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Research article

First report on parasitic infections of *Pangasius macronema* in Can Tho City, Vietnam

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Abstract

The study aimed to evaluated parasite infections of *Pangasius macronema* from January to December 2023. A total of 200 samples (including 100 farmed and 100 wild *Pangasius macronema*) were randomly collected from Can Tho city, Viet Nam. Samples were examined for clinical signs and fresh smears were prepared for parasite examination. Most of the analyzed fish were healthy, without any clinical signs. However, some exhibited distended abdomens and white spots on the liver. The results revealed eight parasite genera in *P. macronema*, including: *Apiosoma* sp., *Myxobolus* cysts, *Dactylogyrus* sp., *Epistylis* sp., *Ichthyonyctus* sp., Metacercariae of digenetic trematodes, *Protoopalina* sp. and *Trichodina* sp. Six genera were found on the gills and three in the intestine and liver. The composition, intensity and prevalence of parasites were generally higher in wild *P. macronema* compared to cultured *P. macronema*. In wild fish, *Trichodina* sp. had the highest prevalence, infecting 66.0% of gills with an intensity of 1-27 parasite fish^{-1}, while *Myxobolus* cysts had the lowest prevalence of 16.0% in the liver with an intensity of 1-6 cysts per fish. In cultured fish, *Trichodina* sp. also had the highest prevalence, infecting 47.0% of gills with an intensity of 2-19 parasite fish^{-1} and *Dactylogyrus* sp. had the lowest prevalence of 22.0% on the gills with an intensity of 1-7 parasite fish^{-1}. Generally, these findings reflect the relatively occurrence of parasites among the cultivated and wild *P. macronema*, confirming the necessary of strick measures to control the infections.

Keywords: Can Tho city, Ectoparasite, Endoparasite, *Pangasius macronema*, Viet Nam.

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INTRODUCTION

The Mekong Delta, with its favorable natural conditions, has significantly promoted the development of aquaculture, contributing substantially to the national economy. In recent years, while the farming of striped catfish and other freshwater fish has encountered certain challenges related to prices and diseases, the *Pangasius macronema* has emerged as a promising aquaculture species due to its fast growth rate and good tolerance to environmental conditions. The *P. macronema* is a native species commonly found in the freshwater Mekong River basin. In Vietnam, this species is highly valued for its firm, delicious meat and is often caught from the Mekong River with a relatively high market price. In recent years, *P. macronema* has attracted significant attention due to its easy rearing, high density culture, high yield and profitability. However, to date, there have been relatively few studies on this species within the Pangasiidae family in the Mekong Delta, including works by Yen, 1992; Khoa, 1993; Truong and Tran, 1993; Thuong, 2000; Duc, 2020; Tran Dong Phuong An, 2023; 2024. Particularly, the genera of *Trichodina* sp. (48.3%), *Epistilis* sp. (4.1%), *Myxobolus* sp. (5.2%), and *Thaparocleidus siamensis* (5.6%) were the common groups affected the skin and gills of striped catfish (*Pangasianodon hypophthalmus*) (Hoa et al., 2021). Moreover, six parasite species (including *Nyctotherus piscicola*, *Trichodina heterodentata*, *Ichthyophthirius multifiliis*, *Protoopalina* sp., *Hexamita* sp., and *Ancyrocephalus* sp.) were identified in the striped catfish and silver dollar (*Metynnis hypsauchen*), with the prevalence of parasite infection rate was 46.43% (65/140 fish) (Rahmati-Holasoo et al., 2023). Overall, the results of these studies mainly focused on describing species composition, biological and reproductive characteristics, and highlighting their importance in fisheries. Despite its high economic value, research on the health and diseases of this species remains limited, especially regarding parasitic pathogens.

The rapid development of aquaculture and the increase in intensive farming practices have led to an increase in disease outbreaks, with parasitic diseases being the most common. Parasitic diseases do not severely affect fish health. However, when infected in large numbers, they can cause slow growth and even mass mortality by creating conditions for the invasion of secondary bacterial, viral, and fungal pathogens, affecting production and food safety. Diseases caused by parasites belonging to the Protozoa and helminth phyla have been reported by many authors as causing significant losses in various Pangasiidae species worldwide (Hang, 2023b). However, in Vietnam, there have been no published studies on parasitic diseases in cultured *P. macronema*. Additionally, there is a lack of research on the occurrence of parasites in wild *P. macronema*. As aquaculture rapidly develops and farming environments become increasingly unfavorable, with disease outbreaks becoming more complex, understanding parasitic pathogens has become increasingly urgent.

To contribute to the knowledge base on *P. macronema* and to support farmers in improving production efficiency, this study aims to identify the parasitic pathogens in cultured *P. macronema* in Can Tho. The results of this study will provide the scientific basis for developing effective disease control measures, contributing to ensuring the quality of aquatic products and enhancing the economic value of aquaculture in the region.

MATERIALS AND METHODS

Collection and examination of samples

Cultured *P. macronema* samples (cultured fish) were randomly collected from aquaculture ponds in Can Tho (latitude from 9°55’08” to 10°19’38” North and from 105°13’38” to 105°50’35” East). A total of 200 *P. macronema* samples were collected and analyzed for parasites. Among them, ten fish were randomly

collected from each pond, and a total of 10 pond culture were sampled. Additionally, wild *P. macronema* samples (wild fish) were collected from fishermen in rivers and canals within Can Tho. Ten fish were randomly collected per sampling event, and a total of 10 sampling events were conducted. All collected samples were transported alive in separate plastic bag to the Laboratory of Aquatic Pathology at the College of Aquaculture and Fisheries, Can Tho University, Viet Nam. Fish were anesthetized by 0.1 ppm MS222 (Sigma-Aldrich, MO, USA) before sampling. The fish were euthanized by cervical dislocation. The protocol was also carried out in accordance with national guidelines on the protection and experimental animal welfare in Vietnam No. 79/2015/QH13. All fish samples were dissected as soon as possible after collection. Identification of fish specimens was carried out according to the Integrated Taxonomic Information System (ITIS). The total length (cm), and wet weight (g) of each fish were measured.

Samples analysis and parasitological identification

The methodology for parasitological examination was adapted from the studies conducted following Ky, 2007; Noga, 2010; Hang, 2023a. Ectoparasite analysis entailed the careful extraction of mucus from the body surface, followed by the preparation of fresh mounts for microscopic observation at magnifications ranging from 100X to 400X. A similar protocol was employed for endoparasite examination, where mucous samples were collected from: liver, gallbladder, the intestine and stomach. These samples were likewise prepared as fresh mounts and subjected to microscopic scrutiny at magnifications of 10X to 40X.

We assessed parasite infection levels using the methods of Margolis et al. 1982; Hang, 2023a, including: (1) infection prevalence, (2) mean infection intensity, (3) mean abundance, (4) Shannon diversity index and (5) Shannon equitability index.

The categorization of parasitic infections found in fish specimens hinges upon a foundational analysis of their morphological and structural characteristics, with the taxonomic classification of protozoan parasites adhering to the established methodologies delineated by Lom and Dyková, 1992; Robert, 2003; Ky, 2007; Noga, 2010; Woo and Bruno, 2011. Furthermore, the systematic classification of monogenean trematodes aligns with the frameworks proposed by Noga, 2010; Woo and Bruno, 2011. Whereas the categorization of digenean trematodes is informed by the research of Ky, 2007; Woo and Bruno, 2011.

The level of parasitic infestation, predicated upon the incidence and intensity of infection, was meticulously calculated and graphically represented utilizing the Microsoft Excel software.

RESULTS

Parasite composition in cultured and wild fish

The sampling process was conducted in cultured ponds and natural environments in Can Tho. Cultured fish samples had lengths ranging from 5.9-18.9 cm and weights from 10.2-52.3 g. Wild fish samples had lengths ranging from 5.3-17.8 cm and weights from 7.9-15.7 g. The number of samples and sample characteristics are summarized in the following Table 1.

Table 1 Information on cultured and wild fish

Information	Cultured fish	Wild fish
Sample number	100	100
Infected samples	88	99
Body length (cm)	15.1±2.1	11.1±2.9
Body weight (g)	27.3±9.1	11.0±2.0
Sign of pathology	No	No
Location of parasite in host	Gill, intestine	Gill, liver, intestine

A total of 200 samples were collected and analyzed, comprising 100 cultured fish samples and 100 wild fish samples. Most of the collected fish exhibited no external or internal pathological signs. Fish, obtained directly from aquaculture ponds or fishermen, displayed no signs of ulcers, hemorrhaging, or pallor. Internal organs showed no abnormal disease manifestations such as hemorrhaging, necrosis, or mucus. Some fish exhibited swollen abdomens, containing gas and livers with tiny, opaque, slightly raised white nodules on the liver surface (Figure 1 and Figure 2). Parasite examination results indicated that fish are commonly infected with parasites in organs such as gills, intestines and liver, with infection rates and intensities varying among parasite species.

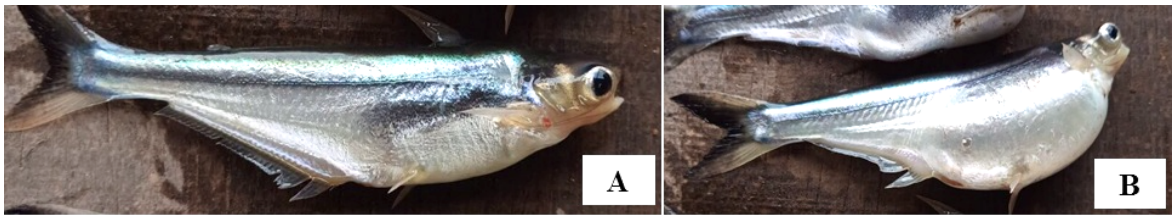

Figure 1 External clinical signs of fish samples. A healthy fish; B fish with a swollen abdomen

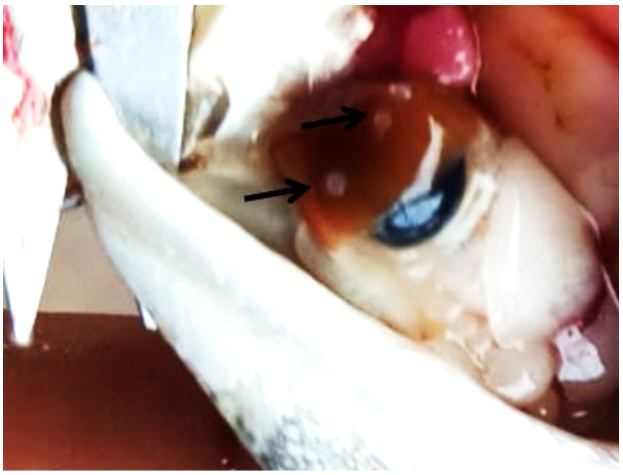

Figure 2 Fish liver with white spots (black arrow)

Parasite examination of the 200 fish samples identified eight parasite genera belonging to two groups. Endoparasites included three genera: *Myxobolus* cysts (Figure 3), *Ichthyonyctus* sp. and *Protoopalina* sp. (Figure 4). Ectoparasites included the following genera: *Apiosoma* sp., *Myxobolus* cysts, *Dactylogyrus* sp., *Epistylis* sp., Metacercaria and *Trichodina* sp. (Figure 5). Parasite composition and their respective locations are summarized in Table 2.

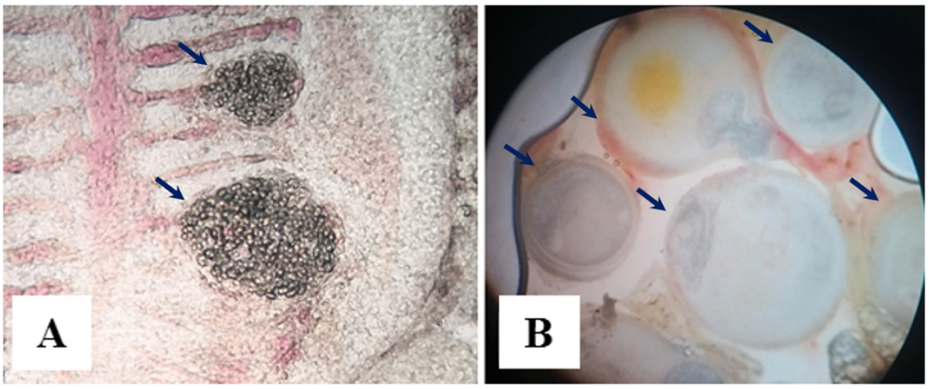

Figure 3 A *Myxobolus* spores in a cyst of fish gill (black arrow) and **B** Metacercaria larvaes of digenetic trematodes in fish liver (black arrow) (× 400).

Table 2 Parasite composition in cultured and wild fish

Parasite	Site of parasitism	
	Cultured fish	Wild fish
Apiosoma sp.	-	Gill
Myxobolus cysts	Gill	Liver
Dactylogyrus sp.	Gill	Gill
Epistylis sp.	Gill	Gill
Ichthyonyctus sp.	-	Intestine
Metacercaria	Gill	Gill
Protoopalina	Intestine	Intestine
Trichodina sp.	Gill	Gill

Note: (-): uninfected

The results summarized in Table 2 indicate that cultured fish in ponds are commonly infected with six parasite genera. Ectoparasites on the gills are the most prevalent. A total of five parasite genera were found on the gills of the fish, including: *Myxobolus* cysts, the monogenean *Dactylogyrus* sp., the ciliate *Epistylis* sp., Metacercaria larvae of digeneans, and the ciliate *Trichodina*. In contrast, only one genus of intestinal ciliate was found in the fish intestines, namely Protoopalina. From Table 3, it can be observed that cultured fish have low Shannon indices, with a Shannon diversity index of 0.44 and a Shannon equitability index of 0.65. This indicates low diversity and equitability of parasite genera within the cultured pond population. The parasite composition found on cultured fish is lower than that detected on wild-caught fish. Additionally, cultured fish samples generally exhibit few abnormal signs of disease. The fish typically have bright coloration and no abdominal swelling, with only a few exhibiting swollen abdomens when experiencing high ciliate infection intensities.

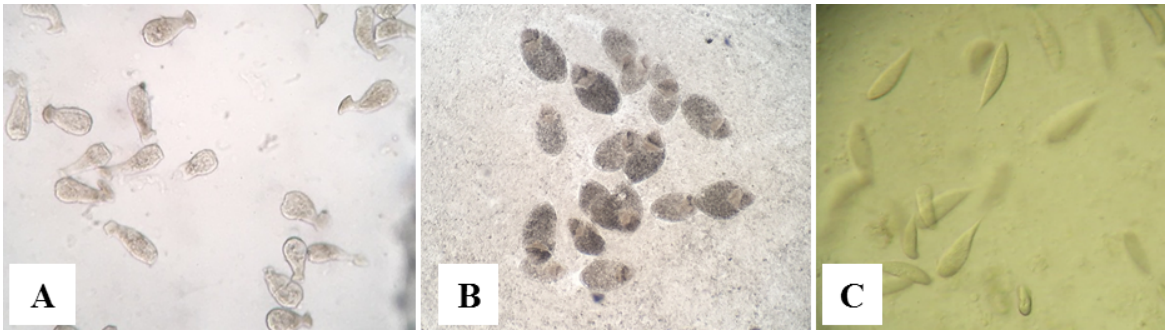

Figure 4 **A** *Apiosoma* sp., **B** *Ichthyonyctus* sp. and **C** *Protoopalina* sp. parasitizing fish (× 200)

For wild-caught fish samples, the results summarized in Table 2 reveal the presence of eight parasite genera. A greater number of parasite genera were found compared to cultured fish samples. Five ectoparasite genera were identified, including: the ciliate *Apiosoma* sp., the monogenean *Dactylogyrus* sp., the ciliate *Epistylis* sp., Metacercaria larvae of digeneans, and the ciliate *Trichodina*. From Table 3, it can be observed that wild fish have the highest Shannon indices, with a Shannon diversity index of 0.78 and a Shannon equitability index of 0.76. This indicates relatively high diversity and equitability of parasite genera within the wild population. All of these parasite genera were found infecting the gills of the fish. Unlike pond-sourced fish, wild-caught fish are commonly infected with *Myxobolus* cysts, an endoparasite found on the liver. These cysts typically form tiny, opaque white nodules on the liver surface. Additionally, these fish are also infected with two other intestinal ciliate genera: *Ichthyonyctus* sp. and *Protoopalina*.

Table 3 Shannon diversity indices of parasites infecting fish

Group of fish	The Shannon diversity index	The Shannon equitability index
Cultured fish	0.44	0.65
Wild fish	0.78	0.76

Most fish with high-intensity ciliate or *Myxobolus* cysts infections often exhibit pathological signs of abdominal swelling, containing significant gas within the abdominal cavity. This may be due to the effects of endoparasites damaging the intestinal mucosa and liver cells, thereby disrupting the fish's digestive function.

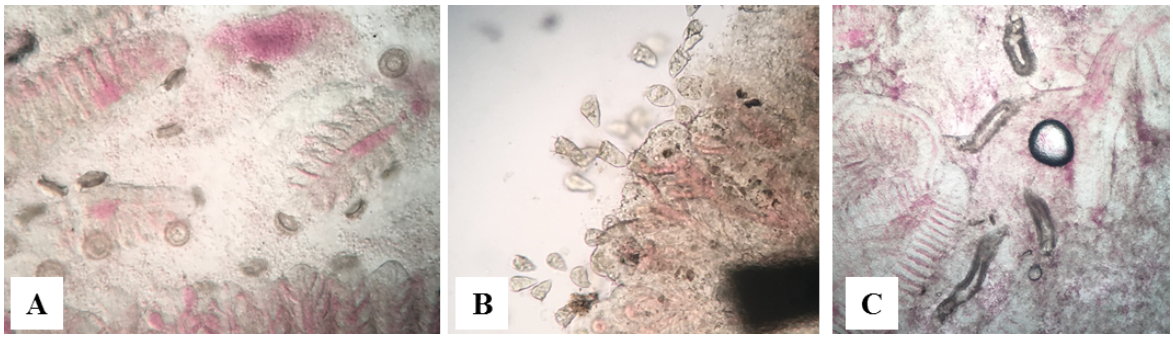

Figure 5 **A** *Trichodina*, **B** *Epistylis* sp. and **C** *Dactylogyrus* sp. on the gills of fish (× 200)

Parasitic infection prevalence and intensity in cultured and wild fish

The overall survey results demonstrated that 88 out of 100 cultured fish samples exhibited parasitic infections, resulting in an 88.0% infection rate. Conversely, wild fish presented a substantially higher infection rate, with 99 out of 100 samples (99.0%) affected. However, disparities exist in the infection rates and intensities among individual parasite species. Table 2 summarizes these findings, revealing a greater diversity of parasite species (8 species) in wild fish compared to farmed fish (6 species). Furthermore, Tables 4 and 5, along with Figure 6 and 7, illustrate higher infection rates, mean infection intensities, and mean abundances in wild fish relative to their cultured counterparts.

Table 4 Mean infection intensity (parasites fish^{-1}) of parasites on cultured and wild fish

Parasites	Mean infection intensity	
	Cultured fish	Wild fish
Apiosoma sp.	-	16.8
Myxobolus cysts	7.4	3.1
Dactylogyrus sp.	2.8	2.7
Epistylis sp.	5.4	10.8
Ichthyonyctus sp.	-	24.4
Metacercaria	1.8	3.1
Protoopalina	12.8	26.7
Trichodina sp.	8.9	12.8

Note: (-): uninfected

Among the ectoparasitic Protozoa on cultured fish, the genus *Trichodina* sp. exhibited the highest mean infection intensity compared to other genera, averaging approximately 8.9 parasites/fish on gill samples, with intensities ranging from 2-19 parasites/fish. Conversely, the mean abundance of *Trichodina* sp. was lower (4.2 parasites/fish). *Myxobolus* cysts followed, with a relatively high infection intensity of 7.4 cysts/fish and a mean abundance of 10.1 cysts/fish. *Epistylis* sp. was observed on fish gills with low infection intensities, ranging from 1-12 parasites/fish, while exhibiting a high mean abundance (10.1 parasites/fish). Additionally, several fish samples were found to be infected with Metacercaria larvae of digenetic trematodes on their gills, albeit with the lowest infection intensity, approximately 1.8 parasites/fish, ranging from 1-3 parasites/fish.

Table 5 Mean abundance (parasites fish^{-1}) of parasites on cultured and wild fish

Parasites	Mean Abundance	
	Cultured fish	Wild fish
Apiosoma sp.	-	6.4
Myxobolus cysts	10.1	1.1
Dactylogyrus sp.	2.3	6.8
Epistylis sp.	10.1	36.7
Ichthyonyctus sp.	-	28.8
Metacercaria sp.	1.0	2.1
Protoopalina sp.	12.4	35.3
Trichodina sp.	4.2	8.5

Note: (-): uninfected

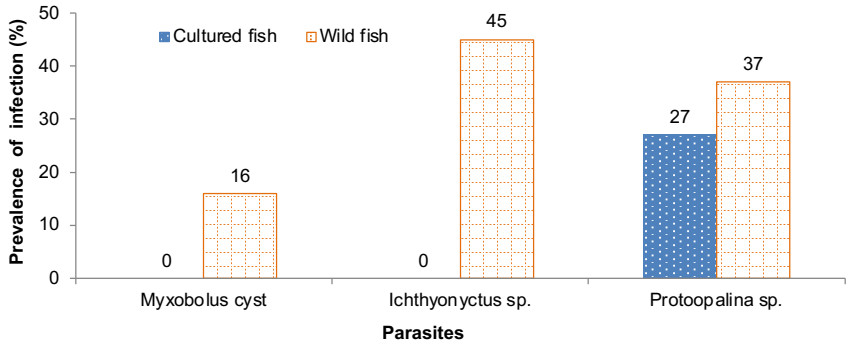

Figure 6 Prevalence of infection rate of ectoparasites genera on the gills of cultured and wild *P. macronema*

Dactylogyrus sp. infections in cultured fish ranged from 1-7 parasites fish-1, averaging 2.8 parasites fish-1, with a mean abundance of 2.3 parasites fish-1. Similarly, *Dactylogyrus sp.* infections in wild fish exhibited comparable low intensities, ranging from 1-8 parasites fish-1, averaging 2.7 parasites fish-1, with a mean abundance of 6.8 parasites fish-1. Moreover, the infection intensity of this ciliate was also quite high, averaging approximately 24.4 parasites fish-1, ranging from 5-52 parasites fish-1. The mean abundance also reached a high level, up to 28.8 parasites fish-1.

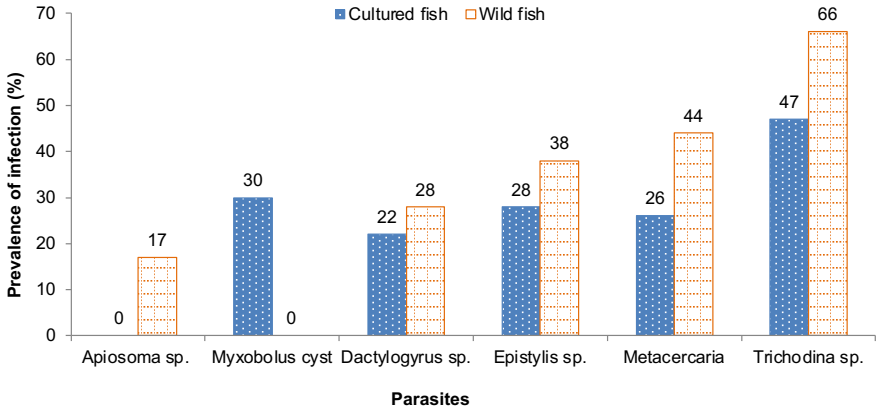

Figure 7 Prevalence of infection rate of endoparasite genera in cultured and wild *P. macronema*

DISCUSSION

Although fish provide a source of high quality protein with low cholesterol, they are easily susceptible to parasite infections. Those parasites are one the most infectious agents directly to affect aquaculture producton worldwide. The present study aimed to estimate the parasite infections as well as evaluated the diversity of zoonotic parasites in *P. macronema*. The results found that parasite analysis revealed relatively low infection intensities of most ectoparasitic genera on the gills of commercially cultured fish samples compared to wild fish.

Regarding the ectoparasitic monogenean *Dactylogyrus* sp., infection intensities were relatively low in both cultured and wild fish. Monogeneans, an oviparous group comprising various species, are frequently found infecting the gills

of wild striped catfish and other freshwater catfish species, parasitizing gill arches with higher intensities than those recorded in this study Hang (2008; 2017). Similar to other fish species, monogeneans are common ectoparasites affecting various catfish species of the order Siluriformes (Verma et al., 2017a). According to Verma et al. (2017a), over 379 monogenean species belonging to the order Dactylogyridea have been documented on catfish, with species of the genera *Thaparocleidus* and *Dactylogyrus* sp. being the most diverse, including over 18 species found on catfish hosts of the genus *Pangasius* (Pariselle et al., 2006; Šimková et al., 2013; Verma et al., 2017b). Reports by Salehah and Sharom (2019) documented infection rates up to 100% and infection intensities up to 106 parasites fish^{-1} in *Pangasius* samples collected in their study. In Vietnam, studies have primarily focused on hosts including striped snakehead (*Channa striata*), walking catfish (*Clarias batrachus*), whiskered catfish (*Hemibagrus wyckioides*) and striped catfish (*Pangasianodon hypophthalmus*) across various regions (Ky, 2007; Hang, 2012; Quyen et al., 2014; Hang, 2015; Hang, 2017). Unlike the ectoparasitic Protozoa, monogenean trematodes exhibit a relatively low infection rate in fish. They are typically found on the gills, with no infections observed on the skin. *Dactylogyrus* is a common monogenean genus found on the gills of fish. The infection rate of *Dactylogyrus* sp. on wild fish is approximately 28.0%, higher than the 22.0% observed in commercially cultured fish. The monogenean trematode *Dactylogyrus*, an oviparous species, commonly infects the skin and gills of various freshwater fish in the Mekong Delta. High infection rates of this parasite have caused mortality in cultured fish, including catfish, tilapia, marble goby, and striped snakehead, particularly in cage culture systems (Ky, 2007). Biu et al. (2014) reported a relatively low prevalence of *Dactylogyrus* sp. infections on the gills of cultured catfish in Nigeria, ranging from 5%-10% depending on fish size. Similarly, this study only documented the presence of *Dactylogyrus* sp. on catfish, with no other monogenean species observed. Pariselle (1999) documented several oviparous monogenean species belonging to the genus *Thaparocleidus* infecting wild fish throughout Southeast Asia. Lim et al. (2016) also reported a high prevalence of monogeneans on the gills of cultured red tilapia in Malaysia, with infection rates ranging from 20%-85% depending on the parasite species. Sang et al. (2021) documented, for the first time, oviparous monogeneans belonging to the genera *Thaparocleidus* and *Mizelleus* infecting wild fish samples in Dak Lak province. These genera belong to the same group as *Dactylogyrus* sp., which this study observed on *P. macronema* in the Mekong Delta.

In addition, in the wild fish samples, the ciliate *Ichthyonyctus* sp. was also found parasitizing in the intestines. This result is higher than the results of a recent study recording the ciliate infection intensity in wild striped catfish, with an infection intensity of only about 4-10 parasites fish^{-1} in the report by Quyen et al. (2014), but quite similar to the report by Hang (2017) when this study recorded an *Ichthyonyctus* sp. infection intensity of approximately 20.8 parasites fish^{-1}. Besides, the wild fish samples were also found to be infected with many *Myxobolus* cysts parasitizing on the fish's liver. They parasitize with a relatively low infection intensity, averaging approximately 3.1 cysts fish^{-1}, ranging from 1-6 cysts fish^{-1}. This mean infection intensity is lower than the mean infection intensity recorded on the gills of commercially cultured fish. Similarly, the mean abundance was 1.1 parasites fish^{-1}, significantly lower than the mean abundance recorded on the gills of commercially cultured fish. Similar to previous studies, the results of this study also recorded that gills are still the organ most commonly found to be infected with Protozoa parasites. However, the parasite infection rate in cultured fish often fluctuates lower than the infection rate in wild fish. Specifically, the ciliate *Apiosoma* sp. was only found to infect wild fish, not cultured fish, with the lowest infection rate among the parasite groups, fluctuating around 17.0%. Conversely, *Myxobolus* cysts were found to infect the gills of cultured fish and not wild fish, with an infection rate fluctuating around 30.0%. *Epistylis* sp. infected the gills of cultured and wild fish, with a higher rate than *Apiosoma* sp., with infection rates of 28.0% and 38.0%,

respectively. The skin of fish was not recorded as infected with parasites. This may be because fish belong to the catfish family, with a layer of mucus covering the outer skin for protection, so parasites do not have favorable conditions to attach and parasitize. Besides, among the four ectoparasites Protozoa genera on fish gills, the ciliate *Trichodina* sp. often parasitizes with the highest infection rate compared to other genera. The infection rate of *Trichodina* sp. on wild fish was the highest (66.0%) and higher than that of commercially cultured fish in ponds (47.0%).

In addition, *Myxobolus* cysts were observed parasitizing the liver of wild fish with a relatively low infection rate of approximately 16.0%. Diseases caused by Myxozoa (including *Myxobolus*, *Henneguya* and *Thelohanellus*) have caused significant damage to freshwater cultured fish during the fingerling stage (Ky, 2007; Molnár et al., 2019). Myxozoa parasitize over 30 freshwater fish species in Vietnam, such as pangasius fish, carp, grass carp, giant gourami and climbing perch (Ky, 2007; Hang, 2012; Thanh, 2014). The disease can be found in fish farming areas in the North, Central, Central Highlands, and Southern regions. The infection rate of Myxozoa in some fish species is quite high and has caused disease outbreaks leading to mass fish deaths. Similar to the study's findings, Myxozoa commonly parasitize and form cysts in the gills, internal organs such as the mesentery, liver, kidneys, bile ducts and intestinal walls. When parasitizing, Myxozoa obstructs oxygen exchange during respiration and nutrient absorption and metabolism in the digestive tract. Giant gourami fingerlings infected with *Myxobolus* sp. in the gills exhibit bubbling, hindering respiration and leading to mass mortality during farming (Hang, 2012). A study by Quyen et al. (2014) also recorded two species of *Myxobolus* sp. parasitizing striped catfish.

According to Molnár et al. (2019), Myxosporea parasites, belonging to the *Myxozoa phylum*, commonly infect various aquatic species globally. Characterized by their diverse nature, these organisms typically exhibit pear-shaped spores containing one or two equal polar capsules with two coiled polar filaments inside, while the posterior shell can elongate into a slender tail. *Myxobolus* spores frequently infect freshwater aquatic organisms such as snakeheads, cyprinids, catfish, and tilapia. The morphological findings of this study align with the descriptions provided by (Robert, 2003; Theerawoot, 2008; Molnár et al., 2019).

In addition to *Myxobolus*, *Trichodina* sp. parasites are also commonly found on fish gills. Among the five ectoparasite genera, *Trichodina* sp. exhibits the highest infection rate. According to Hoa et al. (2004) and Molnar et al. (2019), these mobile ciliates are widely distributed and affect various fish species, including carp, grass carp, silver carp, bighead carp and pangasius fish. Furthermore, *Trichodina* sp. infections have been documented in several Clarias catfish species, including *C. gariepinus, C. macrocephalus* and *C. batrachus*, as well as in tilapia species such as Nile tilapia and red tilapia, with infection rates ranging from 10-26% (Theerawoot, 2008; Woranan thakij and Maneepitaksanti, 2014; Mumba, 2015; Molnár et al., 2019). This study's morphological observations are consistent with the descriptions by Mumba (2015) and Molnár et al. (2019). Trichodina, when viewed laterally, resembles a bell, while its ventral side appears disc-like. Observed ventrally, *Trichodina* sp. possesses a large adhesive disc with a denticulate ring. This ring comprises numerous closely arranged denticles, forming a circular pattern.

For the endoparasite group, the study detected the ciliate *Protoopalina* sp. parasitizing with a relatively low intensity in the intestines of commercially cultured fish, with an infection intensity reaching 12.8 parasites fish^{-1}, ranging from 5-23 parasites fish^{-1} in most intestinal fluid samples. The infection intensity of *Protoopalina* sp. in the intestines of wild fish was higher compared to commercially cultured fish. Accordingly, the mean infection intensity was more than double, with 27.7 parasites fish^{-1}, ranging from 5-65 parasites fish^{-1}. Similarly, the mean abundance of *Protoopalina* sp. in the intestines of wild fish was also higher compared to commercially cultured fish, at 35.3 parasites fish^{-1} and 12.4 parasites fish^{-1}, respectively.

The reports by Ky (2007), Molnár et al. (2019) suggest that the protozoan group Protozoa is a very common ectoparasite group on most cultured fish species in Vietnam, especially catfish species. Therefore, the recorded research results are also quite consistent with the above observations. For cultured fish in ponds, three Protozoa genera were recorded, including: *Myxobolus* cysts, *Epistylis* sp. and *Trichodina*. For wild fish, the number of parasitic genera was higher, including: *Apiosoma* sp., *Myxobolus* cysts, *Epistylis* sp. and *Trichodina*. According to Hang (2009) and Molnár et al. (2019) the ciliates *Epistylis* sp. and *Apiosoma* sp. are protozoans that obtain nutrients by filtering food particles from the surrounding water. They attach to fish as a substrate without deriving nutrients from the host, but their presence can hinder respiration, growth and activity. The analysis revealed a higher prevalence of this ciliate infections on the gills compared to previous studies. Reported infection rates on gills are typically low, around 8-10%, while skin infections range from 12-15%, depending on the fish's living conditions (Biu et al., 2014; Mahsol et al., 2014; Mumba, 2015; Molnár et al., 2019).

Unlike the ectoparasitic Protozoa group or monogenean trematodes, digenean trematodes parasitize fish with a considerably high infection rate. They were commonly found parasitizing the gills of fish in the Metacercaria larval stage, with no infections observed on the fish skin. The Metacercaria larvae of digenean trematodes on the gills of wild fish exhibit an infection rate fluctuating around 44.0%, higher than the 26.0% infection rate observed in commercially cultured fish. Synthesized research results indicate that Metacercaria larvae of digenean trematodes infect various fish species. Infection rates and intensities vary depending on the fish species and geographical location. Numerous freshwater fish species have been documented with digenean trematode larval infections, primarily concentrated in freshwater fish species. The recorded results reveal high infection rates of digenean trematode groups such as: *Clonorchis sinensis, Haplorchis pumilio, H. taichui, H. yokogawai, Centrocestus formosanus, Stellantchasmus falcatus, Procerovum varium* and *Echinochasmus japonicus* (Van De et al., 2007; Hung et al., 2015; Doanh and Nawa, 2016). Similar to the study's findings, Metacecaria larvae of many of these digenean trematode species have also been detected in striped catfish and various other cultured freshwater fish species, including grass carp, climbing perch, tilapia, walking catfish and Indian carp (Quyen et al., 2012; Hang, 2020). The research by Quyen et al. (2012) also suggests that fish fins and gills exhibit very high larval infection rates, reaching up to 63.23%; these are initially ectoparasitic larvae, subsequently penetrating deeper into the muscles and establishing long-term parasitism in the muscles under suitable conditions. Furthermore, the research by Binh et al. (2014) also identified three metacercariae species on pangasius catfish and documented the presence of metacercaria according to size and geographical area. The highest infection rate for *H. taichui* (43.47%), primarily concentrated in fish in Can Tho, is relatively high compared to previous studies. Recently, reports by Hang (2020) also documented a relatively high metacercariae infection rate in striped catfish, similar to the study's findings, with infection rates typically ranging from 30.7-32.1% depending on the season.

Microscopic observation results indicate that the endoparasites infecting the fish comprise three genera: *Myxobolus* cysts, *Ichthyonyctus* sp. and *Protoopalina*. Notably, the ciliate genus *Ichthyonyctus* sp. infects only the intestines of wild fish. Conversely, the *Protoopalina* sp. genus is observed infecting the intestines of both fish groups. The findings reveal that the ciliate *Ichthyonyctus* sp. typically exhibits the highest infection rate among the 100 analyzed wild fish samples. Accordingly, the average infection rate is approximately 45.0% across the sampling periods. Subsequently, the ciliate genus *Protoopalina* sp. exhibits an infection rate fluctuating around 37.0% in wild fish, higher than the 27.0% infection rate in commercially cultured fish. The ciliates *Protoopalina* sp. and *Ichthyonyctus* sp. are commonly observed infecting *Pangasius bocourti* and other catfish species (Ky, 2007). The presence of the ciliate groups *Protoopalina* sp. and *Ichthyonyctus* sp. is

observed in most intestinal segments during sample examination, but they are primarily concentrated in the intestinal segments containing food.

According to Hoa (2004), although ciliates parasitize in large numbers, these two species do not harm the host; they only exacerbate illness when the host suffers from enteritis. According to (Arthur, 2006; Ky, 2007), ciliates parasitize the posterior intestine of *P. bocourti* of all ages, but the infection rate increases with fish size. The parasites reside between the folds of the intestinal mucosa, deriving nutrients from the host's waste products. When parasitizing alone, this parasite genus, despite its large numbers, does not cause harm, but when the host is afflicted with enteritis caused by bacteria, *Protoopalina* sp. invades in large numbers, rapidly worsening the condition. Observations indicate that *Protoopalina* sp. can damage intestinal epithelial cells, causing localized concavities and potentially damaging the epithelial cell layer of the intestinal wall (Robert, 2003; Noga, 2010; Hang, 2023b).

From the synthesized results, it can be observed that the parasite composition, infection intensity and infection rate of parasites in wild fish are generally higher compared to commercially cultured fish. This could be attributed to disease prevention measures such as regular deworming medication, pond water treatment, which have significantly contributed to preventing parasite infestation in cultured fish. Furthermore, the feed for cultured fish is primarily industrial feed, ensuring greater safety compared to the natural diet of wild fish, which are omnivorous. This consequently reduces the infection rate and intensity of parasites in commercially cultured fish. The study highlighted that *P. macronema* were susceptible to a variety of ectoparasites and endoparasite that might influenced by the climate change, environment, management, and biological factors. Continued research is essential to develop specific monitoring methods to improve the fish health as well as enhance the sustainability in *P. macronema* aquaculture.

CONCLUSIONS

The analysis identified eight parasite genera parasitizing fish, including: *Apiosoma* sp., *Myxobolus* cysts, *Dactylogyrus* sp., *Epistylis* sp., *Ichthyonyctus* sp., Metacercaria larvae of digenetic trematodes, *Protoopalina* sp. and *Trichodina*. Among these, six genera parasitize the gills, and three genera parasitize the intestines and liver. The parasite composition, infection intensity, and infection rate are generally higher in wild fish compared to commercially cultured ones. In wild fish, *Trichodina* sp. exhibited the highest infection rate, infecting 66.0% of the gills, with an infection intensity of 1-27 parasites fish^{-1}, while *Myxobolus* cysts had the lowest infection rate at 16.0% in the liver, with an infection intensity of 1-6 cysts fish^{-1}. In commercially cultured fish, *Trichodina* sp. had the highest infection rate at 47.0% in the gills, with an infection intensity of 2-19 parasites fish^{-1}, while the monogenean trematode *Dactylogyrus* sp. had the lowest infection rate at 22.0% in the gills, with an infection intensity of 1-7 parasites fish^{-1}.

AUTHOR CONTRIBUTION

NTTH: experimental design, sample collection and analysis, manuscript writing and editing, summarized the results, literature review, discussion. TQN: sample analysis, manuscript writing and editing, summarized the results, literature review, discussion.

CONFLIT OF INTEREST STATEMENTS

The authors declare that they have no conflict of interest.

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