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ECOSYSTEMS

Metazoan parasites of white mullet *Mugil curema* Valenciennes, 1836 (Mugiliformes: Mugilidae) and new records of occurrence in the western Atlantic, Brazil

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Abstract: *Mugil curema* is a pelagic fish species and it is considered the most common species of the Mugilidae family on the Brazilian coast. The objective of this study was to compile the existing information on the metazoan parasites of this host, as well as including new records from specimens captured in the Cabedelo city, state of Paraíba, Brazil. In the present study, we listed 81 *taxa* belonging to ten groups previously recorded for the host *M. curema*, and included 16 species recorded in the Cabedelo region. Eight out of 16 parasite *taxa* found in the Cabedelo region are first host records for *M. curema*: *Ligophorus brasiliensis*, *Ligophorus* sp.1, *Ligophorus* sp.2 (Monogenea), Fellodistomidae gen. sp., Bucephalidae gen. sp. (Digenea), Pharyngodonidae gen. sp. (Nematoda), Piscicolidae gen. sp. (Hirudinea) and Lernaeopodidae gen. sp. (Copepoda). Monogenea was the most abundant taxonomic group, followed by Copepoda. Despite the number of existing parasitological studies on this host species, new records of occurrence were made for the Cabedelo region and for the host, indicating that the knowledge about the parasites associated with this fish species is still under construction, especially because of its wide geographic distribution.

Key words: checklist, diversity, ectoparasites, endoparasites, fish parasites, mugilids.

INTRODUCTION

To date, Mugilidae family comprises 20 genera and 78 valid species (Froese & Pauly 2017). These fishes present worldwide distribution occurring in tropical, subtropical and temperate waters (Froese & Pauly 2017), primarily in coastal marine regions, having few species in freshwater regions (Nelson et al. 2016). In addition, they also inhabit estuaries during part of their life cycle as breeding and/or nursery areas (McDowall 2007). The mugilids are characterized by their variable feeding behavior, varying according to the ontogeny (Harrison 2002). In Brazil, this family includes species of the *Mugil* genus, including *Mugil curema* Valenciennes, 1836 (Nelson et al. 2016), which is considered the most common and abundant species along the Brazilian coast (Menezes 1983).

Mugil curema occurs on both sides of the Atlantic and in the eastern Pacific. In the western Atlantic, it extends from the United States to southern Brazil (Menezes 1983). Its representatives are coastal pelagic, of relatively shallow waters and have a gregarious habit that favors the detection of food and helps protect against predators (Carvalho et al. 2007). This fish species has preference for detritus associated with the sediment, microalgae, filamentous algae and inorganic material associated with the substrate, composing its trophic ecology (Yáñez-Arancibia 1976). Its wide distribution, combined with a close association with the sediment and interactions in food webs, enables the occurrence of different groups and species of parasites (Fajer-Ávila et al. 2006).

Several studies have been performed on *M. curema* throughout its geographic range, addressing taxonomy (Menezes 1983, Nirchio et al. 2005, Menezes et al. 2015), growth (McDonough & Wenner 2003, Gallardo-Cabello et al. 2005, Ibañez-Aguirre et al. 2006), population structure (Layman 2000, Monteiro-Neto et al. 2003, Avigliano et al. 2015), reproduction (Solomon & Ramnarine 2007, Albieri et al. 2010, Fernandez & Dias 2013), migration (Collins & Stender 1989, Ibañez & Benítez 2004, Ibañez et al. 2012) and parasitism (Garcia & Williams 1985, Cavalcanti et al. 2005, Morales-Serna et al. 2016).

Parasites are hidden and ubiquitous components of communities, constituting a large part of the biological diversity found in several ecosystems (Poulin & Morand 2004, Dobson et al. 2008, Lafferty 2012, Poulin 2014). Parasitic biodiversity continues to be minimally understood in tropical regions (Lim 1998), and although studies including these organisms have increased in recent years, much remains to be investigated, especially in the marine environment, where it is estimated that one-third of host species remain unknown to science (Appeltans et al. 2012). In addition, being important components of biodiversity, parasites play a key role in ecosystems, as they regulate the abundance or density of host populations (Arneberg et al. 1998), alter food webs (Sato et al. 2012), structure communities (Reisinger & Lodge 2016) and serve as bioindicators of water quality (Lafferty 1997), among other functions.

Fish are considered the vertebrates with the greatest diversity of parasites since they have lived for longer in close association with a wide variety of invertebrate forms (Thatcher 2006). In addition, parasitism is facilitated in the aquatic environment, which helps the propagation of these organisms, as well as their reproduction and life cycle completion, among other factors relevant to the survival of each parasite group (Eiras 2004). There are many studies on the parasites associated with marine fish in the Neotropical region, especially those of commercial importance and zoonotic potential (Holmes 1983, Okumura et al. 1999, Barros et al. 2006, Luque & Poulin 2007, Takemoto et al. 2009, Cardia & Bresciani 2012).

Therefore, this study presents the inventory the metazoan parasites recorded for *M. curema* considering its entire geographic distribution, including new records from hosts captured in the region of Cabedelo city (Paraíba State, Brazil).

MATERIALS AND METHODS

List of parasites

The list of parasites was based on an extensive search of published records, including articles, books, theses and monographs. The records were obtained by searching the Scopus, SciELO, Elsevier, Web of Science, SpringerLink and Google Scholar platforms, and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) Journals Portal using the keywords: *Mugil curema*, *L. curema, M. petrosus, M. harengus, M. metzelaari,* mullet, white mullet, Mugilidae, fish parasites and parasite fauna. The family Mugilidae is a group of fish with complex taxonomy that shares a very conservative external morphology (Nirchio et al. 2003). *Mugil curema* is considered synonymous with four species (Froese & Pauly 2017): *Liza curema* (Valenciennes), *M. petrosus* Valenciennes, *Myxus harengus* Günther and *M. metzelaari* Chabanaud, being these species also included in the survey of parasite fauna of the host *M. curema*. Data were compiled through March 2020. The data for the parasitic fauna of *M. curema* were compiled from several studies that are listed in Table I. In addition, the geographic coordinates from the studies obtained in the bibliographic survey were used to develop a distribution map of the parasites already recorded in the host species. When the geographic coordinates were absent, the centroid of the location obtained from Google Earth was used.

Parasitological survey

The analyzed hosts were obtained directly from fishermen (ice cooled) in the public market of Cabedelo city, state of Paraíba, Brazil. The specimens were fished in the region of the Cabedelo port (6º58’21’’S and 34º50’18’’W) (Figure 1), which is located on the right (eastern) bank of the Paraíba River estuary, in front of the Restinga Island, to the northwest of the city of Cabedelo (L.S. Guedes, unpublished data). The port is located between the coordinates 6º58’21’’S and 34º50’18’’W, comprising a total area of 38.46 hectares.

A total of 60 individuals were analyzed from June 2017 to April 2018, collected bimonthly. All hosts obtained were adults, however, the host sex was not identified. Fish standard length was 22.8 ± 1.4 cm and weight was 258.9 ± 50.1 g (mean ± SD). The hosts were fresh analyzed and complete necropsy was performed. The organs were removed from the hosts and observed under a stereomicroscope: external surfaces of the body, muscle, eyes, gills, nostrils, heart, liver, kidney, gonads, spleen, mesentery, intestine and stomach. All parasites were preserved in 70% ethanol for subsequent identification. Distinct methodology was applied for each taxonomic group for the identification of the specimens of parasites. Nematodes were cleared in lactic acid, Copepoda and Monogenea were mounted in Hoyer’s medium, while Digenea and Acantocephala were stained with acetic carmine (Kritsky et al. 1986). Subsequently, permanent slides were mounted in Canada balsam. Parasites were identified according to Wilson (1911), Noronha (1973), Cressey (1983), Amado & Rocha (1995), Boxshall & Montú (1997), H.H. El-Rashidy (unpublished data), Gibson et al. (2002), Abdallah et al. (2009) and Sarabeev et al. (2013). The fish specimens were identified by the team of the Laboratório de Ictiologia (LABICT) at the Universidade Federal da Paraíba (UFPB), according to Menezes et al. (2015).

The prevalence and mean intensity were calculated according to Bush et al. (1997) for each parasite species. Moreover, the parasitic indices are presented with their corresponding confidence intervals (95% confidence level) and Poulin’s index of dispersion, as suggested by Rózsa et al. (2000). These indices were calculated using the Quantitative Parasitology program, version 1.0.14 (Reiczigel et al. 2013). The parasites identified at species level were listed and deposited in the Coleção de Invertebrados Paulo Young (CIPY) at UFPB, and the fish specimens were listed in the Coleção Científica de Ictiologia da UFPB (UFPB11626).

Table I. Occurrence list of all parasites in *M. curema*: SI (infection/infestation sites), OC (opercular cavity), GI (gills), BS (body surface), EY (eyes), HR (heart), ST (stomach), LI (liver), IN (intestine), MS (muscle), VO (visceral organs), GB (Gallbladder), NI (not informed).

SPECIES	SI	LOCALITY	REFERENCE
MYXOZOA			
Ellypsomixa sp.	GB	BRA: Distrito de Mosqueiro (PA), Vigia de Nazaré (PA)	L.N.S. Dias (unpublished data)
Hanneguya sp.	NI	BRA: São Paulo	Godinho et al. (1988)
Kudoa sp. (= *Sphaerospora* sp.)	GB	MEX: Caribbean Sea off the coast of Mexico	Fiala (2006)
Myxobolus hani	GI	SEN: Senegal	Faye et al. (1999)
Myxobolus sp.	HR, GI, IN	SEN: Atlantic coast of Senegal; BRA: Distrito de Mosqueiro (PA), Vigia de Nazaré (PA), Municipality of Valença (BA)	Faye et al. (1997), L.N.S. Dias (unpublished data), W.F. Souza (unpublished data)
MONOGENEA			
Aristocleidus sp.	GI	MEX: La Mancha Lagoon, Veracruz	M.V. Nieto-Pérez (unpublished data)
Axinidae gen. sp.	GI	MEX: Chamela Bay, Jalisco	Pérez-Ponce de León et al. (1999)
Dactylogyridae gen. sp.	GI	BRA: Municipality of Valença (BA)	W.F. Souza (unpublished data)
Dactylogyrus sp.	GI	MEX: Tres Palos Lagoon, Guerrero	A.P. García (unpublished data)
Gyrodactylus curemae	BS	VEN: Patanemo Bay, Carabobo	Conroy & Conroy (1985)
Ligophorus mugilinus (=*Pseudohaliotrema mugilinus*)	GI	PUR: Joyuda Lagoon; VEN: Margarita Island; MEX: Urias and Teacapan Estuary, Tres Palos Lagoon and Coyuca Lagoon; BRA: Paraíba do Norte River and Mamanguape River (PB)	Garcia & Williams (1985), Fuentes-Zambrano & Nasir (1990), Fajer-Ávila et al. (2006), Violante-González et al. (2007), Violante-González & Aguirre-Macedo (2007), Golzio et al. (2017)
Ligophorus vanbenedeni	GI	MEX: Chamela Bay, Jalisco	Pérez-Ponce de León et al. (1999)
Metamicrocotyla chamelense	GI	MEX: Chamela Bay, Jalisco	Mendoza-Garfias & Pérez-Ponce de León (1998), Pérez-Ponce de León et al. (1999)
Metamicrocotyla macracantha	GI	VEN: La Regina Lagoon, Margarita Island; MEX: Urias and Teacapan Estuary, Chamela Bay, Jalisco; BRA: Municipality of Valença (BA), Rio de Janeiro (RJ)	Garcia & Williams (1985), Fajer-Ávila et al. (2006), W.F. Souza (unpublished data), Moutinho & Alves (2014)
Metamicrocotyla pacifica	GI	MEX: Chamela Bay, Jalisco	Bravo-Hollis (1981)
Solostamenides pseudomugilis	GI	MEX: Chamela Bay, Jalisco	Mendoza-Garfias & Pérez-Ponce de León (1998), Pérez-Ponce de León et al. (1999),
Metamicrocotyla sp.	GI	MEX: La Mancha Lagoon, Veracruz	M.V. Nieto-Pérez (unpublished data)
Neobenedenia pacifica	GI, EY	USA: Indian River Lagoon, Martin County and Turtle Bay (FL), Horn Island (MS); PUR: Bucaná River	Kritsky & Bakenhaster (2017), Bunkley-Williams & Williams (1994)
DIGENEA			

Table I. Continuation.

Ascocotyle (Phagicola) longa	HR, LI	MEX: Tres Palos Lagoon and Coyuca, Guerrero Lagoon; USA: Florida, BRA: Rio Parati, Araquari (SC)	Violante-González et al. (2007), Violante-González & Aguirre-Macedo (2007), Hutton & Sogandares-Bernal (1959), J.S. Gueretz (unpublished data)
Ascocotyle sp. (metacercariae)	MS, VO	BRA: Iguapé City (SP)	Namba et al. (2012)
Austrodiplostomum compactum	EY	MEX: Tres Palos Lagoon and Coyuca, Guerrero Lagoon	Violante-González et al. (2007), Violante-González & Aguirre-Macedo (2007)
Clinostomum complanatum	LI, MS	MEX: Tres Palos Lagoon and Coyuca, Guerrero Lagoon	Violante-González et al. (2007), Violante-González & Aguirre-Macedo (2007)
Haplosplanchnus sp.	IN	USA: Florida	Paperna & Overstreet (1981)
Haplosplanchnus mugilis	IN	CUR: Gulf-Caribbean region	Nahhas & Cable (1963)
Heterophyes heterophyes	NI	Mediterranean Sea and adjacent waters	Paperna & Overstreet (1981)
Hurleytrema sp.	IN	MEX: Gulf of Mexico	Paperna & Overstreet (1981)
Saccocoelioides beauforti (=Culuwiya beauforti)	IN	BRA: São Paulo; VEN: Patanemo, Carabobo and Chichiriviche Bays, Falcón	Conroy & Conroy (1984), Conroy & Conroy (1986)
Xiha fastigata (=Dicrogaster fastigata)	IN	VEN: Patanemo, Carabobo and Chichiriviche Bays, Falcón; BRA: Rio Parati, Araguari (SC)	Conroy & Conroy (1986), J.S. Gueretz (unpublished data)
Dicrogaster sp.	IN	BRA: São Paulo	Conroy & Conroy (1984)
Intromugil mugilicolus	IN	VEN: Patanemo, Carabobo and Chichiriviche Bays, Falcón	Conroy & Conroy (1986)
Intromugil simonei	IN	BRA: São Paulo	Conroy & Conroy (1984)
Lasiotocus glebulentus	IN	VEN: Patanemo, Carabobo and Chichiriviche Bays, Falcón	Conroy & Conroy (1986)
Lasiotocus mugilis	IN	PUR: Ponce	Dyer et al. (1998)
Lecithaster helodes	IN	USA: Mississippi Sound (MS) and adjacent waters	Overstreet (1973)
Lecithophyllum botryophoron (=Lecithophyllum botryophorum)	ST	BRA: Municipality of Valença (BA)	W.F. Souza (unpublished data)
Mecoderus oligoplitis	ST	BRA: Municipality of Valença (BA)	W.F. Souza (unpublished data)
Mesostephanus appendiculatoides (metacercaria)	NI	USA: Florida	Hutton & Sogandares-Bernal (1959)
Pseudoacanthostomum panamense	IN	MEX: Coyuca, Guerrero Lagoon	Violante-González & Aguirre-Macedo (2007)
Rhipidocotyle lepisostei	NI	USA: Grand Isle (LA)	Sparks (1958)
Saccocoelioides carolae	GI	BRA: Municipality of Valença (BA)	W.F. Souza (unpublished data)
Schikhobalotrema elongatum	IN	PUR: Ponce; JAM: Jamaica	Dyer et al. (1998), Nahhas & Cable (1963)

Table I. **Continuation.**

Schikhobalotrema magnum	IN	BRA: São Paulo	Conroy & Conroy (1984)
Schikhobalotrema sp.	IN, ST	VEN: Patanemo, Carabobo and Chichiriviche Bays, Falcón; BRA: Municipality of Valença (BA)	Conroy & Conroy (1986), W.F. Souza (unpublished data)
CESTODA			
Dasyrhynchus pacificus	IN	MEX: Gulf of Mexico	Palm & Overstreet (2000)
Proteocephalidea (larva)	IN	BRA: Municipality of Valença (BA)	W.F. Souza (unpublished data)
ACANTHOCEPHALA			
Floridosentis mugilis (=*Floridosentis elongatus)*	IN	MEX: Tres Palos Lagoon, Guerrero, Bahía de La Paz, Baja California Sur; PUR: Joyuda Lagoon; BRA: Municipality of Valença (BA), Rio Janeiro (RJ); USA: Fowl River, Mobile Bay (AL)	Violante-González et al. (2007), W.F. Souza (unpublished data), Moutinho & Alves (2014), Garcia & Williams (1985), Williams & Gaines-Jr (1974)
Neoechinorhynchus curemai	IN	BRA: Rio Potengi Estuary (RN), Municipality of Valença (BA), Rio Grande do Norte (RN), Rio Parati, Araquari (SC)	Fortes et al. (2000), W.F. Souza (unpublished data), Cavalcanti et al. (2012), J.S. Gueretz (unpublished data)
NEMATODA			
Contracaecum sp. (larva)	LI, MS	MEX: Urias and Teacapan Estuary; BRA: Municipality of Valença (BA)	Fajer-Ávila et al. (2006), W.F. Souza (unpublished data)
Contracaecum multipapillatum (larva)	NI	MEX: Bahía de Almejas, Baja California Sur	Valles-Vega & Prado-Rosas (2014)
Cucullanus djilorensis	IN	SEN: Djilor River, Fatick	Ndew et al. (2014)
Cucullanus sp.	IN	BRA: São Paulo	Conroy & Conroy (1984)
Pseudoterranova sp. (larva)	VO	VEN: Caracas	Bandes et al. (2005)
MALACOSTRACA			
Cymothoa spinipalpa	OC	BRA: Rio Grande do Norte (RN)	Cavalcanti et al. (2011)
Excorallana sp.	OC	BRA: Municipality of Valença (BA)	W.F. Souza (unpublished data)
Gnathiidae (larva)	OC	BRA: Municipality of Valença (BA)	W.F. Souza (unpublished data)
COPEPODA			
Acanthocolax sp.	OC	BRA: Itamaracá Island (PE)	Fonsêca et al. (2000)
Bomolochus bellones	OC, GI	PUR: Joyuda Lagoon	Garcia & Williams (1985)
Bomolochus nitidus	OC, GI	BRA: Santa Cruz Canal, Suape Area (PE), Paraíba do Norte River (PB)	F.T.B. Fonsêca (unpublished data), Golzio et al. (2017)
Caligus bonito	GI	BRA: Ponta Negra Beach (RN)	Cavalcanti et al. (2006)
Caligus minimus	BS	BRA: Santa Cruz Canal and Suape Area (PE)	F.T.B. Fonsêca (unpublished data)
Caligus pomacentrus	GI	BRA: Municipality of Valença (BA)	W.F. Souza (unpublished data)
Caligus praetextus	BS	BRA: Santa Cruz Canal and Suape Area (PE)	F.T.B. Fonsêca (unpublished data)

Table I. Continuation.

Caligus sp.	GI	BRA: Ponta Negra Beach (RN)	Cavalcanti et al. (2006), Fajer-Ávila et al. (2006)
Ergasilus arthrosis	GI	MEX: Veracruz	Chávez-López et al. (1995)
Ergasilus atafonensis	GI	BRA: Atafona (RJ), Santa Cruz Canal and Suape Area (PE), Paraíba do Norte River and Mamanguape River (PB)	Amado & Rocha (1995), F.T.B. Fonsêca (unpublished data), Golzio et al. (2017)
Ergasilus bahiensis	GI	BRA: Paraguaçú River (BA), Santa Cruz Canal and Suape Area (PE), Paraíba do Norte River and Mamanguape River (PB)	Amado & Rocha (1995), F.T.B. Fonsêca (unpublished data), Golzio et al. (2017)
Ergasilus caraguatatubensis	GI	BRA: Caraguatatuba Bay (SP), Municipality of Valença (BA), Santa Cruz Canal and Suape Area (PE), Paraíba do Norte River and Mamanguape River (PB)	Amado & Rocha (1995), F.T.B. Fonsêca (unpublished data), W.F. Souza (unpublished data), Golzio et al. (2017)
Ergasilus congoensis	GI	SEN: Saint Louis, NGR: Lagos	H.H. El-Rashidy (unpublished data)
Ergasilus ecuadorensis	GI	ECU: Ecuador	H.H. El-Rashidy & G.A. Boxshall (unpublished data)
Ergasilus guyananesis	GI	NGR: Lagos; SLE: Sierra Leone	H.H. El-Rashidy (unpublished data)
Ergasilus indistinctus	GI	SEN: Senegal	H.H. El-Rashidy (unpublished data)
Ergasilus lizae (=*Ergasilus nanus*)	GI	PUR: Joyuda Lagoon; BRA: Santa Cruz Canal (PE), Ponta Negra Beach (RN), Municipality of Valença (BA), Rio Parati, Araguari (SC)	Garcia & Williams (1985), F.T.B. Fonsêca (unpublished data), Cavalcanti et al. (2005), W.F. Souza (unpublished data), J.S. Gueretz (unpublished data)
Ergasilus parabahiensis	GI	GUY: Guyana	H.H. El-Rashidy (unpublished data)
Ergasilus paralizae	GI	NGR: Lagos	H.H. El-Rashidy (unpublished data)
Ergasilus versicolor	GI	BRA: Ponta Negra Beach (RN)	Cavalcanti et al. (2005)
Ergasilus sp.	GI	MEX: Urias and Teacapan Estuary	Fajer-Ávila et al. (2006)
Holobomolochus sp.	GI	MEX: Urias and Teacapan Estuary	Fajer-Ávila et al. (2006)
Lernaeenicus longiventris	BS	PUR: Joyuda Lagoon; BRA: Santa Cruz Canal and Suape Area (PE), Rio Parati, Araquari (SC)	Garcia & Williams (1985), F.T.B. Fonsêca (unpublished data), J.S. Gueretz (unpublished data)
Lernaeopodidae gen. sp.	GI	MEX: Urias and Teacapan Estuary	Fajer-Ávila et al. (2006)
Therodamas sp.	GI	BRA: São Paulo (SP)	Conroy & Conroy (1984)
HIRUDINEA			
Myzobdella lugubris	BS	PUR: Santa Teresa Lagoon; USA: Florida	Williams et al. (1994), Sawyer et al. (1975)

Abbreviations for countries: BRA – Brazil; CUR – Curacao; ECU – Ecuador; GUY – Guyana; JAM – Jamaica; MEX – Mexico; NGR – Nigeria; PUR – Puerto Rico; SEN – Senegal; SLE – Sierra Leone; USA – United States; VEN – Venezuela.

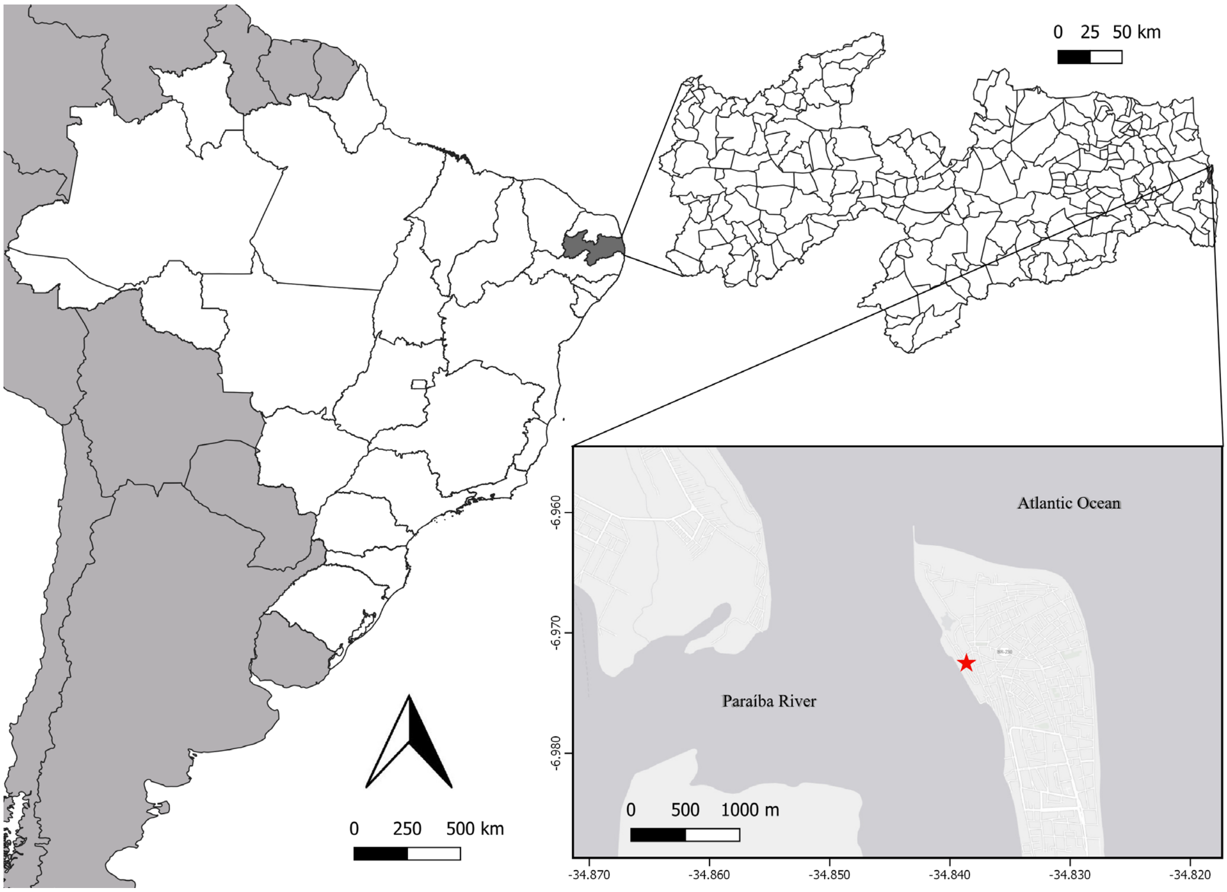

Figure 1. Sampling area, near the Port of Cabedelo (star), state of Paraíba, Brazil.

RESULTS

List of parasites of host *M. curema*

The bibliographic survey resulted in the analysis of 49 scientific studies published between 1958 and 2019, recording the interaction between parasites and the host *Mugil curema* throughout the entire geographic distribution of the host. The studies included: thirty-nine scientific articles, five books (Travassos et al. 1969, Paperna & Overstreet 1981, Bunkley-Williams & Williams 1994, Eiras et al. 2016), five theses (J.S. Gueretz, unpublished data, L.N.S. Dias, unpublished data, F.T.B. Fonsêca, unpublished data, A.P. García, unpublished data, M.V. Nieto-Pérez unpublished data) and one undergraduation monograph (term paper) (W.F. Souza, unpublished data), with most records found from 1991 to 2000 (Figure 2a). When records were obtained from checklist studies, the original description was also consulted. A total of 81 *taxa* belonging to ten groups of parasites were recorded, in 58 localities, in which South America was the continent with the most parasite species associated with this host (n = 35), followed by North America (n = 16) and Africa (n = 7) (Figure 3). Parasitic *taxa* included: Five Myxozoa, 13 Monogenea, 25 Digenea, two Cestoda, two Acanthocephala, five Nematoda, three Malacostraca, 25 Copepoda and one Hirudinea (Figure 2b). Table I contains all species and biogeographic distribution, as well as the sites of infection/infestation. No study on parasites of species considered synonymous with *M. curema* was found.

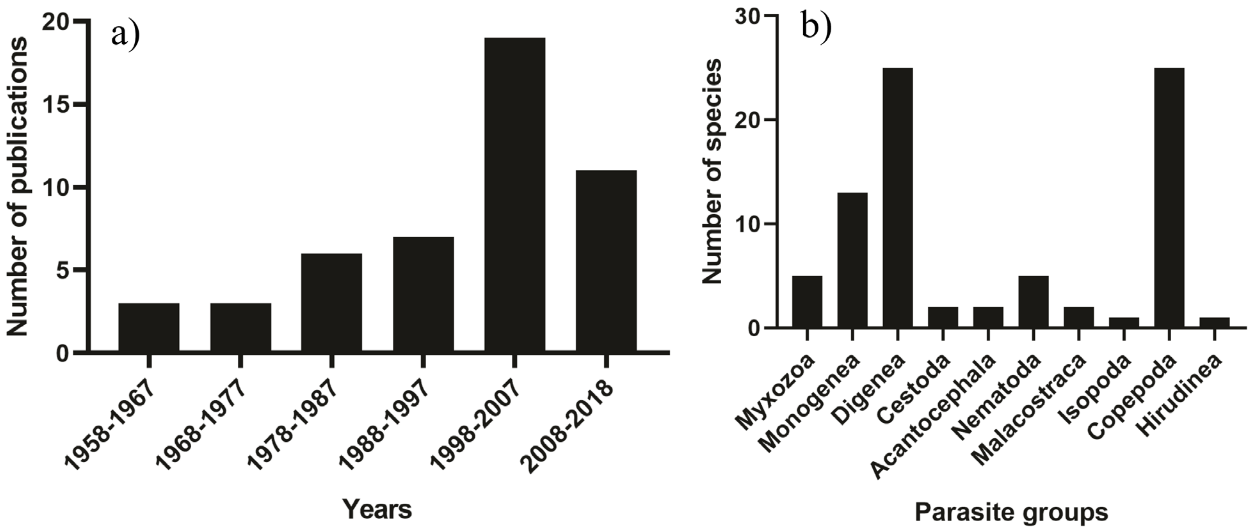

Figure 2. a) Number of publications regarding parasites in association with the host *M. curema*, by decades; b) Number of species of each parasite group recorded in the host *M. curema.*

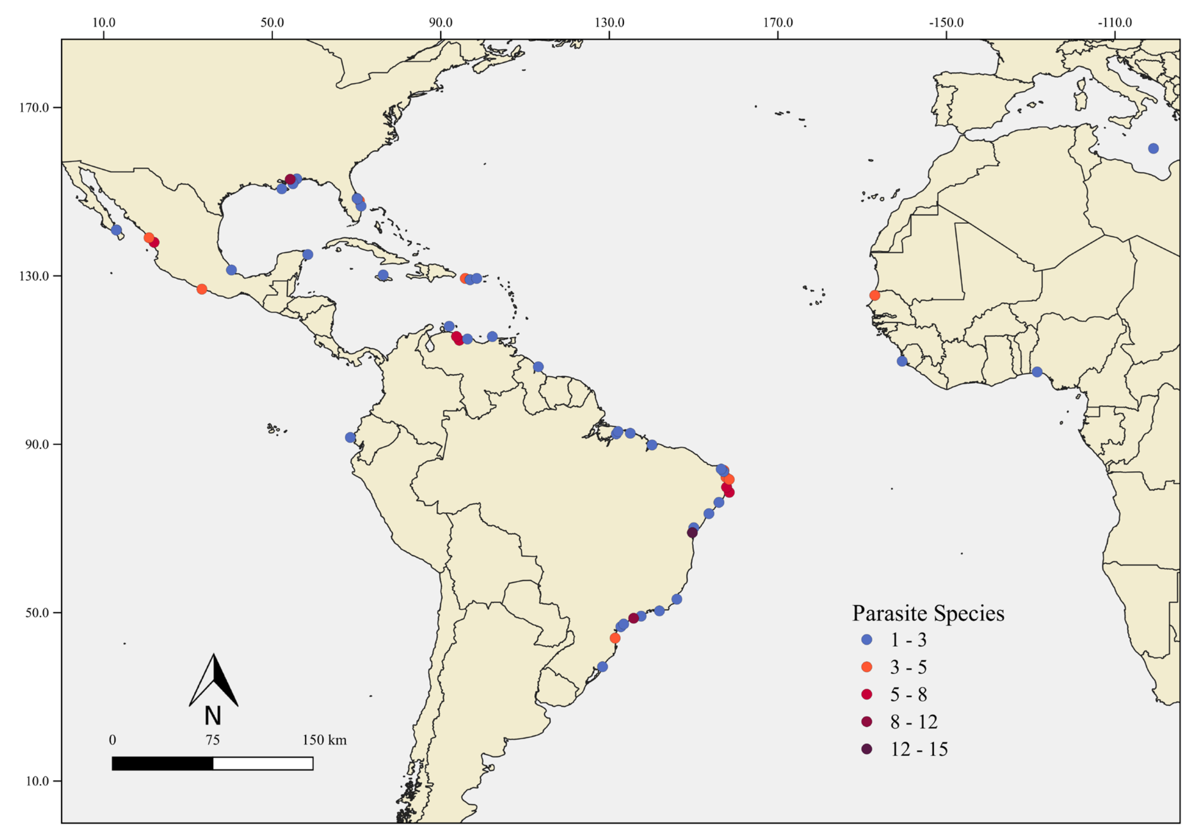

Figure 3. Localities with parasite records associated with the host *M. curema*, by number of species per localities.

New records of occurrence

Sixteen species of metazoan parasites were found in the hosts analyzed from the Cabedelo region: three Monogenea, two Digenea, one Nematoda, one Acanthocephala, one Hirudinea and eight Copepoda. The figure 4 shows a selection of the parasites found in *M. curema* from the Cabedelo region.

In total, 12 784 parasites were collected, highlighting the class Monogenea, due to its greater abundance (n = 10 411), represented by the *taxa L. brasiliensis* Abdallah, Azevedo & Luque, *Ligophorus* sp. 1 and *Ligophorus* sp. 2. The second most abundant taxonomic group was Copepoda, represented in decreasing order of abundance by the species *Ergasilus lizae* Krøyer, *E. bahiensis* Amado & Rocha, *E. caraguatatubensis* Amado & Rocha, *Bomolochus nitidus* Wilson, *E. atafonensis* Amado & Rocha, Lernaeopodidae gen. sp., *Caligus praetextus* Bere and *Caligus minimus* Otto. Among the digenetic organisms, the family Bucephalidae is noteworthy. To verify the results of the parasitic indexes, consult the Table SI – Supplementary Material.

DISCUSSION

Studies on parasites are important because they constitute a large component of global biodiversity that is often neglected. A general view over the number of papers published in the last decades can be useful to understand how scientific knowledge varies in time for a

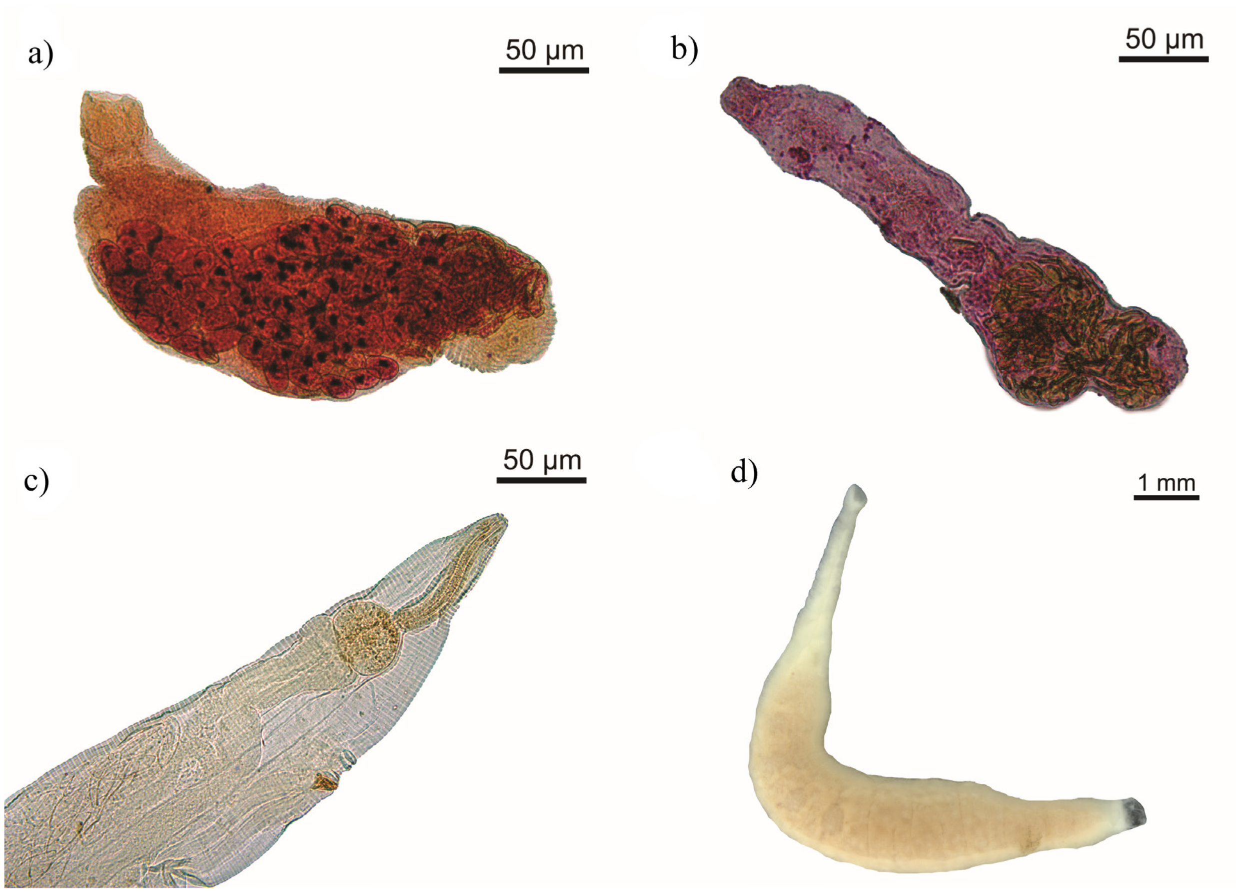

Figure 4. A selection of the parasites found in *M. curema* from the Cabedelo region, state of Paraíba, Brazil. a) Bucephalidae gen. sp., b) Fellodistomidae gen. sp., c) Pharyngodonidae gen. sp., d) Piscicolidae gen. sp.

specific subject, besides serving as guidance to researchers (Kopp et al. 2007). From 1958 to 1990, the curve of publications in relation to time was in constant growth, but a decrease remains constant over the last two decades. This could be the reflection of the loss of expertise of parasite taxonomist worldwide, discussed by Poulin & Leung (2010) and Poulin (2014). This is the first list of parasite species recorded in the host *M. curema* considering its whole distribution range. Of the 81 parasite associations recorded for *M. curema*, the copepods and digeneans were the largest taxonomic groups in number of *taxa* (25). In the Neotropical region, copepods are the second largest group of parasites in marine fish and the third largest group in freshwater hosts (Luque & Poulin 2007) and, consequently, its diversity associated with *M. curema* may be expected. Digenea also had 25 recorded *taxa*. These organisms are endoparasites, with few exceptions, that can occur in fish – in adult or larval forms – and have complex heteroxenous life cycles, with several stages involving invertebrate and vertebrate hosts (Rocha 2011).

Among the recorded parasites, 42 *taxa* were ectoparasites and 39 *taxa* were endoparasites. *Mugil curema* is a species widely distributed around the globe that lives in the shallow region of the marine coast and uses estuaries as part of its life cycle (Froese & Pauly 2017). In addition, this species presents schooling behavior (Carvalho et al. 2007), which may favor the infestation and transmission of ectoparasites, since organisms such as crustaceans and monogeneans may migrate from one host to another without the need for intermediate hosts to complete their life cycles (Byrnes 1987). However, parasites of the groups Myxozoa, Digenea, Cestoda, Nematoda and Acanthocephala have heteroxenous life cycles. They often possess complex life cycles, with one or more intermediate hosts (e.g. other invertebrates, fish and/or birds) required for development or growth. Thus, the diversity of endoparasites can depend on the diet of the host or foraging (Lo et al. 1998).

In the Cabedelo region, sixteen *taxa* were recorded, of which nine had been previously recorded in the *M. curema* host species in other geographic regions (Amado & Rocha 1995, F.T.B. Fonsêca, unpublished data, Golzio et al. 2017, W.F. Souza, unpublished data, Moutinho & Alves 2014).

Monogeneneans are helminths ectoparasites that present high specificity to their hosts (Jorissen et al. 2017). This specificity may be dynamic and influenced by several aspects, such as the age of the parasite or host, sex of the host, season of the year and presence or absence of other parasite species, among other factors (Rohde 1994). In the present study, these parasites were found in high abundance, and three species of the genus *Ligophorus* were identified - a genus of parasites exclusive to Mugilidae family (Sarabeev et al. 2013). The species *L. brasiliensis* was recorded only for the host *Mugil liza* Valenciennes in the state of Rio de Janeiro, southeastern Brazil (Abdallah et al. 2009). Therefore, this is the first record of *L. brasiliensis* for the host *M. curema* in northeastern Brazil.

The digeneans found were identified as belonging to the families Fellodistomidae and Bucephalidae. Fellodistomidae is characterized by the presence of vitelline follicles located on the (inner) sides of the organism, with muscular ornaments or fine spines on the body surface. Digenetic organisms of this family are small organisms that parasitize the stomach or intestine of marine fish and, occasionally, bivalves and gastropods (Gibson et al. 2002). These organisms were found only in one host, with low infection rate, which did not allow for precise identification due to the lack of available specimens.

Bucephalidae is a family of parasites of marine, freshwater and estuarine fish that is considered cosmopolitan, which may also use some invertebrates as intermediate or paratenic hosts (Gibson et al. 2002). Its members are characterized by the presence of an apical fixation organ known as "*rhynchus*", which is dissociated from the digestive system and has terminal genitalia (Maurya et al. 2018). Despite being a family with wide geographical distribution, only *Rhipidocotyle lepisostei* Hopkins has been recorded in North America (Sparks 1958) for the host *M. curema*; this is the first and unique record of this family parasitizing the host *M. curema*.

Members of the phylum Acanthocephala are obligate intestinal parasites of aquatic organisms and some terrestrial vertebrates (Rocha 2011). In Brazil, approximately 45 species of acanthocephalans have been recorded and most species are considered endemic to South America (Santos et al. 2008). *Floridosentis mugilis* (= *Floridosentis elongatus*) (Machado-Filho) was the first species of Acanthocephala described in Brazil in the host *Mugil platanus* Valenciennes in the state of Rio de Janeiro (Noronha 1973). In *M. curema*, these parasites were found in Mexico (Violante-González et al. 2007), Puerto Rico (Garcia & Williams 1985) and in Brazil in the states of Bahia and Rio de Janeiro (W.F. Souza, unpublished data, Moutinho & Alves 2014).

The nematodes found in the present study belong to the family Pharyngodonidae due to the presence of four large cephalic papillae in the oral opening and one esophageal bulb (Moravec 1998). The representatives of this family are intestinal fish parasites, with few species occurring in mammals (Anderson 2000) and lizards (Ávila & Silva 2010). These parasites may be important pathogens in fish at high infection intensity or under cultivation conditions (Moravec 2000); however, in the present study these parasites showed low infection rates.

Leeches of the family Piscicolidae are predominantly parasites of fish, being their majority exclusively marine (Sket & Trontelj 2008), characterized by a global distribution in tropical and subtropical oceans (Utevsky & Trontelj 2004). There is only one record of leech parasites in the host species of the present study in Porto Rico and United States, thus this is the first record of Hirudinea in Brazil (Williams et al. 1994, Sawyer et al. 1975).

Copepods are the most common and abundant ectoparasites of fish in freshwater and marine ecosystems (Boxshall & Halsey 2004). The copepods *Ergasilus caraguatatubensis*, *E. bahiensis*, *E. atafonensis*, *E. lizae*, *Bomolochus nitidus*, *Caligus minimus* and *C. praetextus* have been recorded in the host *M. curema* in the Brazilian states of São Paulo, Rio de Janeiro, Bahia (Amado & Rocha 1995), Rio Grande do Norte (Cavalcanti et al. 2005, 2006), Pernambuco (F.T.B. Fonsêca, unpublished data) and Paraíba, the latter being in estuarine systems and only in juvenile fish (Golzio et al. 2017). Other hosts have been reported to be parasitized by these copepods, all of them from the Mugilidae family (Knoff et al. 1994, 1997, Amado & Rocha 1995, Cavalcanti et al. 2004, 2005), except for *C. praetextus*, which had been recorded in other hosts such as *Aspistor luniscutis* (Valenciennes), *Centropomus undecimalis* (Bloch), *Chaetodipterus faber* (Broussonet), *Cynoscion* sp., *Genidens barbus* (Lacepède), *Orthopristis ruber* (Cuvier), *Scomberomorus* sp. and *Umbrina* sp. (Luque et al. 1998, Tavares & Luque 2001, 2004a, b).

Differences in the number of parasite species associated with this host around the world may reflect regional discrepancies in sampling efforts, as well as in research groups studying fish parasites in different geographical regions. Despite the diversity of fish and parasite species in the world, the study of biological interactions among these organisms can be considered neglected, especially concerning *M. curema*, which is a fish worldwide distributed. In fact, most of parasitological studies with this host have been carried out in Brazil, especially in localities from Southeast and South regions, where the greatest number of research centers and specialists in fish parasites are located (Pinto & Melo 2013). Interestingly, studies on the diversity of parasites of the host *M. curema* are lower in the African continent, where the number of studies on fish parasites in general is still low (Ellender & Weyl 2014). Thus, further studies are needed to evaluate the possible biogeographical implications of the composition of the parasitic fauna of this host in other locations within its geographic distribution.

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SUPPLEMENTARY MATERIAL

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JMF, ACFL and GHCV designed the study. JMF and VMML carried out the fieldwork, the laboratory analysis and the bibliographic revision. JMF wrote the manuscript with contributions from all co-authors.