* from Piasecki et al. (2006). Minor differences were found between the present materials and those of Piasecki et al. (2006). Particularly, first antenna has four segments (Figs. 28.2, 30.3) (reported as three), no observed expod on the first maxilla (Figs. 28.5, 30.7) (reported as reduced exopod), and no observed seta near the base of subchela on maxilliped (Figs. 28.2, 30.9). Other characters of the two described species are generally identical with the present specimens. Therefore, I get the present specimens identified as *A.* cf. p*ercarum*/*sandrae*.

Summary

Channel catfish were infected with the highest number of metazoan parasite biodiversity (14 species), followed by hybrid catfish (12 species) and blue catfish (seven species) (Table 6). All of the described metazoan parasite species in hybrid catfish are new records (12 species, including *Henneguya postexilis*, *H. exilis*, *H. adiposa*, *Ligictaluridus mirabilis*, *L. pricei*, *Corallobothrium fimbriatum*, *C. parafimbriatum*, *Corallotaenia intermedia*, *Spiroxys contortus*, *Pyganodon* cf. *grandis*, *Neoergasilus japonicus*, and *Achtheres* cf. *percarum*/*sandrae*); whereas blue catfish are new host records of four parasite species, including *Corallobothrium fimbriatum*,

C. parafimbriatum, *Henneguya* cf. *postexilis*, and *Neoergasilus japonicus*; and channel catfish also become new host records of four parasite species, including *C. parafimbriatum*, *Corallotaenia intermedia*, *Achtheres* cf. *percarum*/*sandrae*, and *Spiroxys* cf. *contortus*.

Table 6. Host specificity of metazoan parasites collected during the present study. "X" indicated infection.

parasite species	channel catfish	blue catfish	hybrid catfish
1. *Henneguya* cf. *postexilis*	X	X	X
2. *Henneguya* cf. *exilis*	X		X
3. *Henneguya* cf. *adiposa*	X		X
4. *Henneguya* cf. *ictaluri*	X	X	
5. *Ligictaluridus mirabilis*	X	X	X
6. *Ligictaluridus pricei*	X	X	X
7. *Corallobothrium fimbriatum*	X	X	X
8. *Corallobothrium parafimbriatum*	X	X	X
9. *Corallotaenia intermedia*	X		X
10. *Megathylacoides* cf. *giganteum*	X		
11. *Megathylacoides* cf. *thompsoni*	X		
12. *Spiroxys* cf. *contortus*	X		X
13. *Pyganodon* cf. *grandis*			X
14. *Neoergasilus japonicus*	X	X	X
15. *Achtheres* cf. p*ercarum*/s*andrae*	X		X

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APPENDICES

Table 2. Parasites previously reported from channel catfish, blue catfish, and hybrid catfish (as of March 2011)

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*furcatus*	intestine	Mexico	wild	Acanthocephala	*Neoechinorhynchus*	*golvani*	Salgado-Madonado, 2008	
				wild		*Pomphorhynchus*	*bulbocolli*	Golvan and Buron, 1988	from BMNH
		intestine	North America, USA			*Tanaorhamphus*	sp.	Van Cleave, ?	from USNPC, Accession No.: 065375.00 Storage No. SH229:25-75/6
					Annelida	*Illinobdella*	*moorei*	Manter, ?	From Manter Museum Collection Number: 23100
		not specified	Louisiana	not specified	Arthropoda	*Achtheres*	*lacae*	Causey, 1957	from Hoffman 1999
		not specified	Southeast USA	not specified		*Ergasilus*	*arthrosis*	Johnson and Rogers, 1973	from Hoffman 1999
		not specified	not specified	not specified			*cerates*	Johnson and Rogers, 1973	from Hoffman 1999
		not specified	not specified	not specified			*versicolor*	Wilson, 1911	from Hoffman 1999
		not specified	Louisiana	wild-river fish		*Lernaea*	*cyprinacea*	Causey, 1957	
		body surface, fins	Alabama	tank challenge	Ciliophora	*Ichthyophthirius*	*multifiliis*	Xu et al., 2011	
		not specified	not specified	not specified	Cnidaria	*Henneguya*	*exilis*	Kudo, 1929	from Hoffman 1999
		gills	Mississippi	tank challenge			*ictaluri*	Bosworth et al, 2003	
		gills	Mississippi	pond challenge				Griffin et al., 2010	experiment, more resistant than channel
		gall bladder	Illinois	not specified			*limatula*	Meglitsch, 1937	from Hoffman 1999
		skin	Alabama	not specified			*pellis*	Minchew, 1977	from Hoffman 1999
		skin and body wall of the peritoneal cavity	not specified	commercial ponds (?)				Griffin et al., 2009	
		gall bladder	Illinois	not specified		*Myxidium*	*kudoi*	Meglitsch, 1937	from Hoffman 1999
		stomach	North America, USA		Nematoda	*Agamonema*	*vomitor*	Chandler, 1934	from USNPC, Accession No.: 039547.00 Storage No. T121-B
		not specified	Presa Falcon,Tamaulipas, Mexico	not specified		*Camallanus*	*oxycephalus*	Mancias-Hinojosa, 1984	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Tenosique,Tabasco, Mexico	not specified			sp.	Del Rio-Rodriguez, 1994	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Presa La Angostura, Chiapas, Mexico	not specified				Vidal-Martinez, 1995	from Perez-Ponce de Lion and Choudhury, 2002
		adult cosmopolitan: cormorants, mergansers, gulls, pelicans. larvae: many fish species, probably not host specificity	not specified	not specified		*Contracaecum*	*spiculigerum*	Rudolphi, 1809	from Hoffman 1999
		not specified	Texas	not specified		*Cucullanus*	*diplocaecum*	Chandler, 1935	from Hoffman 1999
		intestine	Mexico	wild			sp.	Rosas-Valdez and de Leon, 2008	
		not specified	PresaTemascal and Presa Falcon, Mexico	wild		*Dichelyne*	*mexicanus*	Perez-Ponce de Lion and Choudhury, 2002	
		intestine	Mexico	wild				Salgado-Madonado, 2008	
			Tennessee	wild			*robusta*	Hoffnagle et al., 1990	from BMNH
			Mexico	wild		*Gnathostoma*	*binucleatum*	Rosas-Valdez and de Leon, 2008	
		not specified	Angostura, Catazaja, Jalapa de Marques, Sarabia (in Mexico)	not specified			sp.	Leon-Regagnon et al., 2005	human zoonosis

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*furcatus*	not specified	Presa Chicoasen, Chiapas, Mexico	not specified		*Goezia*	*nonipapillata*	Ocana-Nunez,1992	from Perez-Ponce de Lion and Choudhury, 2002
		intestine, mesentery	Mexico	wild		*Hysterothylacium*	sp.	Rosas-Valdez and de Leon, 2008	
		not specified	Presa Falcon,Tamaulipas, Mexico	wild		*Neocucullanellus*	sp.	Mancias-Hinojosa, 1984	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Presa La Angostura, Chiapas, Mexico	not specified		*Procamallanus*	sp.	Vidal-Martinez, 1995	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Presa Falcon, Tamaulipas, Mexico	not specified		*Rhabdochona*	sp.	Mancias-Hinojosa, 1984	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Tenosique,Tabasco, Mexico	not specified				Del Rio-Rodriguez, 1994	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Rio San Pedro Balancan, Mexico	not specified				Pineda-Lopez et al., 1985	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Laguna Emiliano Zapata, Mexico	not specified				Pineda-Lopez et al., 1985	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Laguna El Rosario, Mexico	not specified				Fucugauchi-Suarezdel Real et al., 1988	from Perez-Ponce de Lion and Choudhury, 2002
			Tennessee	wild		*Spinitectus*	*gracilis*	Hoffnagle et al., 1990	from BMNH
		not specified	Presa Falcon, Tamaulipas, Mexico	not specified			sp.	Mancias-Hinojosa, 1984	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Tenosique, Tabasco, Mexico	not specified				Del Rio-Rodriguez, 1994	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Rio San Pedro Balancan, Mexico	not specified				Pineda-Lopez et al., 1985	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Laguna Santa Anita, Tabasco, Mexico	not specified				Fucugauchi-Suarezdel Real et al., 1988	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Kentucky Lake	not specified			*macrospinosus*	Choudhury and Perryman, 2003	museum specimens
		Intestine	Tabasco, southeastern Mexico	not specified			*tabascoensis*	Moravec et al., 2002	museum specimens
		Intestine	Mexico	wild				Salgado-Madonado, 2008	
		not specified	Presa La Angostura, Chiapas, Mexico	not specified		*Spirocamallanus*	sp.	Vidal-Martinez, 1995	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Tenosique, Tabasco, Mexico	not specified		*Thynnascaris*	sp.	Del Rio-Rodriguez, 1994	from Perez-Ponce de Lion and Choudhury, 2002
			Tennessee	wild	Platyhelminthes	*Allacanthochasmus*	*varius*	Hoffnagle et al., 1990	from BMNH
		not specified	may related to *Lepidauchen* sp., from *Ictalurus nebulosus*, Virginia	not specified		*Allocreadium*	*ictaluri*	Holloway and Bogitsh, 1964	from Hoffman 1999
		intestine	Nebraska			*Alloglossidium*	*corti*	Nebraska Game and Parks Commission, ?	From Manter Museum Collection Number: 21982
		not specified	Rio Tuxtepec, Mexico	not specified		*Choanoscolex*	*lamothei*	Perez-Ponce de Lion and Choudhury, 2002	
			Mexico	wild		*Cladocystis*	*trifolium*	Rosas-Valdez and de Leon, 2008	
		gills	not specified	not specified		*Cleidodiscus*	*vancleavei*	Mizelle, 1936; Klassen and Beverley-Burton, 1985	from Hoffman 1999
		not specified	Presa Falcon, Mexico	not specified		*Corallobothrium*	*fimbriatum*	Perez-Ponce de Lion and Choudhury, 2002	
			Tennessee	wild				Hoffnagle et al., 1990	from BMNH
		intestine	North America, USA				*giganteum*	Hoffnagle et al., 1989	from USNPC, Accession No.: 080741.00 Storage No. Sh104-22

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*furcatus*	anomalous forms	Oklahoma	not specified			*procerum*	Sneed, 1950	from Hoffman 1999
		not specified	Presa Falcon, Tamaulipas, Mexico	not specified			sp.	Mancias-Hinojosa, 1984	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Tenosique, Tabasco, Mexico	not specified		*Cotylogaster*	sp.	Del Rio-Rodriguez, 1994	from Perez-Ponce de Lion and Choudhury, 2002
			Tennessee	wild		*Crepidostomum*	*cooperi*	Hoffnagle et al., 1990	from BMNH
		intestine	North America, USA				*ictaluri*	Hoffnagle et al., 1989	from USNPC, Accession No.: 080738.00 Storage No. M1513-20
		vitreous chamber	not specified	not specified		*Diplostomulum*	*scheuringi*	Hughes, 1929	from Hoffman 1999
		not specified	Rio Tuxtepec, Mexico	not specified		*Genarchella*	*tropica*	Perez-Ponce de Lion and Choudhury, 2002	
		stomach	Mexico	wild				Salgado-Madonado, 2008	
		gills	Alabama, Arkansas, Iowa, Illinois, Louisiana, North Dakota, Ohio, Tennessee, Texas, Wisconsin, Ontario	not specified		*Ligictaluridus*	*floridanus*	Mueller, 1936a; Beverley-Burton, 1984; Klassen and Beverley-Burton, 1985	from Hoffman 1999
		gills	Tennessee	not specified			*mirabilis*	Mueller, 1937; Klassen and Beverley-Burton, 1985	from Hoffman 1999
		gills	20 states and New Brunswick, Ontario	not specified			*pricei*	Mueller, 1936a; Beverley-Burton, 1984; Klassen and Beverley-Burton, 1985	from Hoffman 1999
			Tennessee	wild		*Megalogonia*	*ictaluri*	Hoffnagle et al., 1990	from BMNH
		not specified	Tlacotalpan, Veracruz, Mexico, and Temascal, Oaxaca, Mexico	not specified		*Megathylacoides*	*lamothei*	Scholz et al., 2003	
		intestine	Mexico	wild				Salgado-Madonado, 2008	
			Mexico	wild		*Microcotyle*	sp.	Rosas-Valdez and de Leon, 2008	
		not specified	Louisiana	not specified		*Neochasmus*	*ictaluri*	Van Cleave and Mueller, 1932; Sogandares-Bernal, 1955	from Hoffman 1999
			Alabama	wild				Williams and Dyer, 1992	from BMNH
		not specified	Presa Falcon, Mexico	not specified		*Phyllodistomum*	*lacustri*	Perez-Ponce de Lion and Choudhury, 2002	
		not specified	Catahoula Lake, Louisiana, USA	not specified		*Polylekithum*	*catahoulensis*	Curran et al., 2006	from GenBank
		not specified	Pearl River, Mississippi, USA	not specified			*ictaluri*	Curran et al., 2006	from GenBank
			Alabama	wild				Williams and Dyer, 1992	from BMNH
		not specified	not specified	not specified		*Posthodiplostomum*	*minimum*	Hughes, 1928; Hoffman, 1958	from Hoffman 1999
			Alabama	wild				Williams and Dyer, 1992	from BMNH
		not specified	Rio San Pedro Balancan, Mexico	not specified		*Prosthenhystera*	*obesa*	Pineda-Lopez et al., 1985	from Perez-Ponce de Lion and Choudhury, 2002
		gall bladder	Mexico	wild				Salgado-Madonado, 2008	
			Tennessee	wild		*Proteocephalus*	*fragile*	Hoffnagle et al., 1990	from BMNH
		not specified	Presa Chicoasen, Chiapas, Mexico	not specified			sp.	Ocana-Nunez, 1992	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Rio San Pedro Balancan, Emiliano Zapata, Tabasco, Rio Jonuta, Tabasco, Mexico	not specified				Pineda-Lopez et al., 1985	from Perez-Ponce de Lion and Choudhury, 2002

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*furcatus*		Mexico	wild		*Tylodelphys*	sp.	Rosas-Valdez and de Leon, 2008	
Ictalurus	*punctatus*		not specified	wild	Acanthocephala	*Acanthocephalus*	*dirus*	Golvan and Buron, 1988	from BMNH
		polyric caeca, intestine (sometimes)	not specified	not specified		*Leptorhynchoides*	*thecatus*	not specified	from Hoffman 1999
			Ontario	wild				Arai, 1989	from BMNH
			Lake Ontario	wild		*Metechinorhynchus*	*salmonis*	Dechtiar and Christie, 1988	from BMNH
		not specified	not specified	not specified		*Neoechinorhynchus*	*cylindratum*	not specified	from Hoffman 1999
		not specified	worldwide circumpolar distribution	not specified			*rutili*	not specified	from Hoffman 1999
		not specified	not specified	not specified		*Pomphorhynchus*	*bulbocolli*	not specified	from Hoffman 1999
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
			Ontario	wild			*sp.*	Arai, 1989	from BMNH
		not specified	Tennessee	not specified		*Tanaorhamphus*	*longirostris*	Bangham and Venard, 1942	from Hoffman 1999
		not specified	Illinois	not specified				Price and Jilek, 1980	from Hoffman 1999
		not specified	Nebraska	not specified				Samuel et al., 1976	from Hoffman 1999
		not specified	Wisconsin	not specified	Annelida	*Batracobdella*	*phalera*	Amin, 1981a	from Hoffman 1999
		completely covering the gills	Iowa	not specified		*Cystobranchus*	*verrilli*	Mathers, 1948	from Hoffman 1999
		pectoral, caudal, anal fins	North America, USA			*Illinobdella*	*alba*	Baker and crites, 1974	from USNPC, Accession No.: 073762.00 Storage No. M1316-D
		syn. *Myzobdella lugubris*	syn. *Myzobdella lugubris*	not specified			*moorei*	Dechtiar, 1972	from Hoffman 1999
		not specified	not specified	not specified		*Myzobdella*	*lugubris*	not specified	from Hoffman 1999
		pectoral fins	Lake Erie Watershed	not specified				Schulz and Faisal, 2010	
		not specified	Kansas	not specified		*Piscicolaria*	*reducta*	Harms, 1959	from Hoffman 1999
		not specified	Wisconsin	not specified			sp.	Pearse, 1924b	from Hoffman 1999
		under barbels on lower jaw	Nebraska			*Placobdella*	*parasitica*	Janovy, ?	From Manter Museum Collection Number: 45981
		not specified	not specified	not specified	Arthropoda	*Achtheres*	*micropteri*	Wright, 1882	from Hoffman 1999
		not specified	Tennessee	not specified				Hoffman, 1983 and 1984	from Hoffman 1999
		not specified	not specified	not specified			*pimelodi*	Kroyer, 1863	from Hoffman 1999
		not specified	Tennessee	not specified				Bangham and Venard, 1942	from Hoffman 1999
		not specified	Lake Erie	not specified				Tidd, 1931	
		not specified	not specified	not specified		*Argulus*	*appendiculosus*	not specified	from Hoffman 1999
		not specified	not specified	not specified			*flavescens*	not specified	from Hoffman 1999
		not specified	Wisconsin	not specified			*japonicus*	Amin, 1981b	from Hoffman 1999
		not specified	Alabama, British Columbia, Iowa, Minnesota, Ohio, Oklahoma, Wisconsin	not specified		*Ergasilus*	*arthrosis*	Roberts, 1970	from Hoffman 1999
		not specified	Kentucky	not specified				Edwards et al., 1977	from Hoffman 1999
		not specified	Southeast USA	not specified				Johnson and Rogers, 1973	from Hoffman 1999
		not specified	not specified	not specified			*cerates*	Johnson and Rogers, 1973	from Hoffman 1999
		syn. *E. cerates*	syn. E. cerates	not specified			*elegans*	syn. E. cerates	from Hoffman 1999
		not specified	Iowa	not specified			*megaceros*	Roberts, 1970	from Hoffman 1999
		not specified	Lake Erie	not specified			*versicolor*	Tidd, 1931	
		many fish species	pond culture in many states	not specified		*Lernaea*	*cyprinacea*	Hoffman, 1967-1985	from Hoffman 1999
		gills	Arkansas	not specified				Goodwin, 1999	
		dorsal fin, on anal, tail, pelvic, and pectora fins	Saginaw Bay, Lake Huron, Michigan	not specified		*Neoergasilus*	*japonicus*	Hudson and Bowen, 2002	
		dorsal and anal fins	Lee County, Alabama	not specified				Hayden and Rogers, 1998	

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*punctatus*	skin scrappings	North America, USA		Ciliophora	*Ambiphrya*	*ameiuri*	Hoffman, 1979	from USNPC, Accession No.: 099445.00 Storage No. 5500-G
		not specified	not specified	not specified			*ictaluri*	not specified	from Hoffman 1999
		not specified	not specified	not specified			*macropodia*	Davis, 1947	from Hoffman 1999
		gill	Southern United States	not specified		*Amphileptus*	*voracus*	Kahl, 1931; David, 1947	from Hoffman 1999
		gills	not specified	not specified		*Epistylis*	sp.	not specified	from Hoffman 1999
		skin	temperature zone worldwide	not specified		*Ichthyophthirius*	*multifiliis*	Dorier, 1926; Schaperclaus, 1954	from Hoffman 1999
		peritoneal cavity	not specified	not specified				Maki et al., 2001	artificial conditions
		body surface, fins	Alabama	tank challenge				Xu et al., 2011	
		skin	Illinois	hatchery		*Scyphidia*	*macropodia*	Meryman, 1975	
		gills	Iowa, West Virginia	not specified		*Trichodina*	*discoidea*	Davis, 1947	from Hoffman 1999
		not specified	Southern Illinois	not specified				Blecka, 1972	from Hoffman 1999
		not specified	Illinois	not specified				Meryman, 1975	from Hoffman 1999
		gills	Iowa	not specified			*vallata*	Davis, 1947	from Hoffman 1999
		gills	Iowa	not specified		*Trichophrya*	*ictaluri*	Davis, 1942	from Hoffman 1999
		gills	many places	not specified			*piscium*	Shulman, 1984	from Hoffman 1999
		gills	Iowa, West Virginia	not specified		*Tripartiella*	*symmetricus*	Davis, 1947	from Hoffman 1999
		not specified	not specified	not specified		*Vorticella*	sp.	Shrestha, 1977	
		blood capillaries of the gills	worldwide distribution in temperate-subtropical areas	farm-raised catfish	Fungi	*Branchiomyces*	*sanguinis*	Plumb, 1979	from Hoffman 1999
		soft nodules in the viscera	Alabama	culture fish		*Exophiala*	*pisciphilas*	McGinnis and Ajello, 1974	from Hoffman 1999
		not specified	not specified	not specified	Mastigophora	*Colponema*	sp.	not specified	from Hoffman 1999
		gills	not specified	not specified		*Costia*	sp.	not specified	from Hoffman 1999
		not specified	Arkansas	not specified		*Cryptobia*	*branchialis*	Hoffman, 1978	from Hoffman 1999
		not specified	Arkansas	not specified				Hoffman, 1975-1985	from Hoffman 1999
		branchialis	Arkansas	not specified			*agitans*	Nie, 1955; Hoffman, 1978	from Hoffman 1999
		fins, body	Arkansas, California, Idaho, South Carolina, Tennessee	not specified		*Heteropolaria*	*colisarum*	Foissner et al., 1985	from Hoffman 1999
		gills	not specified	not specified		*Ichthyobodo (Costia)*	*necator (necatrix)*	Henneguy, 1884; Joyon and Lom,, 1966; Lom and Dykova, 1992	from Hoffman 1999
		gills and skin	not specified	freshwater fishes		*Oodinium*	sp.	not specified	from Hoffman 1999
		liver	West Virginia	not specified		*Pleistophora*	sp.	Herman and Putz, 1970	from Hoffman 1999
		gill filaments	Illinois	hatchery	Mollusca	*Quadrula*	*pustulosa*	Meryman, 1975	
		adipose fin	Mississippi	not specified	Cnidaria	*Henneguya*	*adiposa*	Minchew, 1977	from Hoffman 1999
		adipose fin	not specified	not specified				Griffin et al., 2009	
		carbuncle-like lesion: bases of barbel and pectoral fins	Mississippi	not specified			*diversus*	Minchew, 1977	from Hoffman 1999
		gills	Illinois	not specified			*exilis*	Kudo, 1929	from Hoffman 1999
		gills	Western Lake Erie, USA	wild				Baker and Crites, 1976	from Hoffman 1999
		ultrastructure of interlamellar form	Nebraska	not specified				Current and Janovy, 1976	from Hoffman 1999
		gills	Lake Erie, Ontario	wild				Dechtiar, 1972	from Hoffman 1999
		histopathology of granulomatous branchitis	California	not specified				Duhamel et at, 1986	from Hoffman 1999
		histopathology of leisons on tissues	not specified	not specified				McCraren et al, 1975	from Hoffman 1999

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*punctatus*	gills	Mississippi	not specified				Minchew, 1977	from Hoffman 1999
		gills	Des Moines River, Iowa	not specified				Mitchell, 1978	from Hoffman 1999
		intracellular form on gills	Monterry, Mexico	cultured fish				Segovia Salinas, 1985	from Hoffman 1999
		histopathology of interlamellar on gills	not specified	not specified				Smith and Inslee, 1980	from Hoffman 1999
		gills	U.S.A.	not specified			*ictaluri*	Belem and Pote, 2001	
		gills	not specified	not specified				Pote et al., 2000	
		gills	not specified	not specified				Wise et al., 2008	
		gills	Mississippi	tank challenge				Bosworth et al, 2003	
		gills	Mississippi	pond challenge				Griffin et al., 2010	experiment, more resistant than channel
		not specified	not specified	not specified			*limatula*	Meglitsch, 1937	from Hoffman 1999
		lamellar capillaries & interlamellar regions, associated with *H. postexilis*, intralamellarly	Mississippi	not specified			*longicauda*	Minchew, 1977	from Hoffman 1999
		interlamellar cysts	not specified	not specified			*postexilis*	Minchew, 1977	from Hoffman 1999
		histopathology of severe gill disease	not specified	not specified				Smith and Inslee, 1980	from Hoffman 1999
		skin nodules	Mississippi delta	not specified			*sutherlandi*	Griffin et al., 2008	
		gall bladder	Illinois	not specified		*Myxidium*	*bellum*	Meglitsch, 1937	from Hoffman 1999
		not specified	Arkansas	not specified				Hoffman, 1975	from Hoffman 1999
		not specified	Colorado	not specified				Janeke, 1975	from Hoffman 1999
		not specified	Iowa	not specified			*macrocapsulare*	Mitchell, 1978	from Hoffman 1999
		not specified	not specified	not specified		*Myxobolus*	*plasmodia*	not specified	from Hoffman 1999
		blood, kidney	California	not specified		*Sphaerospora*	*ictaluri*	Hedrick et al., 1990	from Hoffman 1999
		not specified	not specified	not specified	Nematoda	*Rhabdochona*	*decaturensis*	Mayberry et al., 2000	
		hang out of the fish anus	not specified	not specified		*Camallanus*	*oxycephalus*	Ward and Magath, 1917	from Hoffman 1999
		not specified	not specified	not specified			sp.	not specified	from Hoffman 1999
		not specified	Presa Falcon,Tamaulipas, Mexico	not specified				Casanova-Bustillos, 1984	from Perez-Ponce de Lion and Choudhury, 2002
		not specified	Nazas river basin, Northern Mexico	not specified		*Contracaecum*	sp.	Perez-Ponce de Lion et al., 2010	
		adult cosmopolitan: cormorants, mergansers, gulls, pelicans. larvae: many fish species, probably not host specificity	not specified	not specified			*spiculigerum*	Rudolphi, 1809	from Hoffman 1999
		not specified	not specified	not specified		*Dacnitoides*	*cotylophora*	Ward and Magath, 1917	from Hoffman 1999
		not specified	Wisconsin	not specified			*robusta*	Anthony, 1963	from Hoffman 1999
		not specified	Rio Pantepec, Mexico	wild		*Dichelyne*	*mexicanus*	Perez-Ponce de Lion and Choudhury, 2002	
		intestine	Mexico	wild				Salgado-Madonado, 2008	
		not specified	Ohio	not specified		*Eustrongylides*	*tubifex*	Baker and Crites, 1976	from Hoffman 1999
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
			Ontario	wild				McDonald and Margolis, 1995	from BMNH
		not specified	Lago San Juanico, Mexico	not specified		*Goezia*	sp.	Perez-Ponce de Lion and Choudhury, 2002	
			Arizona	wild		*Hysterothylacium*	sp.	Amin and Minckley, 1996	from BMNH
		not specified	Presa Falcon,Tamaulipas, Mexico	wild		*Neocucullanellus*	sp.	Casanova-Bustillos, 1984	from Perez-Ponce de Lion and Choudhury, 2002

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*punctatus*			wild		*Raphidascaris*	*acus*	Bruce et al., 1994	from BMNH
			Ontario	wild				McDonald and Margolis, 1995	from BMNH
		not specified	not specified	not specified		*Rhabdochona*	*cascadilla*	Wigdor, 1918	from Hoffman 1999
		not specified	not specified	not specified			sp.	not specified	from Hoffman 1999
		not specified	Rio Pantepec, Mexico	not specified				Perez-Ponce de Lion and Choudhury, 2002	
		not specified	not specified	not specified		*Spinitectus*	*carolini*	not specified	from Hoffman 1999
		not specified	not specified	not specified			*gracilis*	Ward and Magath, 1917	from Hoffman 1999
		not specified	Presa Falcon,Tamaulipas, Mexico	not specified			sp.	Casanova-Bustillos, 1984	from Perez-Ponce de Lion and Choudhury, 2002
		the anterior esophageal region	the Red & Assiniboine rivers, southern Manitoba, Canada	not specified			*macrospinosus*	Choudhury and Perryman, 2003	
		not specified	not specified	not specified		*Spiroxys*	sp.	not specified	from Hoffman 1999
		not specified	not specified	not specified	Platyhelminthes	*Clinostomum*	*marginatum*	Mayberry et al., 2000	
			Oklahoma	wild				Lorio, 1989	from BMNH
			Alabama	wild				Plumb and Rogers, 1990	from BMNH
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
		not specified	Ohio	not specified		*Acetodextra*	*amiuri*	Baker and Crites, 1976; Bangham, 1955	from Hoffman 1999
		not specified	Lake Erie	not specified				Bangham and Hunter, 1939	from Hoffman 1999
		not specified	Lake Erie	not specified				Coli, 1954	from Hoffman 1999
		not specified	Kentucky	not specified				Edwards et al., 1977	from Hoffman 1999
		ovary, "exploding" of ova from worm	not specified	not specified				Perkins, 1956	from Hoffman 1999
		not specified	Alabama	not specified				Warner and Hurbert, 1975	from Hoffman 1999
			Kentucky	wild				Timmon et al., 1992	from BMNH
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
		not specified	Ohio	not specified		*Allacanthochasmus*	*varius*	Baker and crites, 1976	from Hoffman 1999
		not specified	may related to *Lepidauchen* sp., from *Ictalurus nebulosus*, Virginia	not specified		*Allocreadium*	*ictaluri*	Holloway and Bogitsh, 1964	from Hoffman 1999
		not specified	many States in USA	not specified		*Alloglossidium*	*corti*	Van Cleave and Mueller, 1934	from Hoffman 1999
		not specified	Rio Panuco, Mexico	not specified				Perez-Ponce de Lion and Choudhury, 2002	
			Lake Ontario	wild				Dechtiar and Christie, 1988	from BMNH
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
			United States	wild				Carney and Brooks, 1991	from BMNH
			Lake Huron	wild				Dechtiar et al., 1988	from BMNH
			Mexico	wild				Perez-Ponce de Leon et al., 1996	from BMNH
			Nearctic	wild			*geminum*	Smythe and Font, 2001	from BMNH
			United States	wild				Carney and Brooks,. 1991	from BMNH
		not specified	Tennessee	not specified			*kenti*	Simer, 1929	from Hoffman 1999
		excysted metacercariae in intestine	Texas	not specified				Meade and Bedinger, 1972	from Hoffman 1999
			Nearctic	wild				Smythe and Font, 2001	from BMNH
			U.S.S.R.	captivity, domesticated		*Amphilina*	*foliacea*	Naimova and Roitman, 1989	from BMNH
		not specified	not specified	not specified		*Apophallus*	*venustus*	not specified	from Hoffman 1999
		not specified	not specified	not specified		*Azygia*	*angusticauda*	Stafford, 1904; Manter, 1926	from Hoffman 1999
		gastrointestinal system	Illinois	hatchery				Meryman, 1975	

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*punctatus*	stomach and caeca	not specified	not specified			*longa*	Leidy, 1851; Manter, 1926	from Hoffman 1999
		not specified	not specified	not specified		*Bolbophorus*	*confusus*	Kraus, 1914	from Hoffman 1999
		not specified	Mississippi, fish farming	wild				Terhune et al, 2002	
		flesh, near the skin	Louisiana, Mississippi	wild			*damnificus*	Overstreet et al., 2002	
		not specified	Mississippi delta	not specified				Levy et al, 2002	
			Lake Erie	wild		*Bothriocephalus*	sp.	Dechtiar and Nepszy, 1988	from BMNH
		intestine	North America, USA				*acheilognathi*	Choudhruy and Cole, 2003	from USNPC, Accession No.: 094187.00 Storage No. 135A-14
		intestine	Mexico	wild		*Campechetrema*	sp.	Salgado-Madonado, 2008	
		not specified	Rio Pantepec, Mexico	not specified				Perez-Ponce de Lion and Choudhury, 2002	
			Texas	wild		*Centrocestus*	*formosanus*	Mitchell et al., 2002	from BMNH
			Mexico	wild				Scholz and Salgado-Maldonado, 2000	from BMNH
		not specified	Lake Erie	lake		*Cleidodiscus*	*floridanus*	Dechtiar, 1972	
		not specified	Lake Erie	lake			*pricei*	Dechtiar, 1972	
			U.S.S.R.	captivity, domesticated				Naimova and Roitman, 1989	from BMNH
			Alabama	wild			sp.	Duarte et al., 1993	from BMNH
			Mexico	wild			*floridanus*	Galaviz-Silva, 1990	from BMNH
		not specified	not specified	not specified		*Clinostomum*	*complanatum*	Rudolphi, 1819	from Hoffman 1999
		not specified	Illinois	not specified		*Corallobothrium*	*fimbriatum*	Essex, 1927	from Hoffman 1999
		not specified	North America	not specified				several authors	from Hoffman 1999
		not specified	Lago San Juanico, Presa Falcon, and Rio Pantepec, Mexico	not specified				Perez-Ponce de Lion and Choudhury, 2002	
			Arizona	wild				Amin and Minckley, 1996	from BMNH
			Ontario	wild				McDonald and Margolis, 1995	from BMNH
			Wisconsin	wild				Amin, 1991	from BMNH
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
		syn. Megathylacoides giganteum	syn. *Megathylacoides giganteum*	not specified			*giganteum*	syn. *Megathylacoides giganteum*	from Hoffman 1999
			Arizona	wild				Amin and Minckley, 1996	from BMNH
			Wisconsin	wild				Amin, 1991	from BMNH
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
		not specified	Presa Falcon,Tamaulipas, Mexico	not specified			sp.	Casanova-Bustillos, 1984	from Perez-Ponce de Lion and Choudhury, 2002
		anomalous forms	Oklahoma	not specified			*thompsoni*	Sneed, 1950	from Hoffman 1999
		anomalous forms	not specified	not specified				Sneed, 1961	from Hoffman 1999
		not specified	not specified	not specified		*Crassiphiala*	*ambloplitis*	not specified	from Hoffman 1999
		intestine	Illinois	river		*Crepidobothrium*	*fragile*	Essex, 1929	
		gall bladder and intestine	not specified	not specified			*cornutum*	Stafford, 1904	from Hoffman 1999
		not specified	not specified	not specified			*ictaluri*	Surber, 1928	from Hoffman 1999
			Minnesota, Illinois, Iowa, Nebraska	wild				Caira, 1989	from BMNH
			Indiana	wild		*Cyathocotyloides*	sp.	Buckner et al. 1985	from BMNH
		not specified	not specified	not specified		*Dactylogyrus*	sp. (?)	not specified	from Hoffman 1999
			Mexico	wild			*extensus*	Perez-Ponce de Leon et al., 1996	from BMNH
			Alabama	wild			sp.	Duarte et al., 1993	from BMNH
		eye lens	North America, USA			*Diplostomulum*	*flexicaudum*	Hoffman, 1963	from USNPC, Accession No.: 101694.00 Storage No. 296A-18/25

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*punctatus*	not specified	not specified	not specified			sp.	not specified	from Hoffman 1999
		eyes	Ohio	not specified			*spathaceum*	Hoffman, 1970	from Hoffman 1999
			Alabama	wild				Plumb and Rogers, 1990	from BMNH
			Bulgaria	wild				Margaritov, 1992	from BMNH
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
			Lake Huron	wild				Dechtiar et al., 1988	from BMNH
			Mexico	wild		*Diplostomum*	*sp.*	Perez-Ponce de Leon et al., 1996	from BMNH
			North America, USA			*Distomum*	*opacum*	Ward, 1984	from USNPC, Accession No.: 000036.00 Storage No. M242-C
		intestine	Illinois	hatchery		*Eubothrium*	sp.	Meryman, 1975	
			Bulgaria	captivity, domesticated		*Gyrodactylus*	*stankovici*	Margaritov, 1992	from BMNH
		not specified	Gadsden County, Florida	wild			*ictaluri*	Rogers, 1967	from Harris et al., 2004
			U. S. S. R.	captivity, domesticated			*katharineri*	Naimova and Roitman, 1989	from BMNH
		not specified	not specified	not specified			*nebulosus*	Kritsky and Mizelle, 1968	from Harris et al., 2004
			Mississippi	captivity, domesticated			*sp.*	Durbrow, 1991	from BMNH
			Canada	wild				McDonald and Margolis, 1995	from BMNH
			Alabama	wild				Duarte et al., 1993	from BMNH
			Lake Erie	wild					from BMNH
		intestine	Ontario	not specified		*Haplobothrium*	*bistrobilae*	Dechtiar, 1972	from Hoffman 1999
		not specified	Lake Erie	lake		*Haplobothrium*	*globuliforme*	Dechtiar, 1972	
		life cycle: adult stage	Indiana	not specified		*Holostephanus*	*ictaluri*	Stang and Cable, 1966	from Hoffman 1999
		adult in intestine	Indiana	not specified				Vernberg, 1952	from Hoffman 1999
			Indiana	wild				Buckner et al. 1985	from BMNH
		syn. *Allocreadium ictaluri (mentioned aboved)*	syn. *Allocreadium ictaluri (mentioned aboved)*	not specified		*Lepidauchen*	*ictaluri*	syn. *Allocreadium ictaluri (mentioned aboved)*	from Hoffman 1999
		gills	Louisiana	not specified		*Ligictaluridus*	*bychowskyi*	Price and Mura, 1969; Beverley-Burton, 1985	from Hoffman 1999
		gills	Florida	not specified			*floridanus*	Mueller, 1936a; Beverley-Burton, 1984; Klassen and Beverley-Burton, 1985	from Hoffman 1999
			Lake Huron	wild				Dechtiar et al., 1988	from BMNH
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
			Ontario	wild				McDonald and Margolis, 1995	from BMNH
			Lake Ontario	wild				Dechtiar and Christie, 1988	from BMNH
		gills	Tennessee	not specified			*mirabilis*	Mueller, 1937; Klassen and Beverley-Burton, 1985	from Hoffman 1999
			Ontario	wild				McDonald and Margolis, 1995	from BMNH
		gills	Florida	not specified			*pricei*	Beverley-Burton, 1984	from Hoffman 1999
		gills	20 states and New Brunswick, Ontario	not specified				Klassen and Beverley-Burton, 1985	from Hoffman 1999
		not specified	former Soviet Union	not specified				Mirzoyeva, 1977	from Hoffman 1999
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*punctatus*		Lake Ontario	wild				McDonald and Margolis, 1995	from BMNH
		not specified	Wisconsin	not specified		*Macroderoides*	*spiniferus*	Pearse, 1924a	from Hoffman 1999
		not specified	not specific	not specified		*Megalagonia*	*ictaluri*	Surber, 1928	from Hoffman 1999
		not specified	Pearl River, Mississippi, USA	not specified				Curran et al., 2006	from GenBank
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
			Lake Huron	wild				Dechtiar et al., 1988	from BMNH
		not specified	Illinois	not specified		*Megathylacoides*	*giganteum*	Essex, 1928; Frese, 1965; Jones et al., 1956	from Hoffman 1999
		not specified	Ohio	not specified				Baker and Crites, 1976; Bangham, 1941	from Hoffman 1999
		not specified	not specified	not specified				Bangham and Venard, 1942	from Hoffman 1999
		not specified	Lake Huron	not specified				Bangham, 1955	from Hoffman 1999
		not specified	Kentucky	not specified				Edwards et al., 1977	from Hoffman 1999
		not specified	Kansas	not specified				Harms, 1959	from Hoffman 1999
		not specified	California	not specified				Hensley and Nahhas, 1975	from Hoffman 1999
		not specified	Arkansas	not specified				Hoffman et al., 1974	from Hoffman 1999
		not specified	Texas	not specified				Lawrence and Murphy, 1967	from Hoffman 1999
		not specified	California	not specified				Miller et al., 1973	from Hoffman 1999
		not specified	Kansas	not specified				Wilson, 1957	from Hoffman 1999
		not specified	Rio Pantepec, Mexico	not specified				Perez-Ponce de Lion and Choudhury, 2002	
		not specified	Assiniboine River at Portage, La Prairie Dam, Manitoba, Canada	river				Scholz et al., 2003	
			Lake Huron	wild				Dechtiar et al., 1988	from BMNH
			Ontario	wild				McDonald and Margolis, 1995	from BMNH
			Lake Ontario	wild				Dechtiar and Christie, 1988	from BMNH
		not specified	Lake Huron, Michigan	not specified		*Microphallus*	*opacus*	Bangham, 1939 and 1955	from Hoffman 1999
			Lake Ontario	wild				Dechtiar and Christie, 1988	from BMNH
		liver	Illinois	hatchery		*Neascus*	sp.	Meryman, 1975	
			Wisconsin	wild		*Ophiotaenia*	*fragilis*	Amin, 1991	from BMNH
		not specified	not specified	not specified				not specified	from Hoffman 1999
		not specified	Wisconsin	not specified		*Ornithodiplostomum*	*ptychocheilus*	Amin, 1982	from Hoffman 1999
		intestine	North America, USA			*Paramphistomum*	*stunkardi*	Bangham, 1999	from USNPC, Accession No.: 089477.02 Storage No. M1746-13
		not specified	Ontario	not specified		*Parasitotrema*	*ottawanensis*	Miller, 1940	from Hoffman 1999
		not specified	Kentucky	not specified		*Phyllodistomum*	*lacustri*	Aliff, 1977	from Hoffman 1999
		not specified	Tennessee	not specified				Bangham and Venard, 1942	from Hoffman 1999
		not specified	Lake Erie, Ontario	not specified				Dechtiar, 1972	from Hoffman 1999
		not specified	Kansas	not specified				Harms, 1959	from Hoffman 1999
		not specified	Eastern Texas	not specified				Meade and Bedinger, 1972	from Hoffman 1999
		not specified	Rio Pantepec, Mexico	not specified				Perez-Ponce de Lion and Choudhury, 2002	
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
		not specified	Kentucky	not specified			*staffordi*	Aliff, 1977	from Hoffman 1999
		intestine	North America, USA			*Plagiorchis*	*corti*		from USNPC, Accession No.: 095491.01 Storage No. Sh225:18-34/35

catfish genus	catfish species	sites of infection	geographical localities	setting	parasite phylum	parasite genus	parasite species	reference	remarks
Ictalurus	*punctatus*	intestine	Texas			*Polylekithum*	*catahoulensis*	Barger, ?	From Manter Museum Collection Number: 49521
			Wisconsin	wild			*ictaluri*	Amin, 1991	from BMNH
		not specified	Texas	not specified		*Posthodiplostomum*	*minimum*	Meade and Bedinger, 1972	from Hoffman 1999
		not specified	not specified	not specified		*Prohemistomum*	*chandleri*	not specified	from Hoffman 1999
		not specified	Pearl River, Mississippi, USA	not specified		*Prosthenhystera*	*obesa*	Curran et al., 2006	from GenBank
		gall bladder	North America, USA				*oonastica*	Rogers, 1979	from USNPC, Accession No.: 075499.00 Storage No. MT21:23 H
		gall bladder	South American and Mexico	not specified			sp.	not specified	from Hoffman 1999
		not specified	not specified	not specified		*Proteocephalus*	*ambloplitis*	not specified	from Hoffman 1999
			Ontario	wild				McDonald and Margolis, 1995	from BMNH
			Lake Erie	wild				Dechtiar and Nepszy, 1988	from BMNH
			Wisconsin	wild				Amin, 1990	from BMNH
		intestine	North America, USA				*macrocephalus*	Hoffman, 1981	from USNPC, Accession No.: 101889.00 Storage No. SH230:22-13/18
			Wisconsin	wild			sp.	Amin, 1991	from BMNH
		stomach	coastal Mississippi and Louisiana	not specified		*Thometrema*	*lotzi*	Curran et al., 2002	
		intestine and stomach	New York	not specified		*Vietosoma*	*parvum*	Van Cleave and Mueller, 1932	from Hoffman 1999
		not specified	Arkansas	not specified				Hoffman et al., 1974	from Hoffman 1999
		not specified	not specified	not specified				Lyster, 1939	from Hoffman 1999
		not specified	not specified	not specified	Rhizopoda	*"Amoeba"*		not specified	from Hoffman 1999
		not specified	not specified	not specified		*Acanthamoeba*	sp.	not specified	from Hoffman 1999
		body surface, fins	Alabama	tank challenge	Ciliophora	*Ichthyophthirius*	*multifiliis*	Xu et al., 2011	
		not specified	not specified	pond		*Scyphidia*	sp.	Shrestha, 1977	
		body and gills	not specified	pond		*Trichodina*	sp.	Shrestha, 1977	
I. punctatus, female × *I. furcatus*, male		gills	Mississippi	tank challenge	Cnidaria	*Henneguya*	*ictaluri*	Bosworth et al, 2003	
		gills	Mississippi	pond challenge				Griffin et al., 2010	experimental conditions
		gills	Mississippi	cage challenge				Beecham et al., 2011	experimental conditions
		not specified	not specified	pond	Platyhelminthes	*Cleidodiscus*	sp.	Shrestha, 1977	

Table 3. Morphometic data for *Ligictaluridus mirabilis* (Mueller, 1937) Klassen and Beverley-Burton, 1985 (measurements in microns)

Host	Geographic locality	Body length	Body width	Body length/ width	Haptor length	Haptor width	Haptor length/ width	Pharynx diameter	Penis length	Accessory piece length	Dorsal hamulus length	Dorsal bar length	Dorsal bar width	Dorsal length/ width	Ventral hamulus length	Ventral bar length	Ventral bar width	Ventral bar length/ width	Hooklet length	References
Pylodictis olivaris	Mississipi, U.S.A	Up to 1300	185	–	89	–	–	–	107	89	73	89	–	–	73	89	–	–	–	Mueller, 1937
Ameiurus melas, Ictalurus punctatus, I. furcatus	Tennessee, U.S.A	986 (621–1290)	109 (64–150)	–	91 (64–129)	92 (57–143)	–	41 (29–50)	73 (51–100)	67 (31–85)	55 (30–65)	74 (44–108)	–	–	56 (38–69)	71 (47–86)	–	–	14–20	Mizelle and Cronin, 1943
I. punctatus	Ontario, Canada	884 (725–1128)	272 (167–379)	–	43 (32–52)	77 (55–114)	–	25 (18–30)	96 (78–105) 87 (76–102)	107 (87–121) 92 (73–96)	65 (47–72)	114 (94–131)	14 (7–20)	–	68 (54–80)	116 (88–143)	12 (7–18)	–	16–25	Klassen and Beverley-Burton, 1985 (chloral gum)
I. punctatus	Ontario, Canada	630 (513–794)	130 (79–174)	–	–	–	–	–	80 (57–100) 69 (46–89)	94 (62–119) 72 (46–98)	58 (40–70)	76 (49–89)	9 (4–13)	–	67 (51–76)	78 (62–88)	9 (6-11)	–	14–18	Klassen and Beverley-Burton, 1985 (permount)
I. punctatus	Alabama, U.S.A	527 (450–610)	122 (73–215)	10.77	58 (42–115)	119 (90–210)	0.49	40 (29–65)	61 (43–68)	73 (60–85)	48 (38–55)	76 (58–88)	15 (8–23)	5.24	51 (44–62)	74 (65–84)	17 (8–19)	4.63	19 (16–23)	Present study
I. furcatus	Alabama, U.S.A	470 (430–540)	106 (102–108)	6.22	53 (50–58)	122 (113–133)	0.44	32 (28–38)	57 (54–61)	74 (70–77)	44 (37–50)	67 (50–78)	14 (12–18)	4.68	44 (38–47)	71 (66–77)	15 (12–18)	4.75	16 (11–19)	Present study
female *I. punctatus* × male *I. furcatus*	Alabama, U.S.A	608 (410–770)	121 (61–165)	9.90	63 (49–84)	120 (92–148)	0.53	44 (25–65)	64 (46–72)	73 (67–79)	49 (40–55)	74 (50–85)	15 (5–30)	6.07	50 (43–55)	78 (64–89)	16 (7–23)	5.44	18 (17–22)	Present study

Table 4. Morphometric data for *Ligictaluridus pricei* (Mueller, 1936) Beverley-Burton, 1984 (measurements in microns)

Host	Geographic locality	Body length	Body width	Body length/ width	Haptor length	Haptor width	Haptor length/ width	Pharynx diameter	Penis length	Accessory piece length	Dorsal hamulus length	Dorsal bar length	Dorsal bar width	Dorsal length/ width	Ventral hamulus length	Ventral bar length	Ventral bar width	Ventral bar length/ width	Hooklet length	References
Ictalurus natalis, I. nebulosus, I. punctatus	Florida, U.S.A	620	140	–	–	About as wide as body	–	40	<37	–	48	58	–	–	48	50	–	–	About 16	Mueller, 1936
I. furcatus,I. melas, I. natalis, I. nebulosus, I. punctatus	Tennessee, U.S.A	520 (386–928)	80 (57–114)	–	76 (50–107)	69 (43–100)	–	30 (24–41)	34 (25–54)	32 (22–55)	48 (35–74)	45 (29–52)	–	–	44 (34–54)	42 (28–47)	–	–	13–18	Mizelle and Cronin, 1943
I. nebulosus	Wisconsin, U.S.A	545 (378–720)	99 (73–138)	–	75 (65–86)	95 (77–120)	–	38 (29–45)	35 (29–38)	24 (20–36)	53 (45–70)	45 (41–49)	–	–	51 (47–54)	43 (40–47)	–	–	13–18	Mizelle and Resensberger, 1945
I. nebulosus	Ontario, Canada	526–636	92–108	–	67–82	117–126	–	39–44	33–36	25–28	36–45	39–44	5–8	–	32–39	35–40	3–6	–	14–18	Hanek and Fernando, 1972
I. nebulosus	Lubin Province, Poland	380–780	45–155	–	68–107	58–130	–	17–37	30–33	–	37–46	41–58	4–5	–	42–49	38–48	8–9	–	15–18	Prost, 1973
I. nebulosus	Ontario, Canada	510 (280–810)	158 (70–405)	–	88 (69–126)	113 (88–161)	–	36 (21–60)	33 (24–41) 28 (20–35)	30 (20–35) 27 (17–30)	41 (38–45)	51 (43–56)	9 (7–17)	–	44 (41–48)	47 (40–52)	12 (7–23)	–	13–19	Klassen and Beverley-Burton, 1985
Ictalurus punctatus	Alabama, U.S.A	438 (400–490)	97 (77–120)	4.56	61 (49–71)	91 (70–112)	0.68	32 (29–37)	29 (23–38)	26 (19–31)	40 (36–44)	53 (46–58)	13 (10–16)	4.04	45 (43–49)	52 (47–56)	9 (8–11	5.77	16 (13–19)	Present study
Ictalurus furcatus	Alabama, U.S.A	381 (310–430)	79 (68–108)	4.89	52 (47–60)	85 (65–98)	0.62	28 (20–40)	29 (22–36)	26 (19–35)	40 (32–51)	49 (44–55)	11 (8–13)	4.44	42 (35–46)	47 (43–52)	9 (7–12)	5.49	15 (13–18)	Present study
female *I. punctatus* × male *I. furcatus*	Alabama, U.S.A	490 (430–580)	118 (88–148)	4.27	63 (38–100)	87 (38–104)	0.74	34 (28–41)	31 (23–36)	31 (23–43)	42 (37–49)	54 (50–58)	15 (12–18)	3.70	46 (44–48)	48 (42–52)	9 (7–14)	5.52	14 (13–16)	Present study

Table 5. Morphometric data for *Henneguya* spp. from ictalurid fishes of the Southeastern United States (measurements in microns)

Host	parasite species	SBL	SBW	longer PCL	shorter PCL	PCW	PLT	SL	SW	CPL	CPSC	TSL	CL	CB	CC	SI	reference
Ictalurus furcatus	*Henneguya pellis*	14.8 (13.0–17.1)	4.7 (4.0–5.7)	7.2 (6.2–8.4)	6.5 (5.5–8.0)	1.7 (1.4–1.9)	8	–	–	77.7 (57.4–96.4)	anteriorly	92.5 (73.3–113.5)	5000	3000	white, circular	skin and body wall of the peritoneal cavity	Pote et al., 2000; Griffin et al., 2009b
I. furcatus	*H. pellis*	13.0 (11.0–14.5)	5.0 (4.5–5.2)	6.9 (5.5–8.5)	–	1.8 (1.5–2.0)	8–10	–	–	87.8 (66–112)	anteriorly	100.4 (79–124)	2000	1000	white, circular	skin	Michew, 1977; Pote et al., 2000
I. punctatus	*H. sutherlandi*	15.4 (12.2–19.3)	5.5 (4.5–6.8)	6.1 (4.0–7.9)	–	1.7 (1.0–2.2)	6	–	–	50.5 (34.8–71.4)	anteriorly	60.3 (50.6–69.1)	2000	1000	blister–like, round or ovoid	skin	Griffin et al., 2008
I. punctatus	*H. diversis*	14.8 (13.5–16.5)	4.0 (3.2–5.0)	6.2 (6.0–7.5)	–	1.5 (1.0–2.0)	6–8	–	–	34.6 (25–47)	posteriorly	49.5 (40–62)	up to 600	up to 250	tumor–like	base of barbels, pectoral fins and along isthmus, liver, and kidney	Michew, 1977; Pote et al., 2000
I. punctatus	*H. postexilis*	15 (13.5–17)	3.4 (3.5–4.0)	6.6 (5.9–7.2)	–	1.5 1.0–2.0)	6–8	–	–	37.0 (28–49)	posteriorly	52.0 (42–62)	12.0–80.0	12.0–70.0	small, dense	gills	Michew, 1977; Pote et al., 2000
I. punctatus	*H. ictaluri*	23.9 (20.8–26.1)	6.0 (4.5–6.4)	8.1 (7.6–9.6)	–	2.5 (2.0–3.2)	–	–	–	63 (48.1–80.2)	entire length	–	–	–	no visible cysts	gills	Pote et al., 2000
I. punctatus, Ameiurus melas, A. nebulosus	*H. exilis*	18.0–20.0	4.0–5.0	8.0–9.0	–	1.0–1.5	9–12	–	–	–	no split	60.0–70.0	2000	500	white, visible to naked eyes	gills	Kudo, 1929; Minchew, 1977; Lin et al., 1999; Pote et al., 2000
A. nebulosus	*H. gurleyi*	18.2 (15.7–20.3)	5.4 (3.8–6.1)	5.9 (4.8–7.1)	–	1.2 (1.0–1.5)	–	–	–	41.1 (34.0–49.9)	–	60.9 (48.7–68.5)	up to 1800	up to 1800	–	dorsal, pectoral, and anal fins	Kudo, 1920; Pote et al., 2000; Iwanowicz et al., 2008
I. punctatus	*H. longicauda*	16.2 (14–17.5)	4.0 (3.4–4.5)	7.7 (7.0–8.5)	–	1.8 (1.5–2.0)	9–12	–	–	90.5 (75–110)	posteriorly	108.3 (91–127)	120–370	110–130	white, circular	gills	Michew, 1977; Pote et al., 2000
A. nebulosus	*H. ameiurensis*	23.2	4.1	5.4	–	1.6	–	–	–	15–41.5	–	–	340–1200	190–760	–	barbels	Nigrelli and Smith, 1940; Pote et al., 2000
I. punctatus	*H. adiposa*	17.1 (14.7–20.5)	4.1 (3.4–4.6)	7.2 (5.8–8.3)	–	1.3 (0.9–1.9)	at least 8	–	–	38.0 (23.2–48.8)	posteriorly	55.6 (40.7–65.8)	–	–	white, nodular, elongate, translucent, and linear	adipose fin	Pote et al., 2000; Griffin et al., 2009a
I. punctatus	*H. adiposa*	16.3 (12–19)	4.0 (3.5–5.0)	7.7 (6.2–9.0)	–	1.5 (1.0–2.0)	6–8	–	–	44.8 (28–59)	posteriorly	61.0 (45–75)	290–500	120–150	white, nodular	adipose fin	Michew, 1977; Pote et al., 2000
I. punctatus, I. furcatus	*H. limatula*	13.0–17.0	5.0–6.0	6.5–8.0	6.5	1.0–2.0	–	–	–	27.0–37.0	almost no split, posterior bifucation (sometimes)	–	–	–	–	gall bladder	Meglitsch, 1937
I. furcatus	*H.* cf. *ictaluri*	17.59 (15–20)	5.32 (4–6)	6.73 (6–8)	6.27 (5–8)	2.05 (2–3)	9–10	7.59 (6–10)	4.23 (3–5)	68.23 (53–93)	anteriorly, medially, posteriorly, or no split	85.73 (70–113)	419 (325–490)	280.42 (160–365)	ovoid to round	gills	Present study
I. furcatus	*H.* cf. *postexilis*	15.71 (15–17)	4	7 (6–8)	6.29 (6–7)	2	11	6.29 (6–7)	3	37.71 (31–45)	anteriorly, medially, posteriorly, or no split	54.14 (48–61)	–	–	ovoid, small cysts	gills	Present study
I. punctatus	*H.* cf. *ictaluri*	17.57 (16–18)	4.14 (4–5)	7.57 (7–8)	6.71 (6–7)	2	10–11	7.43 (5–9)	3.14 (3–4)	56.71 (49–73)	anteriorly, medially, posteriorly, or no split	74.29 (64–90)	–	–	elongate or ovoid	gills	Present study

Host	parasite species	SBL	SBW	longer PCL	shorter PCL	PCW	PLT	SL	SW	CPL	CPSC	TSL	CL	CB	CC	SI	reference
I. punctatus	*H.* cf. *postexilis*	15.69 (12–23)	4.19 (3–6)	6.48 (4–8)	6.12 (4–8)	2	9–12	6.23 (4–10)	3.18 (3–5)	41.16 (25–55)	anteriorly, medially, posteriorly, or no split	56.59 (40–70)	198.08 (70–395)	136.67 (55–270)	variable: round, ovoid or elongate; small, thick-walled, fragile	gills	Present study
I. punctatus	H. cf. exilis	17.52 (15–20)	4.62 (4–6)	7.10 (6–8)	6.87 (6–8)	2	9–13	6.96 (5–9)	3.62 (3–5)	49.52 (36–66)	anteriorly, medially, posteriorly, or no split	67.44 (55–83)	–	–	variable: round, ovoid or elongate; thick-walled, translucent	gills	Present study
I. punctatus	*H.* cf. *adiposa*	18.45 (12–22)	4.18 (3–5)	7.32 (6–8)	7.05 (5–8)	2	8	8.50 (7–10)	3.32 (3–4)	39.55 (30–51)	anteriorly, medially, posteriorly, or no split	60.23 (50–72)	–	–	irregular, thick, white, nodular; embeded quite deeply into the tissue	adipose fin	Present study
female *I. punctatus* × male *I. furcatus*	*H.* cf. *adiposa*	19.0 (18–21)	4.10 (4–5)	8.30 (8–9)	7.90 (6–9)	2	8	8.20 (7–10)	3.10 (3–4)	45.30 (38–53)	anteriorly, medially, posteriorly, or no split	64.30 (57–68)	–	–	irregular, thick, white, nodular,; embeded quite deeply into the tissue	adipose fin	Present study
female *I. punctatus* × male *I. furcatus*	*H.* cf. *postexilis*	16.41 (12–19)	4.59 (4–6)	6.59 (6–8)	6.09 (5–8)	2.02 (2–3)	9–12	7.09 (4–9)	3.20 (3–4)	39.32 (31–51)	anteriorly, medially, posteriorly, or no split	55.63 (47–69)	–	–	elongate to ovoid; small, thick-walled	gills	Present study
female *I. punctatus* × male *I. furcatus*	*H.* cf. *exilis*	18.34 (15–21)	4.73 (4–6)	7.59 (6–9)	7.46 (6–9)	2	9–13	6.79 (3–10)	3.63 (3–4)	48.76 (38–63)	anteriorly, medially, posteriorly, or no split	66.40 (54–82)	–	–	variable: D-shaped, elongate, ovoid, or round; small, thick-walled	gills	Present study

SBL: spore body length; SBW: spore body width; PCL: polar capsule length; PCW: polar capsule width; PLT: polar filament turns; SL: sporoplasm length; SW: sporoplasm width; CPL: caudal process length; CPSC: caudal process splitting characters; TSL: total spore length; CL: cyst length; CB: cyst breadth; CC: cyst characters; SI: site of infection.

Table 7. Prevalence and mean intensity of parasites in channel catfish.

collection	number of examined catfish	fork length (cm)	parasite	Prev-P1	Prev-P2	Prev-P3	MI-P1	MI-P2	MI-P3
22-Jan-10 (stocking)	10	12.4–16.0 (14.00)	Myxozoa	0.90	0.90	0.90	2.20	2.20	2.20
			Monogenea	1.00	1.00	1.00	1.40	1.40	1.40
			Cestoda	0.10	0.10	0.10	1.00	1.00	1.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
22-Feb-10	9 (P1=3; P2=3; P3=3)	10.4–14.9 (11.80)	Myxozoa	1.00	1.00	1.00	2.00	1.70	2.30
			Monogenea	1.00	1.00	1.00	1.00	1.00	1.70
			Cestoda	0.67	0.33	0.00	2.00	1.00	0.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
5-Apr-10	12 (P1=4; P2=4; P3=4)	8.5–13.6 (10.90)	Myxozoa	1.00	0.75	1.00	3.00	1.75	2.00
			Monogenea	1.00	1.00	1.00	1.30	2.50	1.00
			Cestoda	0.50	0.50	0.25	2.00	1.50	3.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
13-May-10	15 (P1=5; P2=5; P3=5)	9.7–17.7 (13.14)	Myxozoa	1.00	0.60	0.80	1.60	2.67	1.74
			Monogenea	1.00	0.80	1.00	2.40	2.40	2.80
			Cestoda	0.40	1.00	0.40	2.00	1.80	1.50
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	1.00	0.60	1.00	2.60	1.00	1.80
21-Jun-10	8 (P1=4; P2=0; P3=4)	12.4–19.4 (16.52)	Myxozoa	0.00	–	1.00	0.00	–	1.25
			Monogenea	1.00	–	1.00	2.00	–	1.25
			Cestoda	0.25	–	0.00	2.00	–	0.00
			Nematoda	0.25	–	0.00	1.00	–	0.00
			Unionidae	0.00	–	0.00	0.00	–	0.00
			Copepoda	0.25	–	0.00	1.00	–	0.00
23-Jul-10	9 (P1=6; P2=3; P3=0)	15.8–22.8 (18.71)	Myxozoa	0.50	0.33	–	1.33	1.00	–
			Monogenea	1.00	1.00	–	1.17	1.67	–
			Cestoda	0.67	0.00	–	1.50	0.00	–
			Nematoda	0.00	0.00	–	0.00	0.00	–
			Unionidae	0.00	0.00	–	0.00	0.00	–
			Copepoda	0.00	0.00	–	0.00	0.00	–
14-Sep-10	9 (P1=6; P2=2; P3=1)	20.1–25.9 (22.83)	Myxozoa	1.00	1.00	0.00	1.33	2.50	0.00
			Monogenea	1.00	1.00	1.00	1.20	2.00	1.00
			Cestoda	0.67	1.00	0.00	2.00	1.00	0.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
17-Oct-10	5 (P1=2; P2=0; P3=3)	23.7–29.3 (26.2)	Myxozoa	0.50	–	0.67	2.00	–	2.50
			Monogenea	1.00	–	1.00	1.50	–	1.00
			Cestoda	1.00	–	0.00	2.50	–	0.00
			Nematoda	0.00	–	0.00	0.00	–	0.00

collection	number of examined catfish	fork length (cm)	parasite	Prev-P1	Prev-P2	Prev-P3	MI-P1	MI-P2	MI-P3
17-Oct-10	5 (P1=2; P2=0; P3=3)	23.7–29.3 (26.2)	Unionidae	0.00	–	0.00	0.00	–	0.00
			Copepoda	0.00	–	0.00	0.00	–	0.00
21-Nov-10	9 (P1=5; P2=3; P3=1)	20.2–32.9 (26.29)	Myxozoa	1.00	1.00	1.00	2.60	2.33	2.00
			Monogenea	1.00	1.00	1.00	1.80	1.67	3.00
			Cestoda	0.80	1.00	1.00	1.50	2.00	2.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.20	0.00	0.00	1.00	0.00	0.00
19-Jan-11	13 (P1=4; P2=4; P3=5)	22.7–30.6 (26.81)	Myxozoa	1.00	1.00	1.00	3.00	2.00	2.20
			Monogenea	1.00	1.00	1.00	1.75	1.25	2.20
			Cestoda	0.75	1.00	1.00	2.00	1.25	2.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
25-Feb-11	13 (P1=7; P2=6; P3=0)	22.5–34.9 (25.88)	Myxozoa	1.00	1.00	–	2.43	2.67	–
			Monogenea	1.00	1.00	–	2.14	1.50	–
			Cestoda	1.00	1.00	–	1.86	2.50	–
			Nematoda	0.00	0.00	–	0.00	0.00	–
			Unionidae	0.00	0.00	–	0.00	0.00	–
			Copepoda	0.00	0.50	–	0.00	1.33	–

Prev-: prevalence; MI: mean intensity; P1: pond 1; P2: pond 2; P3: pond 3.

Table 8. Prevalence and mean intensity of parasites in blue catfish.

collection	number of examined catfish	fork length (cm)	parasite	Prev-P1	Prev-P2	Prev-P3	MI-P1	MI-P2	MI-P3
22-Jan-10 (stocking)	10	11–13.5 (12)	Myxozoa	0.00	0.00	0.00	0.00	0.00	0.00
			Monogenea	0.67	0.67	0.67	2.40	2.40	2.40
			Cestoda	0.00	0.00	0.00	0.00	0.00	0.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
22-Feb-10	9 (P1=3; P2=3; P3=3)	13.1–14.9 (14)	Myxozoa	0.00	0.00	0.00	0.00	0.00	0.00
			Monogenea	1.00	1.00	1.00	1.70	2.30	2.00
			Cestoda	0.00	0.00	0.00	0.00	0.00	0.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	1.00	0.67	0.00	2.00	1.50
5-Apr-10	11 (P1=6; P2=5; P3=0)	12.1–15.7 (14.52)	Myxozoa	0.17	0.40	–	1.00	1.50	–
			Monogenea	0.67	1.00	–	2.25	2.80	–
			Cestoda	0.50	0.40	–	1.67	1.50	–
			Nematoda	0.00	0.00	–	0.00	0.00	–
			Unionidae	0.00	0.00	–	0.00	0.00	–
			Copepoda	0.33	0.00	–	2.50	0.00	–
13-May-10	9 (P1=5; P2=5; P3=0)	13.9–20.4 (16.34)	Myxozoa	0.00	0.00	–	0.00	0.00	–
			Monogenea	1.00	1.00	–	2.20	2.40	–
			Cestoda	0.00	0.00	–	0.00	0.00	–
			Nematoda	0.00	0.00	–	0.00	0.00	–
			Unionidae	0.00	0.00	–	0.00	0.00	–
			Copepoda	0.60	0.40	–	2.00	1.00	–
21-Jun-10	3 (P1=1; P2=2; P3=0)	13.9–15.8 (14.93)	Myxozoa	0.00	0.00	–	0.00	0.00	–
			Monogenea	1.00	1.00	–	1.00	2.00	–
			Cestoda	0.00	0.00	–	0.00	0.00	–
			Nematoda	0.00	0.00	–	0.00	0.00	–
			Unionidae	0.00	0.00	–	0.00	0.00	–
			Copepoda	0.00	0.00	–	0.00	0.00	–
23-Jul-10	12 (P1=12; P2=0; P3=0)	14.6–22.2 (18.21)	Myxozoa	0.00	–	–	0.00	–	–
			Monogenea	1.00	–	–	1.42	–	–
			Cestoda	0.83	–	–	2.60	–	–
			Nematoda	0.00	–	–	0.00	–	–
			Unionidae	0.00	–	–	0.00	–	–
			Copepoda	0.00	–	–	0.00	–	–
14-Sep-10	5 (P1=5; P2=0; P3=0)	19.9–22.7 (21.38)	Myxozoa	0.20	–	–	1.00	–	–
			Monogenea	1.00	–	–	2.00	–	–
			Cestoda	0.20	–	–	1.00	–	–
			Nematoda	0.00	–	–	0.00	–	–
			Unionidae	0.00	–	–	0.00	–	–
			Copepoda	0.00	–	–	0.00	–	–
17-Oct-10	5 (P1=2; P2=2; P3=1)	22.7–28.2 (24.56)	Myxozoa	0.00	0.00	0.00	0.00	0.00	0.00
			Monogenea	1.00	0.50	0.00	1.00	1.00	0.00
			Cestoda	0.50	1.00	0.00	3.00	1.00	0.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00

collection	number of examined catfish	fork length (cm)	parasite	Prev-P1	Prev-P2	Prev-P3	MI-P1	MI-P2	MI-P3
17-Oct-10	5 (P1=2; P2=2; P3=1)	22.7─28.2 (24.56)	Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
21-Nov-10	2 (P1=2; P2=0; P3=0)	17.8─24.2 (21.0)	Myxozoa	0.50	─	─	3.00	─	─
			Monogenea	1.00	─	─	2.50	─	─
			Cestoda	1.00	─	─	2.50	─	─
			Nematoda	0.00	─	─	0.00	─	─
			Unionidae	0.00	─	─	0.00	─	─
			Copepoda	0.50	─	─	2.00	─	─
19-Jan-11	5 (P1=2; P2=3; P3=0)	21.6─26.7 (24.28)	Myxozoa	1.00	0.33	─	1.50	1.00	─
			Monogenea	1.00	1.00	─	1.00	1.33	─
			Cestoda	1.00	1.00	─	2.50	1.00	─
			Nematoda	0.00	0.00	─	0.00	0.00	─
			Unionidae	0.00	0.00	─	0.00	0.00	─
			Copepoda	0.00	0.00	─	0.00	0.00	─
25-Feb-11	3 (P1=3; P2=0; P3=0)	22.2─23.8 (23.20)	Myxozoa	0.00	─	─	0.00	─	─
			Monogenea	1.00	─	─	2.00	─	─
			Cestoda	0.67	─	─	1.50	─	─
			Nematoda	0.00	─	─	0.00	─	─
			Unionidae	0.00	─	─	0.00	─	─
			Copepoda	0.33	─	─	1.00	─	─

Prev-: prevalence; MI: mean intensity; P1: pond 1; P2: pond 2; P3: pond 3.

Table 9. Prevalence and mean intensity of parasites in hybrid catfish.

collection	number of examined catfish	fork length (cm)	parasite	Prev-P1	Prev-P2	Prev-P3	MI-P1	MI-P2	MI-P3
22-Jan-10 (stocking)	10	9.8─11.9 (10.6)	Myxozoa	0.00	0.00	0.00	0.00	0.00	0.00
			Monogenea	1.00	1.00	1.00	1.90	1.90	1.90
			Cestoda	0.00	0.00	0.00	0.00	0.00	0.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
22-Feb-10	9 (P1=3; P2=3; P3=3)	8.0─10.7 (9.4)	Myxozoa	0.00	0.33	0.33	0.00	1.00	1.00
			Monogenea	1.00	0.67	0.67	2.00	1.50	2.00
			Cestoda	0.67	0.33	0.67	1.00	1.00	2.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
5-Apr-10	24 (P1=9; P2=6; P3=9)	8.3─12.1 (9.8)	Myxozoa	0.56	0.33	0.44	2.20	1.50	1.25
			Monogenea	1.00	0.83	1.00	2.10	2.60	1.78
			Cestoda	0.89	0.50	0.44	1.86	2.67	1.25
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.17	0.00	0.00	1.00	0.00
13-May-10	26 (P1=7; P2=9; P3=10)	8.0─14.6 (12.53)	Myxozoa	0.00	0.11	0.20	0.00	1.00	1.00
			Monogenea	1.00	1.00	1.00	1.86	2.00	2.70
			Cestoda	0.00	0.11	0.70	0.00	1.00	1.71
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.43	0.22	0.00	1.00	1.00	0.00
			Copepoda	0.14	0.22	0.40	1.00	1.17	1.50
21-Jun-10	14 (P1=6; P2=5; P3=3)	13.1─19.3 (15.60)	Myxozoa	0.17	0.00	0.33	1.00	0.00	1.00
			Monogenea	1.00	1.00	1.00	2.67	2.20	1.67
			Cestoda	0.00	0.00	0.00	0.00	0.00	0.00
			Nematoda	0.17	0.00	0.00	1.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
23-Jul-10	23 (P1=4; P2=10; P3=8)	15.9─23.8 (19.0)	Myxozoa	0.00	0.10	0.38	0.00	1.00	1.33
			Monogenea	1.00	1.00	1.00	1.50	1.20	1.34
			Cestoda	1.00	0.00	0.00	1.75	0.00	0.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
14-Sep-10	14 (P1=8; P2=2; P3=4)	18.8─30.4 (22.98)	Myxozoa	0.25	0.00	0.50	1.00	0.00	1.00
			Monogenea	1.00	1.00	1.00	2.25	1.00	1.00
			Cestoda	0.50	0.00	0.25	1.50	0.00	1.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.00	0.00	0.00	0.00	0.00
17-Oct-10	15 (P1=6; P2=8; P3=1)	20.9─27.9 (24.67)	Myxozoa	0.33	0.13	0.00	1.00	1.00	0.00
			Monogenea	1.00	0.38	0.00	2.00	1.00	0.00
			Cestoda	1.00	0.63	0.00	1.67	1.60	0.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00

collection	number of examined catfish	fork length (cm)	parasite	Prev-P1	Prev-P2	Prev-P3	MI-P1	MI-P2	MI-P3
17-Oct-10	15 (P1=6; P2=8; P3=1)	20.9─27.9 (24.67)	Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.13	0.00	0.00	1.00	0.00
21-Nov-10	20 (P1=6; P2=10; P3=4)	18.3─33.8 (24.80)	Myxozoa	0.83	0.90	0.50	1.60	1.00	1.00
			Monogenea	1.00	1.00	1.00	1.83	1.70	1.50
			Cestoda	0.83	0.90	0.25	1.80	2.22	2.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.10	0.00	0.00	1.00	0.00
			Copepoda	0.00	0.10	0.25	0.00	1.00	1.00
19-Jan-11	29 (P1=8; P2=16; P3=5)	20.0─32.0 (25.32)	Myxozoa	0.63	0.56	0.80	1.60	1.11	1.20
			Monogenea	1.00	0.88	1.00	2.13	1.64	2.00
			Cestoda	0.88	0.69	0.80	2.29	1.36	2.25
			Nematoda	0.00	0.00	0.25	0.00	0.00	1.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.00	0.06	0.00	0.00	1.00	0.00
25-Feb-11	26 (P1=14; P2=8; P3=4)	21.2─35.7 (26.83)	Myxozoa	0.43	0.63	0.25	1.00	1.00	1.00
			Monogenea	1.00	1.00	1.00	1.57	1.38	2.25
			Cestoda	1.00	1.00	0.75	1.71	2.25	2.00
			Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
			Unionidae	0.00	0.00	0.00	0.00	0.00	0.00
			Copepoda	0.07	0.00	0.25	2.00	0.00	1.00

Prev-: prevalence; MI: mean intensity; P1: pond 1; P2: pond 2; P3: pond 3.