Ectoparasites infecting *Mugil curema* (Mugiliformes: Mugilidae) in Amapá state estuary, in the northern Brazilian coast region

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Abstract

In fish, one of the most important interactions is that occur between parasite species and environment. Wild fish interactions with parasites of different taxa can result in diseases for fish and consequently damages to the fishing industry. This study investigated the ectoparasite fauna in *Mugil curema* in Amapá state estuary, in Brazilian coast region. The parasite prevalence was 51.4%, and a total of 282 parasites were collected among *Ligophorus brasiliensis* (Dactylogyridae), *Excorallana longicornis* (Corallanidae), larvae of *Gnathia* sp. (Gnathiidae) and *Ergasilus atafonensis* (Ergasilidae), but the dominance was of *L. brasiliensis*. The parasites presented highly aggregated dispersion, except for *Gnathia* sp. that had a random dispersion. There was a predominance of hosts parasitized by zero and one species. The relative condition factor did not differ between parasitized and non-parasitized fish. The body size of hosts did not influence the parasite abundance. The community of ectoparasites consisted of low species richness with low infection levels. This is the first study on parasites of fish from the coast of the State of Amapá and is the first report of *Gnathia* sp. for *M. curema*.

Introduction

Fish have a great importance for human populations, as well as for nutrition of animals with zootechnical interest. Fishing is one of the fundamental and effective ways to quickly find food in nature, from the earliest times, in order to meet the existential needs, which is why it became one important branch of economics (Golzio et al. 2017; Nedić et al. 2018). *Mugil curema* (Valenciennes, 1836), named white mullet, a pelagic fish of the family Mugilidae in Americas that is distributed from Cape Cod (USA) to Brazil, has a great importance for fishing. It has also been reported in the Senegal River outlet southwards to Namibia, in Africa (Ibáñez-Agurre et al. 2006; Froese & Pauly 2021). This white mullet species is an important commercial fishing resource because of its fatty meat of good quality. Juveniles of *M. curema* enter the lacustrine-estuarine systems, where they grow to reach the adult stage, and then migrate in shoals to the coastal pelagic zone to spawn. This fish feeds on microscopic or filamentous algae and planktonic organisms (Cavalcanti et al. 2011; Moutinho & Alves 2014; Ruiz-Ramírez et al. 2017). Due to the development of aquaculture programs for *M. curema*, ecological studies on parasites have increased in wild populations of this fish.

Understanding how the parasites are distributed and their interactions with host fish populations and environment are among the basic aims of parasitology of fish (Cavalcanti 2011; Golzio et al. 2017; Nedić et al. 2018; Neves & Tavares-Dias 2019). In this context, parasite-host-environment systems constitute excellent study models to explore these essential aspects of parasitic ecology in wild fish populations. Thus, for wild *M. curema* from the Brazilian coast it has been reported infections by crustaceans Caligidae gen. sp., *Caligus* sp., *Acanthocolax* sp.; *Caligus bonito* (Wilson, 1905), *Caligus minimus* (Otto, 1821), *Caligus praetextus* (Bere, 1936), *Cymothoa spinipalpa* (Thatcher, Araújo, Lima & Chellappa, 2007), *Ergasilus* sp.; *Ergasilus versicolor* (Wilson, 1911), *Ergasilus lizae* (Kroyer, 1863), *Ergasilus atafonensis* (Amado & Rocha, 1995), *Ergasilus caraguatatubensis* (Amado & Rocha, 1995), *Ergasilus bahiensis* (Amado & Rocha, 1995), *Bomolochus nitidus* (Wilson, 1911) and *Excorallana longicornis* (Lemos de

Castro, 1960), monogeneans *Ligophorus mugilinus* (Hargis, 1955), *Ligophorus brasiliensis* Abdallah, (Azevedo & Luque 2009), *Ligophorus* spp. and *Metamicrocotyla macracantha* (Alexander, 1954), and digenean *Ascocotyle* sp. metacercariae (Amado & Rocha, 1995; Fonsêca et al. 2000; Cavalcanti et al. 2005; Cavalcanti et al. 2011; Namba et al. 2012; Moutinho & Alves 2014; Golzio et al. 2017; Esteves-Silva et al. 2020; Falkenberg et al. 2021). However, parasites of *M. curema* from the Amapá State estuary have not been addressed.

In migratory fish populations, migration potentially affects the distribution and abundance of parasites in ecosystems (Salgado-Maldonado et al. 2019); thus, they have a wide ecological interaction in aquatic ecosystems of its geographic distribution. One of these most important interactions is with different taxa of parasite species, which can result in diseases. Such diseases can be highly damaging for fish and consequently to the local economics (Cavalcanti et al. 2011; Golzio et al. 2017; Nedić et al. 2018; Neves & Tavares-Dias 2019). Parasitic diseases usually occur when there is an imbalance between environment, host and parasite community in fish population (Pedro et al. 2016; Mentz et al. 2016). Ectoparasites can have the potential to exert effects on the behavior, biology, development, health and appearance of the host fish (Fonsêca et al. 2000; Cavalcanti et al. 2011; Nedić et al. 2018; Neves & Tavares-Dias 2019). Providing that the associations between ectoparasites and impacts have been established, this could offer predictive tools to assess the magnitude of impacts on fish populations (Fajer-Ávila et al. 2006; Golzio et al. 2017; Neves & Tavares-Dias 2019). Thus, it is important to know the parasitic fauna of wild fish populations and to consider the effects of parasites on host health, because these may help to understand impacts on fish populations and effects of aquatic ecosystems on parasite communities (Mentz et al. 2016; Neves & Tavares-Dias, 2019). The aim of this study was to investigate the ectoparasite fauna in *M. curema* from the Amapá state estuary, in the Brazilian coast.

Material And Methods

Fish collection and study area

Thirty-five specimens of *M. curema* were collected bimonthly, between June 2017 and March 2018 in the Maracá-Jipiôca Ecological Reserve (1° 50" 00"N; 2° 12" 00"; 50° 33" 00" W). Fishes were caught using gill nets with different mesh sizes (30, 40 and 50 mm), which remained about 4 hours/day in the water. Later, each fish was placed in a plastic bag and stored in thermal boxes containing ice, transported to the base of the Chico Mendes Institute for Biodiversity Conservation (ICMbio) 2018 in the Maracá-Jipiôca Ecological Reserve and identified (Nelson et al. 2016).

The Maracá-Jipiôca Ecological Reserve is located along the Atlantic zone of the State of Amapá. It has 750 km and extends between the mouth of the Oiapoque and Araguari rivers, being separated from the coast by the channels of Caraporis or Varadorouro de Maracá. It is made up of three islands: Maracá Norte, Maracá Sul and Jipiôca that are located on the river-marine floodplain, between the municipalities of Amapá and Oiapoque (Monteiro 2009).

This study was developed in accordance with the principles adopted by the Brazilian College of Animal Experimentation (COBEA), and with the authorization from ICMBio (#59031-1) and authorization from Ethics Committee on Animal Use of Embrapa Amapá (Protocol N° 014/2018).

Collection and analysis of parasites

At the site, the body surface, operculum and anus of fish were examined for the presence of ectoparasitic crustaceans. Fish were weighed (g) and measured in total length (cm), and necropsied for parasitological analysis. Gills were removed and fixed in 5% formalin for collection of ectoparasites and examined under stereomicroscope and microscope. The collection, fixation, preservation, counting and staining of the parasites for identification followed Eiras et al. (2006).

The ecological terms used for the parasite infracommunities followed Bush et al. (1997). We used the dominance frequency (percentage of the infracommunities in which a parasite species is numerically dominant) (Rohde et al. 1995; Magurran 2004). In order to detect the distribution pattern of the parasite infracommunities (Rózsa et al. 2000), the index of dispersion (ID) and the Poulin discrepancy index (D) were calculated using the Quantitative Parasitology 3.0 software for species with prevalence >10 %. The ID significance for each infracommunity was tested by *d*-statistics (Ludwig & Reynolds 1988). The length and body weight of fish were used to compare the relative condition factor (Kn) of parasitized and non-parasitized fish (Le Cren 1951) using the *t*-test. The correlation between the parasite abundance with length and weight of hosts was estimated using the Spearman correlation coefficient (Zar 2010).

Results

In *M. curema*, ectoparasite prevalence was 51.4%, and a total of 282 parasites were collected among *Ligophorus brasiliensis* Abdallah, Azevedo & Luque, 2009 (Monogenea: Dactylogyridae), *Excorallana longicornis* Lemos de Castro, 1960 (Isopoda: Corallanidae), larvae of *Gnathia* Leach, 1814 (Isopoda: Gnathiidae) and juveniles of *E. atafonensis* (Copepoda: Ergasilidae), but the dominance was of *L. brasiliensis* (Table 1).

Table 1
Species de ectoparasites in *Mugil curema* from the Amapá State estuary, northern Brazil.

Species of parasites	P (%)	MI	MA	TPN	FD (%)	SI
Monogenea						
<i>Ligophorus brasiliensis</i>	25.7	27.7	7.1	249	88.3	Brânquias
Crustacea						
<i>Excorallana longicornis</i>	2.9	3.0	0.09	3	1.1	Tegumento
<i>Ergasilus atafonensis</i>	17.1	1.8	0.3	11	3.9	Brânquias
<i>Gnathia</i> sp.	28.6	1.9	0.5	19	6.7	Brânquias
P: Prevalence, MI: Mean intensity, MA: Mean abundance, FD: Frequency of dominance, TNP: Total number of parasites, SI: Site of infection.						

Parasites presented a highly aggregated dispersion, except for *Gnathia* sp. that had a random dispersion pattern (Table 2). There was a predominance of hosts infected by zero and one species (Fig. 1).

Table 2
Dispersion index (ID), *d*-statistics and discrepancy index (D) for the ectoparasites infracommunities in *Mugil curema* from the Amapá State estuary, northern Brazil.

Species of parasites	ID	<i>d</i>	D	Dispersion type
<i>Ligophorus brasiliensis</i>	2.603	4.998	0.806	Aggregated
<i>Gnathia</i> sp.	1.412	1.492	0.756	Random
<i>Ergasilus atafonensis</i>	1.829	2.846	0.838	Aggregated

The relative condition factor (Kn) did not differ ($t = 0.56$; $p = 0.58$) between parasitized ($Kn = 1.00 \pm 0.001$) and non-parasitized hosts ($Kn = 0.99 \pm 0.04$). No significant correlation was found between parasite abundance with the length and weight of *M. curema* (Table 3).

Table 3
Spearman correlation coefficient (*rs*) of body parameters with the abundance of parasites in *Mugil curema* from the State of Amapá estuary (Brazil).

Parameters	Length		Weight	
	<i>rs</i>	p	<i>rs</i>	p
Parasite species	<i>rs</i>	p	<i>rs</i>	p
<i>Ligophorus brasiliensis</i>	-0.06	0.74	0.08-	0.66
<i>Gnathia</i> sp.	0.14	0.42	-0.02	0.92
<i>Ergasilus atafonensis</i>	0.03	0.85	0.14	0.41

Discussion

Parasite communities can be described quantitatively using several descriptors (e.g. abundance, intensity, richness, prevalence and diversity), which provide information on the structure of the parasitic community at different levels. Once the diversity and infection levels of parasites can be influenced by abiotic and biotic factors (Pedro et al. 2016; Santos et al. 2017; Neves & Tavares-Dias 2019), studies on species composition of parasites are required to understand the role of the parasite community in ecosystems (Mentz et al. 2016; Pedro et al. 2016; Neves & Tavares-Dias 2019). The ectoparasite community on *M. curema* was low, consisting of only one species of Monogenea and three species of Crustacea. Similar composition of the ectoparasite community was reported for *M. curema* from Puerto Rico, which was infected by two species of Monogenea and three species of Crustacea (Garcia & Williams 1985). However, the ectoparasite community in *M. curema* from the estuary of the State of Paraíba (Brazil) was composed of one species of Monogenea and six species of Crustacea (Golzio et al. 2017). In addition, the parasitic prevalence (51.4%) in *M. curema* from the coast of the State of Amapá was lower than reported for this same host species (94.6%) from the coast of the State of Rio Grande do Norte (Brazil), which was infected only by crustaceans *E. versicolor* and *E. lizae* (Cavalcanti et al. 2005).

In *M. curema*, *L. brasiliensis* and *E. atafonensis* presented an aggregated dispersion pattern, while larvae of *Gnathia* sp. had a random dispersion. Host fish populations represents a collection of patches of resources among which the parasites are heterogeneously distributed. In general, parasite infracommunities are distributed in an aggregated manner between individual hosts, regardless of whether they are from poor or rich communities. This means that most host fish have a few parasites, while most parasites are concentrated in a few hosts. This aggregation allows the coexistence of species that would otherwise be excluded; hence, more parasite species can coexist in the same host population (Salgado-Maldonado et al. 2019). However, it has also been reported random dispersion of parasites in fish populations (Fajer-Ávila et al. 2006; Pedro et al. 2016). The random distribution has been attributed to demographic randomness mechanisms. Specifically parasites are associated with a certain probability that an individual will die or a new infection will occur in a given time frame and with environmental randomness, which involves situations in which processes such as birth, death and immigration and emigration rates control the parasite population growth and are not constant for a given species, but depend on environmental factors (Von Zuben 1997; Pedro et al. 2016).

The body condition of fish may be expressed by the weight-length relationship and constitutes the condition factor of the individual and population. This body parameter is a quantitative indicator of welfare and body condition of a fish population, reflecting recent environmental and nutritional conditions, or even the effect of parasitism (Guidelli et al. 2009; Vasconcelos & Tavares-Dias 2016). Another consequence of parasitic infection in fish is body weight reduction, frequently associated with lipid decrease and muscle water content increase (Mentz et al. 2016). Fish size may influence the parasite load, since larger fish would present major infections due to longer exposure to the environment and larger contact with the ectoparasite species (Santos et al. 2017). However, in *M. curema* of the present study, the relative condition factor was not affected by the parasite load, as well as size (length

and weight) of the hosts. The reason might be because the infection levels were low and this mullet species is resistant to stressors, like parasites, and thus showed no clinical signs of diseases. In contrast, Santos et al. (2017) reported an increase in abundance of *E. versicolor* in *Mugil gaimardianus* (Desmarest, 1831) from the estuary of the State of Pará (Brazil) according to the size of hosts.

Species of *Ligophorus* (Euzet and Suriano, 1977) are monogeneans highly specific to mullet species, because such ectoparasites and these Mugilidae have a long coevolutionary process (Golzio et al. 2017; Pahor-Filho et al. 2019). However, these parasites can cause damages to gills of mullets, such as severe hyperplasia and necrosis of the respiratory epithelium (Pahor-Filho et al. 2019) depending on infection levels. *Mugil curema* of the current study was infected by *L. brasiliensis*, a monogenean species originally described in *Mugil liza* Valenciennes, 1836 from the Guandu River, in the State of Rio de Janeiro, Brazil (Abdallah 2009). In addition, the infection levels by *L. brasiliensis* were higher than that reported for this same host from the estuary of the State of Paraíba, which was infected by *Ligophorus mugilinus* (Hargis, 1955) (Golzio et al. 2017). Falkenberg et al. (2021) reported first time the record of *L. brasiliensis* for *M. curema*. Therefore, this is the second record of *L. brasiliensis* for *M. curema*.

Fish generally interact closely with the substratum in estuarine environments. Thus, fish ectoparasites are considered endemic components of the substratum of these environments and can reflect habitat conditions, which include their interactions with benthic and planktonic organisms (Fajer-Ávila et al. 2006). Parasitic crustaceans have varied life cycle and history. Williams Jr & Bunkley-Williams (2019) do not consider Corallanidae isopods as true parasites, because so little is known about their associations with host fish. Nevertheless, some species of Corallanidae are known by feeding on fish blood. We found *E. longicornis* infecting *M. curema* at a low infection level, similar finding was reported by Esteves-Silva et al. (2020), for this same host from Amapá coast (Brazil). Approximately 226 species of *Gnathia* in 12 genera and a single family are known around the world and although occurring at all latitudes they are more diverse and abundant in the tropics. The life cycle of Gnathiidae in fish is simple. The first juvenile stage occurs in fish, and the parasite that leaves the female finds a host, gorge and swell up with blood, and become the second stage (praniza larvae). The praniza larvae eventually drops off the host and finds a secluded place on the bottom to develop into the next phase, the zuphea, which swims up and finds a host to repeat this cycle (Williams Jr & Bunkley-Williams 2019). *Mugil curema* was infected by *Gnathia* sp. at a low infection level. Ergasilidae species are found mostly in freshwater ecosystems and sometimes in estuarine and shallow coastal water ecosystems (Boxshall & Defaye 2008; Williams Jr & Bunkley-Williams 2019). They present a simple life cycle with two phases: naupliar and copepodid (Williams Jr & Bunkley-Williams 2019). Although, in *M. curema* it was found *E. longicornis*, *Gnathia* sp., *E. atafonensis* and *E. longicornis*, this latter parasite species had the lowest infection level. This was the first record *Gnathia* sp., and second record of *E. longicornis* for *M. curema*.

Conclusions

This is the first study on the ectoparasites of *M. curema* from the estuary of the State of Amapá, showing new geographical records of parasites for this host collected in the northern Brazilian region. Furthermore,

the community of ectoparasites was composed of one species of Monogenea and three Crustacea, which were ectoparasites with low species richness, low prevalence, low intensity and abundance. Lastly, this is an important contribution to the knowledge of the regional parasite diversity, and serves as a basis for future studies.

Declarations

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Author contributions

All authors have participated in conception and design, or analysis and interpretation of the data; drafting the article or revising it critically for important intellectual content; and approval of the final version.

Compliance with ethical standards

Conflict of interest Authors declare that there is no conflict of interest regarding the publication of this paper.

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Figures

Figure 1

Species richness of ectoparasites in *Mugil curema* from the State of Amapá estuary (Brazil).