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Short Communication

Occurrence of *Kudoa* sp. in the skeletal musculature of *Plagioscion squamosissimus* (Heckel, 1840) from the Amazon estuary, Brazil

Ocorrência de *Kudoa* sp. na musculatura esquelética de *Plagioscion squamosissimus* (Heckel, 1840) proveniente do estuário amazônico, Brasil

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Abstract

Mosqueiro Island, located in Guajará Bay, a district of Belém, belongs to the Amazon estuary and is characterized by intense fishing activity. *Plagioscion squamosissimus* (Heckel, 1840), popularly known as "pescada branca", is one of the fish species composing the local ichthyofauna and is commercialized on the island. This species is parasitized by myxozoans of the genus *Kudoa* Meglitsch, 1947, endoparasites of the phylum Cnidaria with tropism for skeletal muscle that compromise fish flesh quality and commercial value. This study aimed to characterize the histopathological changes caused by *Kudoa* sp. in *P. squamosissimus* from Mosqueiro Island. Twenty specimens were obtained dead from artisanal fishermen and necropsied at the Laboratory of Morpho-Molecular Integration and Technologies (LIMT), Federal Rural University of the Amazon (UFRA) for necropsy. Infected tissues were fixed in Davidson's solution for histological processing. Of the 20 specimens examined, 8 (40%) were infected with *Kudoa* sp. in the epaxial skeletal musculature. No macroscopic lesions were observed, although progressive muscle softening (myoliquefaction) was evident during the fish necropsy. Histopathology revealed multifocal necrotic lesions, intramuscular and intermuscular pseudocysts containing myxospores, and connective tissue deposition consistent with advanced infection. These findings expand the knowledge of *Kudoa* sp. infecting *P. squamosissimus* and its ichthyoparasitism in the Amazon region.

Keywords: Pescada branca, myxozoans, Mosqueiro Island, ichthyoparasitism.

Resumo

A ilha de Mosqueiro, inserida na Baía do Guajará, distrito de Belém, pertence ao estuário amazônico e é caracterizada por intensa atividade pesqueira. O *Plagioscion squamosissimus* (Heckel, 1840), popularmente conhecido como "pescada-branca", é uma das espécies que compõem a ictiofauna local e é comercializado na ilha. Essa espécie é parasitada por mixozoários do gênero *Kudoa* Meglitsch, 1947, endoparasitos do filo Cnidaria com tropismo muscular, comprometendo a qualidade e o valor comercial do pescado. O objetivo deste estudo foi caracterizar as alterações histopatológicas causadas por *Kudoa* sp. em *P. squamosissimus* da ilha de Mosqueiro. Foram obtidos 20 espécimes mortos de pescadores artesanais e necropsiados no Laboratório de Integração Morfo-molecular e Tecnologias (LIMT) da Universidade Federal

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Rural da Amazônia (UFRA). Os tecidos infectados foram fixados em solução de Davidson para processamento histológico. Dos 20 espécimes examinados, 8 (40%) apresentaram infecção por *Kudoa* sp. na musculatura epiaxial. Não foram observadas lesões macroscópicas; porém, houve amolecimento progressivo da musculatura (mioliquefação) durante a necropsia. A histopatologia revelou lesões necróticas multifocais, pseudocistos intramusculares e intermusculares contendo mixósporos e deposição de tecido conjuntivo compatível com infecção avançada. Esses achados ampliam o conhecimento sobre *Kudoa* sp. em *P. squamosissimus* e seu ictioparasitismo na região amazônica.

Palavras-chave: Pescada branca, mixozoários, Mosqueiro, ictioparasitismo.

Introduction

Plagioscion squamosissimus (Heckel, 1840) belongs to the order Perciformes and the family Sciaenidae. It is a benthopelagic, sedentary fish with crepuscular and nocturnal habits that reproduces throughout the year, with peak spawning occurring during the flood season (Camargo & Lima-Júnior, 2007). Its diet is primarily carnivorous, consisting mainly of crustaceans and aquatic insects during the juvenile stage, and shifting to fish and shrimp in adulthood (Oliveira et al., 2015; Lima et al., 2017).

In 2024, a total catch volume of 75.15 t of *P. squamosissimus* was recorded, with 68.39 t (91%) originating from the State of Pará, of which approximately 9.03 t were exported (Brasil, 2025). Although fishery resources are abundant in the Amazon region, their availability may be compromised by several factors, particularly parasitic infections, whose transmission is favored by the unique characteristics of the aquatic environment. Among these parasitic agents, myxozoans are one of the most diverse groups affecting the health and productivity of both farmed and wild fish populations worldwide (Banu & Rathinam, 2023).

Myxozoans are a group of endoparasites belonging to the phylum Cnidaria that infect both marine and freshwater invertebrates and vertebrates (Kent et al., 2001). Their life cycle is indirect and comprises two developmental phases: one occurring in fish (intermediate host) and the other in annelids (definitive host), completing a two-host life cycle (Americus et al., 2020). Their infection may occur through either the oral (annelids) or parenteral (fish) route (Grabner & Fiala, 2025). The genus *Kudoa* Meglitsch, 1947 is a group of parasites belonging to the order Multivalvulida, characterized by possessing four or more capsular valves, each with one polar capsule (Velasco et al., 2022).

Among mixozoans, species of the genus *Kudoa* cause lesions in the somatic musculature of fish through the action of proteolytic enzymes, which are produced to soften the host's muscle tissue and facilitate parasite development (Andrada et al., 2005; Whipps & Kent, 2006). Infection may compromise the commercial value of affected fish, particularly when macroscopic cysts are present, in addition to the milky-white appearance of the infected flesh, which makes it unappealing and unsuitable for commercialization (Whipps & Kent, 2006). If consumed, the meat of fish infected with *Kudoa* speciens may cause allergic reactions or gastrointestinal illness (Kawai et al., 2012).

In Brazil, some *Kudoa* species have been described, for example: *Kudoa orbicularis* Azevedo, Rocha, Matos, Oliveira, Matos, Al-Quraishy & Casal, 2016, *Kudoa aequidens* Casal, Matos, Matos & Azevedo, 2008, *Kudoa amazonica* Velasco, Sindeaux-Neto, Videira, de Cássia Silva do Nascimento, Gonçalves & Matos, 2019, *Kudoa yasai* Cardim, Araújo-Neto, da Silva, Hamoy, Matos & Abrunhosa, 2020, *Kudoa viseuensis* Monteiro, da Silva, Sanches, Hamoy & Matos, 2019, *Kudoa ajurutellus* Araújo Neto, Cardim, da Silva, Hamoy, Matos & Abrunhosa, 2020, *Kudoa eugerres* Casal, Soares, Rocha, Silva, Santos, Nascimento, Oliveira & Azevedo, 2019, *Kudoa rousseauxii* Velasco, Eduard, Sindeaux-Neto, Dias, Matos & Gonçalves, 2022 and *Kudoa benignoi* Eduard, da Silva, de Souza Ferreira, Sindeaux-Neto, Velasco & Gonçalves, 2026. Given the artisanal and subsistence nature of local fishing activities, understanding pathogenic agents affecting the health and quality of captured fish is of direct relevance to the Mosqueiro community. Therefore, the present study aimed to investigate myxozoan infections in *P. squamosissimus* from Mosqueiro Island using histological techniques, thereby contributing to the knowledge of microparasites infecting Amazonian aquatic organisms.

Material and Methods

Fish sampling and parasitological analysis

The study was conducted on Mosqueiro Island (1°04′ S, 48°29′ W), a district of Belém, Pará, Brazil. A total of 20 specimens of *P. squamosissimus* were obtained dead from artisanal fishermen between November 2024 and March 2026. The specimens were selected from the same point of origin, the Cajueiro bridge fish landing site, at different

periods. The dead specimens were stored in insulated box containing ice and transported to the Laboratory of Morpho-Molecular Integration and Technologies (LIMT) at the Federal Rural University of the Amazon (UFRA), located in the metropolitan region of Belém, Pará, where necropsy and histological processing were performed.

Only specimens with intact skeletal musculature and no macroscopic signs of advanced autolysis were included in the study. In the laboratory, biometric measurements were recorded for each fish, including standard length (measured from the anterior region of the head to the end of the caudal peduncle) and body weight, using a ruler and a digital balance, respectively. Necropsy was performed using standard surgical instruments, glass slides, and coverslips, with the aid of a Zeiss Stemi® stereomicroscope and a Zeiss Primo Star® light microscope.

Following biometric measurements, the specimens underwent external examination, including the tegument, fins, oral cavity, eyes, and gills. Subsequently, the peritoneal cavity was opened to allow a systematic examination of the coelomic cavity. The internal organs were then examined, including the heart, liver, stomach, intestine, gallbladder, and urogenital system, with particular attention given to the kidneys, gonads, and urinary bladder, followed by examination of the skeletal musculature in all specimens.

During the examination, tissue fragments of the musculature showing morphological alterations suggestive of parasitic infection, such as cysts, myoliquefation or granulomatous lesions, were collected, squashed and verified by direct microscopy to confirm the presence of spores.

Morphological analysis

To further characterize the parasite detected during the initial parasitological examination, spore morphometry was subsequently performed as described below. A total of 20 myxospores from the same infected host were measured under light microscopy using the ImageJ software (Schneider et al., 2012) to obtain the main morphometric parameters, including spore length, width, and thickness, as well as the length and width of the polar capsules. All measurements and their corresponding mean values were expressed in micrometers (µm), following the methodology described by Lom & Dyková (2006), which also served as a reference for the analysis of spore morphology and the identification of the genus. Data are expressed as mean values followed by the range (minimum-maximum) in parentheses; given the descriptive nature of the study, no inferential statistical analyses were performed.

Histopathological processing

Tissue fragments containing microparasites were fixed in Davidson's solution for 24 h and subsequently preserved in 70% ethanol. The samples were then dehydrated through a graded ethanol series (70-100%), cleared in two changes of xylene, and infiltred in paraffin.

Following paraffin infiltration, the samples were embedded in more paraffin using a MICROM® EC350 embedding station, producing paraffin blocks that were sectioned at a thickness of 5µm with a MICROM® HM315 microtome. The sections were subsequently stained with Hematoxylin and Eosin (H&E), May–Grünwald–Giemsa (MGG) for cellular differentiation of spores and as a complement to H&E, and Gutierrez's trichrome for differentiation between muscle tissue and connective tissue, following the protocol described by Luna (1968).

Results

Of the 20 necropsied specimens, 8 (40%) were infected with *Kudoa* sp., with the parasites located in the epaxial region of the skeletal musculature. A total of seven necropsies were performed, with infected specimens identified in five of them: one in the first necropsy, two in the third, one in the fourth, one in the fifth, and three in the sixth. The *Kudoa*-infected *P. squamosissimus* specimens had a mean length of 24.83 ± 3.66 cm (n = 8) and a mean body weight of 166.63 ± 80.45 g (n = 8). In comparison, non-infected specimens had a mean length of 25.16 ± 1.55 cm (n = 9) and a mean body weight of 177.25 ± 41.86 g (n = 8) (Table 1).

Morphological analysis

Subquadrate spores possessing four polar capsules, characteristic of the genus *Kudoa*, were observed and measured (Table 2). The myxospores measured 6.5 (6.4-6.6) µm in length, 10.1 (9.1-10.5) µm in width, and 8.6 (7.5-9.6) µm in thickness. The polar capsules measured 4.1 (3.9-4.6) µm in length and 1.7 (1.6-1.8) µm in width.

Table 1. Biometric data and parasitological status of *P. squamosissimus* specimens examined for *Kudoa* sp. infection, highlighting the infected specimens.

Specimen	Length	Weight	Parasitological status
1	23.5	200	Negative
2	27	209	Negative
3	25.5	155	Negative
4	**24**	**156**	**Positive**
5	24.4	155	Negative
6	24.5	156	Negative
7	26	212	Negative
8	**24**	**153**	**Positive**
9	**23**	**142**	**Positive**
10	27	228	Negative
11	**25.5**	**155**	**Positive**
12	22.5	103	Negative
13	**33**	**356**	**Positive**
14	26	nd	Negative
15	**20.9**	**89**	**Positive**
16	**22.5**	**118**	**Positive**
17	**25.7**	**164**	**Positive**
18	nd	nd	Negative
19	nd	nd	Negative
20	nd	nd	Negative

Length and weight are expressed in centimeters (cm) and grams (g), respectively. nd: not determined.

Histopathology

In addition to the morphometric features described above, histopathological examination was performed to characterize the tissue-level changes associated with *Kudoa* sp. infection. During necropsy, no macroscopic cysts were observed in the skeletal musculature of *P. squamosissimus*. However, progressive softening of the muscle tissue was evident, with its texture changing from a firm and compact appearance to a slightly gelatinous consistency. This finding is consistent with previous reports describing *Kudoa* spp. infections and the post-mortem myoliquefaction associated with these parasites (Whipps & Kent, 2006). These macroscopic and textural changes were further investigated through histological examination, described below.

Histopathological analysis revealed multifocal necrotic lesions in the skeletal musculature of *P. squamosissimus* (Figures 1C-F), including areas of advanced muscle degeneration and fiber disruption (Figure 1C). Two types of parasite-associated structures were identified: Intramuscular pseudocysts (Figures 1C and 1D) and intermuscular structures containing spores (Figure 1F).

Degeneration and necrosis were most pronounced around the intramuscular pseudocysts, with loss of normal muscle fiber architecture, adjacent areas showing either absence of myonuclei or pyknotic nuclei, findings consistent with chronic tissue compression and reduced nutrient supply. In contrast, the intermuscular structures were associated with focal deposition of connective tissue with a cicatricial aspect, a finding compatible with more advanced stages of *Kudoa* sp. infection (Figure 1F).

Discussion

The prevalence of 40% differs from that reported in most previous studies on the genus *Kudoa* in the Amazon region but is comparable to the prevalence of *K. orbicularis* (47.6%) and *K. aequidens* (35.7%) reported by Azevedo et al. (2016) and Casal et al. (2008), respectively.

With respect to morphometric comparisons with other Amazonian *Kudoa* species, the *Kudoa* sp. identified in the present study exhibited spore measurements most similar to those of *K. ajurutellus*, followed by *K. rousseauxii*,

Table 2. Morphometry of different species of the genus *Kudoa* spp., highlighting the Myxospore Length (ML), Myxospore Width (MW), Spore Thickness (ST), Polar Capsule Length (PCL) and Polar Capsule Width (PCW), in micrometers (µm).

Species	ML	MW	ST	PCL	PCW	Shape	Host/Site of infection	Location	Author
Kudoa sp.	6.5 (6.4 – 6.6)	10.1 (9.1 – 10.5)	8.6 (7.5-9.6)	4.1 (3.9-4.6)	1.7 (1.6-1.8)	Subquadrate	*Plagioscion squamosissimus*/ Muscle	Mosqueiro Island	Present study
Kudoa sp.	5.6 (5.6-5.9)	5.6 (5.4-5.6)	-	1.8 (1.4-2.0)	1.0 (0.9-1.1)	Subquadrate	*Plagioscion squamosissimus*	Outeiro Island	Oliveira et al. (2015)
K. benignoi	5.6 (5.3-5.8)	7.5 (6.5-7.8)	5.5 (4.2-5.8)	2.5 (2.3-2.8)	1.5 (1.2-1.9)	Subquadrate	*Batrachoides surinamensis*/Swim bladder	Curuçá	Eduard et al. (2026)
K. viseuensis	7.2 (6.7-7.4)	5.2 (5.1-5.4)	-	2.7 (2.4-2.9)	1.3 (1.1-1.4)	Squared	*Batrachoides surinamensis*/Muscle	Viseu	Monteiro et al. (2019)
K. ajurutellus	6.6 (6.0-7.4)	8.2 (7.9-9.6)	-	3.5 (2.9-4.0)	1.9 (1.5-2.1)	Squared	*Aspistor quadriscutis*/ Skeletal muscle	Bragança	Araújo et al. (2020)
K. orbicularis	4.3 (3.6-5.0)	5.1 (4.2-5.8)	-	2.1 (1.7-2.6)	1.3 (0.9-1.7)	Subquadrate	*Chaetobranchopsis orbicularis*/Muscle	Marajó Island	Azevedo et al. (2016)
K. rousseauxii	5.4 (4.2-6.7)	8.4 (6.8-9.6)	5.3 (4.0-6.9)	1.8 (1.4-2.0)	1.3 (1.2-1.4)	Squared	*Brachyplatystoma rousseauxii*/Skeletal muscles	Mosqueiro Island	Velasco et al. (2022)
K. ocellatus	4.6 (4.5-4.8)	6.6 (6.2-7.2)	-	2.0 (1.8-2.2)	1.5 (1.3-1.8)	Subquadrate	*Astronotus ocelattus*/ Skeletal muscles	Marajó Island	Silva et al. (2022)
K. aequidens	3.2 (2.9-3.5)	6.8 (6.2-7.1)	-	2.2 (2.0-2.6)	1.2 (1.1-1.5)	Squared	*Aequidens plagiozonatus*/Skeletal muscles	Peixe Boi	Casal et al. (2008)
K. yasai	6.9 (5.6-7.2)	8.2 (7.7-8.6)	5.5 (4.2-6.0)	1.8 (1.3-2.3)	1.4 (1.0-1.8)	Squared	*Macrodon ancylodon*/ Skeletal muscles	Bragança	Cardim et al. (2020)
K. amazonica	5.6 (5.0-5.9)	6.7 (6.3-7.4)	7.5 (7.0-7.9)	1.8 (1.5-2.0)	1.2 (0.9-1.6)	Subquadrate	*Hypophthalmus marginatus*/ Muscle layer of the esophagus	Tocantins River	Velasco et al. (2019)

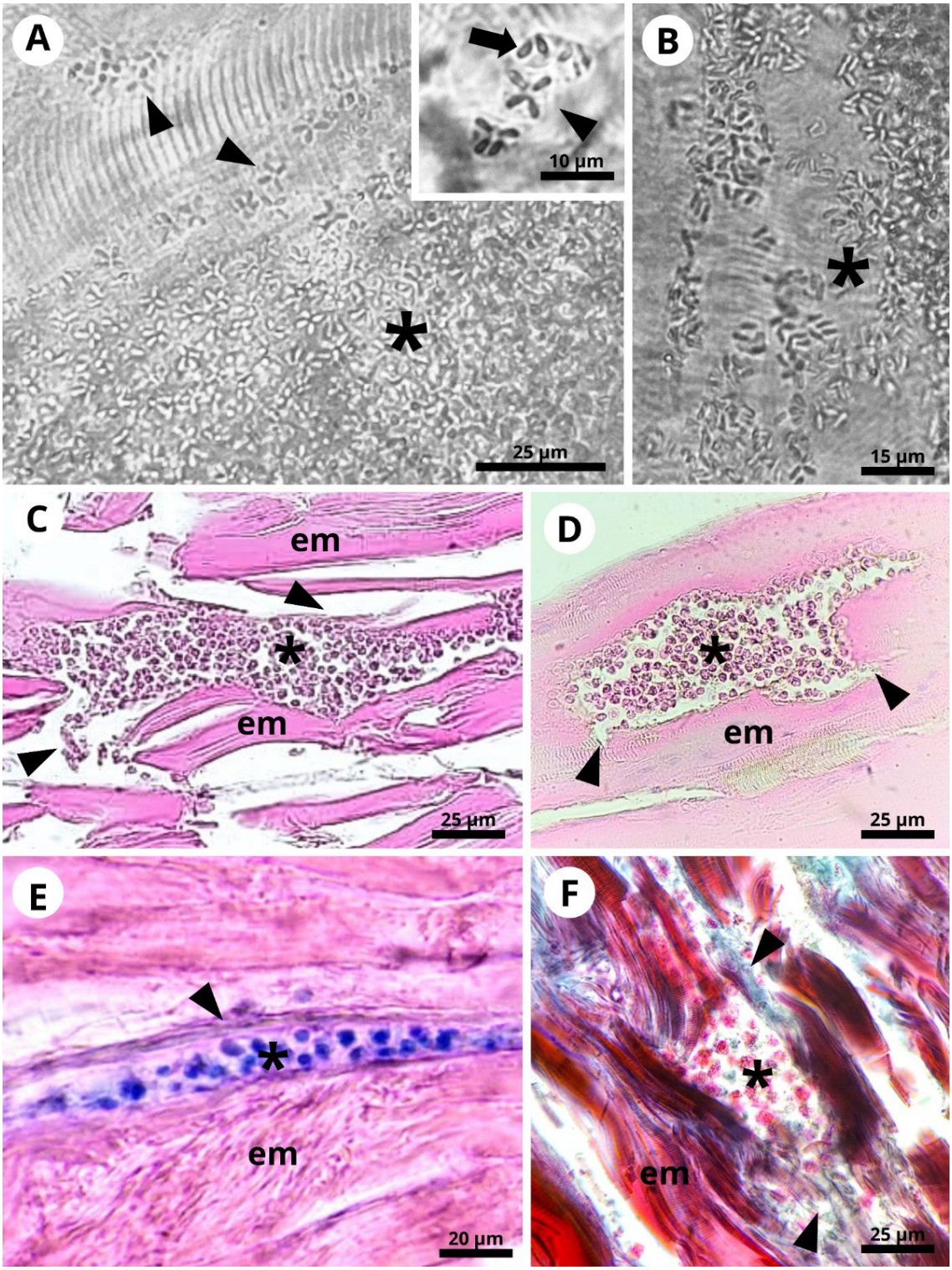


Figure 1. (A) Fresh *Kudoa* spores in the skeletal musculature of *Plagioscion squamosissimus* (Heckel, 1840). Arrowhead: spores containing four polar capsules; (*): cluster of spores within the skeletal musculature. Inset: apical (arrowhead) and lateral (arrow) views of *Kudoa* sp. spores; (B) Cluster of *Kudoa* spores dispersed throughout the skeletal musculature; (C) Hematoxylin and Eosin (H&E)-stained histological section showing an intramuscular pseudocyst containing *Kudoa* spores (*) within the skeletal musculature (em), highlighting areas of muscle fiber rupture and spore release (arrowhead); (D) H&E-stained histological section showing an intramuscular pseudocyst containing *Kudoa* spores (*) within the skeletal musculature (em) of *P. squamosissimus*, highlighting areas of advanced muscle degeneration without spore release (arrowhead); (E) May–Grünwald–Giemsa (MGG)-stained histological section showing an intermuscular structure containing *Kudoa* spores (*) within the skeletal musculature (em), highlighting areas of connective tissue deposition consistent with the endomysium (arrowhead); (F) Gutierrez's trichrome-stained histological section showing an intermuscular pseudocyst containing *Kudoa* spores (*) within the skeletal musculature (em), highlighting areas of connective tissue deposition consistent with post-inflammatory regenerative changes (arrowhead).

although it differed from the latter in spore thickness (Araújo et al., 2020; Velasco et al., 2022). The dimensions of the polar capsules were also most similar to those of *K. ajurutellus* (Araújo et al., 2020). Despite these morphometric similarities, the subquadrate spore shape of the *Kudoa* sp. observed in the present study differs from the square-shaped spores of *K. ajurutellus* (Araújo et al., 2020).

During necropsy, the skeletal musculature gradually became more friable over time, suggesting the post-mortem myoliquefaction process commonly associated with *Kudoa* spp. infections, known as "soft flesh", as described by Jiang et al. (2026). The absence of macroscopically visible pseudocysts is consistent with the *Kudoa* sp. infection previously reported in the same host species by Oliveira et al. (2015).

Necrotic lesions similar to those observed in the present study have also been reported in infections caused by *Kudoa ocellatus* da Silva, da Silva, Lima, Matos, de Carvalho Sanches, Matos & Hamoy, 2022, whereas tissue compression and loss of muscle fiber architecture have been described in *K. benignoi* infections (Silva et al., 2022; Eduard et al., 2026). As reported for *K. ocellatus* and *K. orbicularis*, *Kudoa* sp. infection was also associated with focal deposition of connective tissue in some areas (Azevedo et al., 2016; Silva et al., 2022). In contrast to *K. amazonica*, *K. orbicularis*, and *K. viseuensis*, *Kudoa* sp. did not form macroscopically visible pseudocysts (Azevedo et al., 2016; Monteiro et al., 2019; Velasco et al., 2019).

The muscle degeneration and progressive softening observed in the present study are consistent with the proteolytic activity attributed to *Kudoa* spp., which is thought to facilitate parasite development within the host musculature and to underlie the post-mortem myoliquefaction ("soft flesh") process described for other *Kudoa*-fish associations (Andrada et al., 2005; Whipps & Kent, 2006; Jiang et al., 2026). Beyond the histopathological damage itself, these alterations compromise the sensory and commercial quality of the fillet, reinforcing the economic relevance of *Kudoa* sp. infections for small-scale fisheries on Mosqueiro Island, where *P. squamosissimus* is intensively exploited.

The present study also has limitations that should be acknowledged. The taxonomic identity of the parasite was inferred solely from spore morphometry and host association, without molecular confirmation; therefore, the possibility that the observed spores represent an already described or a new *Kudoa* species cannot be ruled out. Additionally, the relatively small number of specimens examined limits inferences about seasonal or size-related variation in infection intensity. Future studies combining molecular characterization with a larger, seasonally stratified sample would help clarify the taxonomic status of this *Kudoa* sp. and the epidemiological dynamics of the infection in the Amazon estuary.

Conclusion

The results of the present study confirms the occurrence of *Kudoa* sp. infecting the skeletal musculature of *P. squamosissimus* from Mosqueiro Island, with a prevalence of 40%. Morphological and morphometric analyses characterized the spores as subquadrate, bearing four polar capsules, consistent with the genus *Kudoa*. Histopathological examination revealed multifocal necrotic lesions, intramuscular and intermuscular pseudocysts, and focal connective tissue deposition associated with the parasite's presence in the host musculature. These findings contribute to the current knowledge of myxosporean infections and fish parasitism in the Brazilian Amazon, and reinforce the need for further studies, including molecular analyses, to achieve a complete taxonomic characterization of the parasite.

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Data availability

The data supporting the conclusions of this study were published in this article.

Ethics declaration

All fish sampling and necropsy procedures were approved by the Ethics Committee on the Use of Animals (CEUA) of the Federal Rural University of the Amazon under number 9838270723.

Conflict of interest

The authors declare no conflicts of interest.

Author contributions

Ana Júlia Vieira da Silva Platilha: investigation, methodology, resources, writing – original draft. Karoliny Caldas Xavier: writing – review & editing, visualization. Camila Maria Barbosa Pereira: investigation, methodology. Alessandra Epifânio Rodrigues: resources, investigation, methodology. Deborah Camilla dos Santos Costa de Sena: resources, investigation. José Ledamir Sindeaux-Neto: supervision, methodology, visualization, data curation, writing – review & editing. Michele Velasco: Conceptualization, Supervision, Project administration, Funding acquisition, Writing – review & editing. All authors reviewed and approved the final manuscript.

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