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Species diversity of brackish water fishes and their associated endoparasites from the Tamala Fish Sanctuary of Kapatagan, Lanao del Norte, Philippines

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Abstract. *Calderon AMA, Morilla LJG, Estaño LA. 2024. Species diversity of brackish water fishes and their associated endoparasites from the Tamala Fish Sanctuary of Kapatagan, Lanao del Norte, Philippines. Biodiversitas 25: 4745-4755.* Fish plays a vital role in the aquatic ecosystem and is integral to human nutrition and food security. The survey of brackish water fishes and its associated endoparasites in Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Philippines, was carried out in August 2023 in three coastal barangays of Taguitic, Margos, and Lapinig. A total of 174 individuals belonging to 5 families were collected, comprising six species: *Chanos chanos, Oreochromis niloticus, Oreochromis mossambicus, Glossogobius giuris*, *Mugil cephalus*, and *Ambassis nalua*. Among the recorded species, *M. cephalus* harbors the highest abundance (35.63%) and can be found in all three sites, while *O. mossambicus* is the least abundant (2.87%) and is restricted to only one site. Endoparasites in these fish species, comprising nematode, trematode metacercariae, and *Acanthogyrus* sp., were also recovered in this study. The prevalence of infection is reported to be highest in Barangay Taguitic (42.86%), followed by Margos (25.45%) and Lapinig (10.48%). Among the species, *C. chanos* (35.71%) recorded the highest infection rate, followed by *G. giuris* (29.73%), *O. niloticus* (26.09%), and *M. cephalus* (1.61%). In contrast, two species, *O. mossambicus* and *A. nalua,* were not infected with endoparasites. Adult species (24.74%) also exhibit the highest prevalence rate compared to juveniles (9.09%). In terms of intensity, Lapinig (7.64±0.23) has the highest value in the site, followed by Margos (1.5±0.10), then Taguitic (1.4±0.17). With regards to species, *G. giuris* harbors the highest mean intensity (7.82±0.62), followed by *C. chanos* (1.6±0.17), *O. niloticus* (1.42±0.10), and *M. cephalus* (1±0.02). Furthermore, adult fish species (4.33±0.25) exhibit higher mean intensity than juveniles (1.41±0.04). The mean intensity per site, species, and age were significant ($p<0.05$). Endoparasites in these brackish water fish hosts are an excellent biological indicator in aquatic ecosystems. This study provides baseline data for further investigation on fish species diversity and its endoparasites in the area.

Keywords: Brackish water fishes, diversity, endoparasite, prevalence

INTRODUCTION

Fishes are cold-blooded aquatic animals dependent on water for dissolved oxygen, support, food, and shelter. They have the most extensive vertebrate biodiversity, with over 33,000 species. 58% are marine, 41% are freshwater, and 1% are transitioning from freshwater to saltwater and vice versa (Helfrich and Neves 2019). The fish diversity is highly newsworthy to study, most especially in terms of the inventory of fish as an effort to underscore the biodiversity of aquatic species (Hasan and Islam 2020: Ihwan et al. 2020; Nurjirana et al. 2020; Ndobe et al. 2022). Among all habitats, freshwaters are regarded as one of the most biologically diverse with species classified into two groups: Primary freshwater fishes and secondary freshwater species, which differ in their emergence (Guzman and Capaque 2014). In the Philippines, the coastal ecosystem, with its expansive shoreline defined by mangroves and river connections, coral reefs, and seagrass communities, is home to a diverse range of fish with 3,417 species thus far identified (Froese and Pauly 2023). While most fishes evolved to dwell in either fresh or salt water due to their internal chemistry, others have developed ways to thrive in environments with moderate salinity, such as brackish water areas. These organisms of associated wetland environments are highly significant not only as dwellers of their habitats but also for regulating food web dynamics, nutrient balances, and food production (Helfrich and Neves 2019).

Brackish water ecosystems, specifically, play a key role to expanding the fisheries industry by offering nursery habitats, aiding in filtering and detoxification, and serving as migratory pathways for various aquatic species, hence providing vital ecosystem services (Guzman and Capaque 2014; Nurjirana et al. 2022; Hasan et al. 2023; Isroni et al. 2023). However, due to these contributing factors, they are then highly subjected to threats caused by anthropogenic activities, mainly overfishing, by-catch, and habitat modification, causing a gradual decline in their supply (Akinrotimi et al. 2015; Hasan and Widodo 2020; Hasan et al. 2021). Furthermore, these anthropogenic activities have also resulted in pollution, leading to the instability of living organisms (Bukola and Zaid 2015; Islamy and Hasan 2020) and promoting increased parasitism through alterations in biochemical, physiological, and behavior, specifically in nutrition, growth, and reproduction. Endoparasitic protozoans are capable of replicating in their hosts and increasing in abundance and potency when exposed to pollutants, implying that pollution influences parasites of aquatic animals, mainly fishes.

Endoparasites have a detrimental impact on fish in various ways, posing a possible threat to the sustainability of fisheries. These endoparasites can decrease host growth, survival, reproduction, and mortality and transmit diseases that reduce the aquaculture's competence (Koepper et al. 2022). According to the Food and Agriculture Organization of the United Nations (UN-FAO), the Philippines has several essential fishing grounds that have enabled the development of industrial and artisanal fishing activities, and fish consumption has been increasing with the Mediterranean diet's introduction in recent years (De Guia and Quiazon 2018). On the other hand, fish is integral to human nutrition and can contribute to food security. Humans may become accidental endoparasite hosts upon ingesting improperly cooked infected fish (Praveen et al. 2015). Fish-borne parasitic zoonoses are more prevalent in developing countries and may be attributed to their traditional preparation of fish dishes. For instance, anisakid nematodes are well-known to infect commercially important fishes and humans, causing clinical manifestations such as allergic reactions and gastrointestinal disorders (Ramos et al. 2020). The risk of fish-borne parasitic zoonoses caused by trematodes, cestodes, and nematodes has increased, giving rise to infection in humans through liver fluke diseases, intestinal trematodiasis, anisakiasis, and diphyllobothriasis. Humans' different activities and ways of survival allow them to be jeopardized by these diseases, from their contribution to habitat threats to consuming the organisms living in the same area (Akinrotimi et al. 2015; Tiempo et al. 2020; Marie and Petri 2023).

Tamala Fish Sanctuary is a critically essential wetland ecosystem in Kapatagan, Lanao del Norte, Philippines. This sanctuary covers 51.34 hectares of the 864-hectare municipality waters of Barangays Taguitic, Margos, and Lapinig, hence the name, comprising a part of Panguil Bay. The bay has been considered a natural spawning and nesting site for many economically important fin fish and invertebrate species (Canini and Metillo 2017), supporting thousands of small-scale fishers in northwestern Mindanao. Unfortunately, Panguil Bay has undergone a decentralized governance system, multiple resource utilization, and habitat modification. As a result of these exploitation activities, fisheries productivity has gone through a cycle of fluctuating abundance in response to changes. Since the sanctuary plays a vital role in fisheries ecosystem function and services, there is a need to document the important fish species in this area. No studies are being conducted in Tamala Fish Sanctuary on fish diversity and their associated endoparasites.

MATERIALS AND METHODS

Study area

Despite its size, Panguil Bay is a rich fishing field that sustains thousands of fishermen in Mindanao, Philippines. It has an area of 219 square kilometers and is divided into three provinces: Lanao del Norte, Zamboanga del Sur, and Misamis Occidental. Lanao del Norte has known coastal landing areas such as Maigo, Kolambugan, Tubod, Baroy, Lala, and Kapatagan including the study area, Tamala Fish Sanctuary (70°44’99” NW; 39°22’46” NE; 57°06’24” SE; and 39°55’11” SW) covering three coastal barangays of Barangay Taguitic, Barangay Margos, and Barangay Lapinig (Figure 1). Barangay Taguitic, Kapatagan, Lanao del Norte (7.954970°N; 123.655830°E) is considered the border of Tamala Fish Sanctuary on the west, located close to the end of Panguil Bay in the same direction and is characterized as a brackish water environment due to its transition from riverine habitat to the ocean, and vice versa. Barangay Margos, Kapatagan, Lanao del Norte (7.952300°N; 123.668180°E) is in between Barangay Taguitic and Barangay Lapinig. The specific study site lies where the river ecosystem meets the ocean, making it a brackish water ecosystem. Barangay Lapinig, Kapatagan, Lanao del Norte (7.958610°N; 123.676500°E) is the eastern border of Tamala Fish Sanctuary, facing near the center of Panguil Bay. The specific site has a brackish water ecosystem, considering that its water supply comes from the river and the ocean. Barangay Lapinig has notes of mangrove species and nipa palm, and there are also human settlements in the area (Table 1).

Table 1. Location sites in Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Philippines

Site	Coordinates	Description
Barangay Taguitic	7.954970°N; 123.655830°E	Considered the border of Tamala Fish Sanctuary on the west, located close to the end of Panguil Bay in the same direction, and is characterized as a brackish water environment due to its transition from riverine habitat to the ocean, and vice versa.
Barangay Margos	7.952300°N; 123.668180°E	In between Barangay Taguitic and Lapinig. The site lies where the river ecosystem meets the ocean, making it a brackish water ecosystem.
Barangay Lapinig	7.958610°N; 123.676500°E	Eastern border of Tamala Fish Sanctuary, facing near the center of Panguil Bay. It has a brackish water ecosystem, considering that its water supply comes from the river and the ocean. There are notes of mangrove species and nipa palm in the area, as well as human settlements.

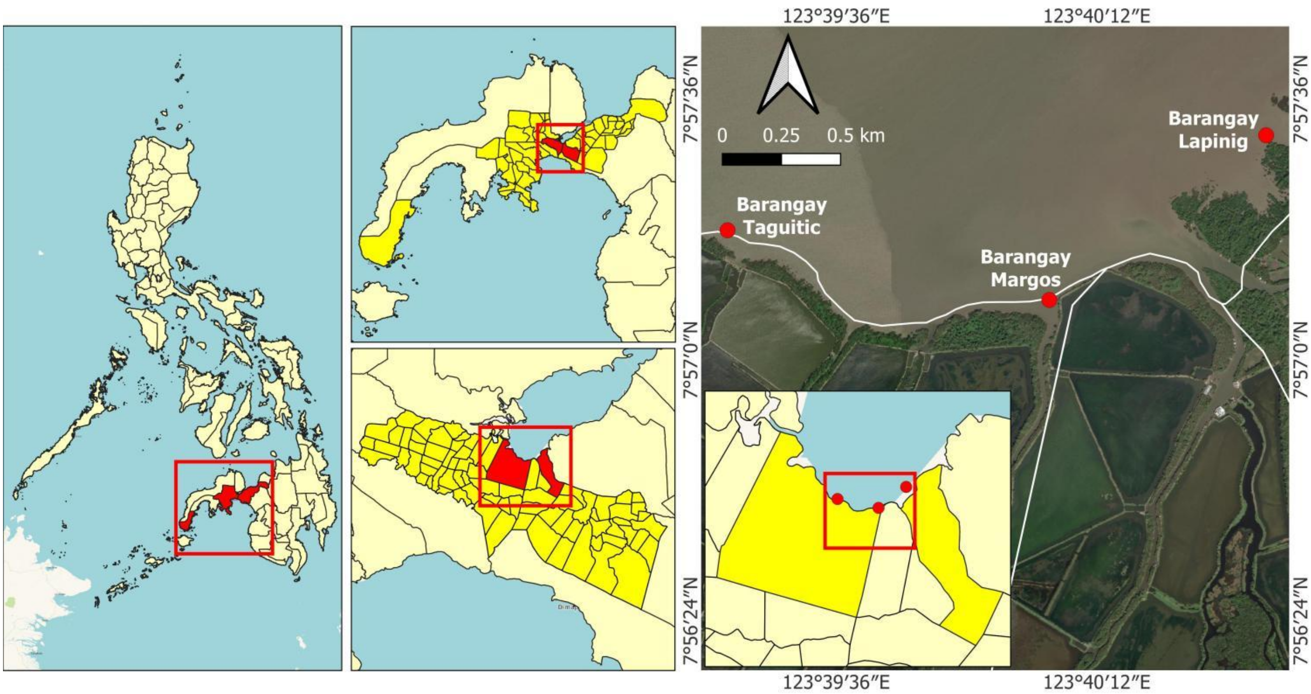

Figure 1. Map of Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Philippines showing the three sampling sites

Sampling design and collection of fish sample

Prior to the collection of samples, various permits were secured from the Bureau of Fish and Aquatic Resources of Kapatagan Lanao del Norte and from Local Government Units (LGUs) of study sites. Fish samples were caught using a fishing net in Barangays Taguitic, Margos, and Lapinig last August 2023 through one-shot sampling with the assistance of the watchmen and fishermen in the sanctuary. The selection of fish samples depended on the species caught using a cast net with a mesh size of 10 mm.

Processing and identification

The collected fish samples were preserved in an ice box and were transported to the laboratory for examination. The species were photo-documented for identification. The total length (mm) and weight (g) of each species were measured using a caliper and digital weighing scale, respectively, and these were used to classify their age class, which varies depending on the species. The age of the fish species was subdivided into two based on their length or weight. *Chanos chanos* (Forsskål, 1775), with a length ranging from 20-500 mm were assigned to juvenile age while individuals >500 mm are adults (Kumagai et al. 1985); *Oreochromis niloticus* (Linnaeus, 1758), <60 mm are juveniles, 60-280 mm are adults; *Oreochromis mossambicus* (Peters, 1852), <144 mm for the juvenile age, >144 mm for adults; *Ambassis nalua* (Hamilton, 1822), <79 mm are juveniles, >79 mm are adults; *Mugil cephalus* (Linnaeus, 1758), that measures <354 mm are classified as juveniles, >354 mm are adults (Harrison 1995); lastly, *Glossogobius giuris* (Hamilton, 1822), that is <105 mm were assigned as juvenile, and those that are 105-114.9 mm are adults (Arianti et al. 2017). Consultations on the local names of the species with the watchmen and local fisher folks were also conducted. Furthermore, the photographs of the parameters, such as the fins, tail, and body lengths, and their weights were presented to experts for further identification and verification.

Isolation and identification of parasites

The fish samples were removed from the ice box and stored upon transportation. They were carefully dissected to retrieve the visceral organs, and the endoparasites were separated and collected in a petri dish using a needle and a probe under a Dissecting Stereo Microscope (DSM). The isolated parasites were then photographed under a Compound Optical Microscope (COM). The identification of parasite species was conducted according to their morphology.

Physicochemical parameters of water

Water samples were obtained from each site of the three barangays sharing the sanctuary, particularly Barangays Taguitic, Margos, and Lapinig. Physicochemical parameters, precisely the water temperature, pH level, and salinity, were determined. These parameters were measured using a centigrade thermometer of 0°C to 110°C and a multi-purpose meter. The results obtained from each sampling site were used to analyze the relationship between the physicochemical parameters and the diversity of fish species through Canonical Correspondence Analysis (CCA) (Cheng et al. 2019).

Statistical analysis

The comprehensive determination of the biodiversity indices and canonical correspondence analysis of brackish water fishes were computed using the Paleontological Statistics software (PAST). These biodiversity indices are as follows: Shannon-Weiner, Evenness, and Dominance. The Shannon-Weiner Diversity Index is sensitive to the abundance and evenness of the measured species.

Prevalence rate and mean intensity of endoparasites

The prevalence rate and mean intensity of endoparasites in brackish water fishes were measured following the formula:

$$Prevalence\ (\%) = \frac{No.of\ infected\ fish}{Total\ no.of\ fish\ examined}\ x\ 100$$

This is to get the percentage of the host population infected with a parasite (prevalence) and the average number of individual parasites of a particular species present in an infected host (intensity). Finally, the obtained prevalence rate among ages, local sites, and species, and its differences were compared and analyzed using the Chi-square of independence test through SPSS v. 20.0 software, applying a confidence level of 95% (Estaño et al. 2020; Munda and Estaño 2020), while its statistical computation was performed using a web-based epidemiologic and statistical tool, OpenEpi.

RESULTS AND DISCUSSION

Species composition

A total of 174 individuals of brackish water fish belonging to 5 families and 6 species were collected in Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Philippines. The composition of these species includes the families Cichlidae, Chanidae, Mugilidae, Gobiidae, and Ambassidae. Cichlidae has the highest species richness, followed by the rest. The most represented species is from the family Mugilidae, specifically *M. cephalus*, with a total of 62 individuals, followed by *O. niloticus* (47), *G. giuris* (37), *C. chanos* (14), *A. nalua* (9), and lastly *O. mossambicus* (5) (Figure 2). All five species were classified as Least Concern (LC) under the International Union for Conservation of Nature Red List (IUCN 2019a,b; 2021; 2023; 2024) except for *O. mossambicus* which was categorized as Vulnerable (VU) (IUCN 2019c). This species of tilapia is listed as Vulnerable as it is threatened by hybridization due to its introduction to other locations for aquaculture (Bills 2019). The list of brackish water fishes, with their families, local names, and conservation status, were recorded in Table 2.

M. cephalus harbors the highest species abundance, accounting for a percent relative abundance of 35.63%. Its ecology influences this as they are catadromous and considered as migratory species (Rosario et al. 2022). Besides that, this species is also euryhaline and has been reported to be raging at 0-75 ppt salinity. This explains why they can be everywhere and thrive in brackish water environments (Bester 2023), similar to the sampling sites. Succeedingly, *O. niloticus* (27.01%) is the second most abundant species in the sanctuary because they are tolerant to different water salinity levels and are noted to grow well in brackish water environments compared to freshwater. Moreover, fingerlings of this species are also introduced to the sanctuary to improve fish catch and help local fishermen, which is why its population has increased significantly since then. *G. giuris* is the third abundant species, with a percent relative abundance of 21.26%; this result can be linked to their invasiveness and ecology as it is observed that this species feeds on insects, crustaceans, and other fish species in their habitat (Romero et al. 2023). *C. chanos*, although found to be highly adaptive, has harbored only a percent relative abundance of 8.05%; this is because it is also one of the popularly marketed species; hence, some of these individuals may have been harvested by the locals. The *A. nalua* has only 5.17% relative abundance, which can be due to its habitat preference, as they are primarily found in mangroves, and its presence outside of its habitat zone can be an effect of human activities that influence their movement. Lastly, *O. mossambicus* (2.87%) recorded the least; the reason for this could be that the species were just introduced in the area for livelihood and was mistaken for *O. niloticus*, one of the most cultured fish in the Philippines (Reyes and Cando 2019), considering that they only refer to these species as 'tilapia' in general.

Table 2. Checklist of brackish water fishes collected in Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Philippines

Scientific name	Common name	Conservation status	Occurrence	Site collected
Ambassidae				
Ambassis nalua (Hamilton, 1822)	Scalloped glassfish	Least Concern (LC)	Native	Lapinig
Chanidae				
Chanos chanos (Forsskål, 1775)	Milkfish	Least Concern (LC)	Native	Taguitic; Margos
Cichlidae				
Oreochromis mossambicus (Peters, 1852)	Mozambique tilapia	Vulnerable (VU)	Introduced	Margos
Oreochromis niloticus (Linnaeus, 1758)	Nile tilapia	Least Concern (LC)	Introduced	Lapinig; Margos
Gobiidae				
Glossogobius giuris (Hamilton, 1822)	Tank goby	Least Concern (LC)	Native	Lapinig; Margos
Mugilidae				
Mugil cephalus (Linnaeus, 1758)	Bluespot mullet	Least Concern (LC)	Native	Taguitic; Margos; Lapinig

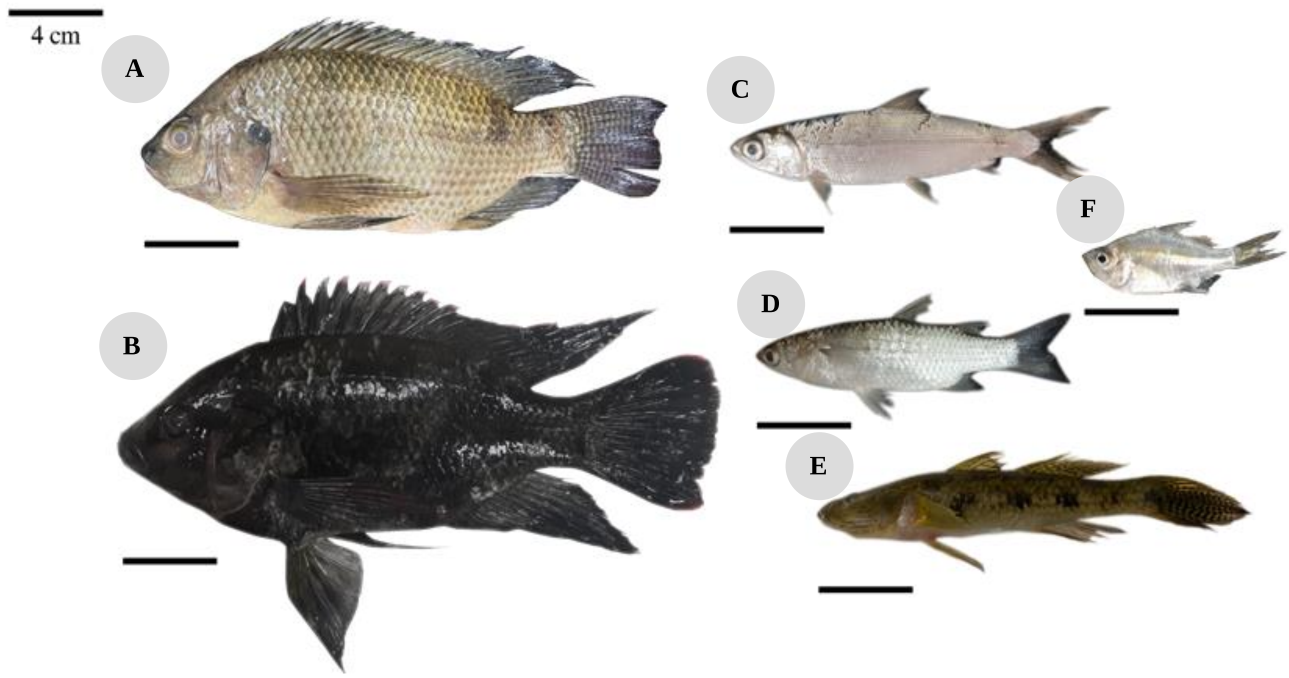

Figure 2. Brackish water fishes of Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Philippines: A. *Oreochromis niloticus*; B. *Oreochromis mossambicus*; C. *Chanos chanos*; D. *Mugil cephalus*; E. *Glossogobius giuris*; and F. *Ambassis nalua*

Table 3. Biodiversity indices of brackish water fishes in Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Mindanao, Philippines

Parameter	Taguitic	Margos	Lapinig
Taxa	2	5	4
Individuals	14	56	104
Dominance	0.6374	0.6805	0.433
Shannon	0.5553	0.7136	0.9637
Evenness	0.8712	0.4082	0.6554

Species diversity indices

Results for the biodiversity indices using the PAST software were obtained (Table 3). The Shannon-Weiner Diversity Index manifested that Barangay Lapinig (H' = 0.9637) has the highest species diversity, followed by Barangay Margos (H' = 0.7136) and Barangay Taguitic (H' = 0.5553). The same sampling site, Barangay Lapinig (104), accounted for the highest number of individuals, while Barangay Taguitic (14) recorded the least. In terms of species Evenness (e^H/S), Barangay Taguitic (e^H/S = 0.8712) has the highest value, followed by Barangay Lapinig (e^H/S = 0.6554), and then Barangay Margos (e^H/S = 0.4082). The results for the Dominance showed a different outcomes, as Barangay Margos (D = 0.6805) harbored the highest value, then Barangay Taguitic (D = 0.6374), and lastly, Barangay Lapinig (D = 0.433). Concerning the number of species per site, Barangay Margos recorded five species of brackish water fishes, Barangay Lapinig with four species, and Barangay Taguitic with only 2 accounted species.

Although the three sites are all located in an estuarine environment, where freshwater river flow meets the ocean, their data vary accordingly. Lapinig obtained the highest species diversity and abundance within the three sampling sites as it is at the sanctuary's border, closely adjacent to the center of Panguil Bay, and occupies a more significant portion of it than other sites. Additionally, Barangay Margos is located between Barangay Lapinig and Barangay Taguitic; for this reason, it possesses the highest number of species per site. However, it has fewer individuals and a lesser diversity index than Lapinig. According to Dyldin et al. (2020), numerous fishes are acknowledged for engaging in natural migrations throughout their life stages; with this, it became favorable for the two sites to have higher species diversity.

On the other hand, Taguitic has the least species richness, diversity, and abundance while also having the highest species evenness, and the structure of the bay could drive this. As observed, Taguitic is considered the other border for the sanctuary and is located closest to where the bay ends. It also has several water sources, including those that are beyond Tamala Fish Sanctuary, and this formation could result in the convergence of water flow, shifting species distribution, influencing migration patterns, and altering the variety of species in the area (Hays 2017). Furthermore, Margos follows Lapinig in terms of species diversity. However, it acquired the highest species dominance and lowest species evenness. The most dominant species in the area is the *O. niloticus*, an introduced species that became invasive. Previous studies by Hasan et al. (2019a), Serdiati et al. (2021), and Champneys et al. (2022) suggested that *O. niloticus* can effectively outcompete native species in their preferred habitat through dominance in interference competition; alongside this, other species tend to be displaced in their habitats and are opted to find alternative ones in order to find resources and thrive.

All three sampling sites exhibit a low species diversity, implying that they are in a physically controlled ecosystem subjected to physicochemical limiting factors. This is classified according to the diversity index criteria by Odum (1971), wherein an index that is equal to or above three (3) equates to high diversity, while those below or equal to one (1) have low diversity. This aligns with the findings of previous studies on fish assemblages in Lushan National Nature Reserve, which show that from 2008 to 2021, there was a decline in species composition and diversity due to multiple anthropogenic activities. Specifically, the water quality of the reserve has been altered due to pollution from domestic sewage and tourism waste, resulting in a decline in the population of fish species that are sensitive to such disturbances (Luo et al. 2022). Similarly, Tamala Fish Sanctuary is also exposed to several anthropogenic activities as there have been existing communities alongside the rivers that have connections to the bay, and there are also times when it is open to the public, contributing to domestic and tourism waste and habitat disturbance. As a comparison, Mahale Mountains National Park, designated as a protected area, has greater fish abundance and diversity than unprotected areas; prohibiting any fishing activities within the area seemed to play a role in this contrast (Sweke et al. 2013).

Cluster analysis

The similarity among the distribution of brackish water fishes was investigated (Figure 3). Two major clusters were formed in the analysis of the six species. The first major cluster manifested that *C. chanos* is related to *A. nalua* and *O. mossambicus* because these three species exhibited the most diminutive species abundance. No studies have been found on the relationship between *C. chanos* and the two species; however, this could be attributed to the anthropogenic disturbances they are experiencing that lead to such results being depicted. As previously mentioned, the abundance of *C. chanos* could be affected by the presence of local fishing in the area, considering its demand in the market. *A. nalua*, on the other hand, may be present outside of the mangrove ecosystem, which they consider as their habitat due to human activities that primarily impact their movement. In addition, the existence of *O. mossambicus* in the area is due to human intervention, specifically its introduction for fish catch improvement (Hasan et al. 2019b). The latter two species share more resemblance based on the cluster as these disturbances resulted in them being only present in one specific site, as compared to *C. chanos*, which was noted in two different locations despite having one of the lowest values in terms of abundance. Meanwhile, *O. niloticus* is also related to the three aforementioned species as they can be found in the same habitat, deducing that it can experience similar interferences. On the contrary, the second cluster shows the closest relationship between *M. cephalus* and *G. giuris*, as both are abundant in the same site. Their abundance in the specific location is also influenced by the presence of anthropogenic activities in the area, considering that among the three sampling sites, the area where *M. cephalus* and *G. giuris* thrive is more secluded as it is closely opposite to the center of Panguil Bay as compared to the others who are much more accessible.

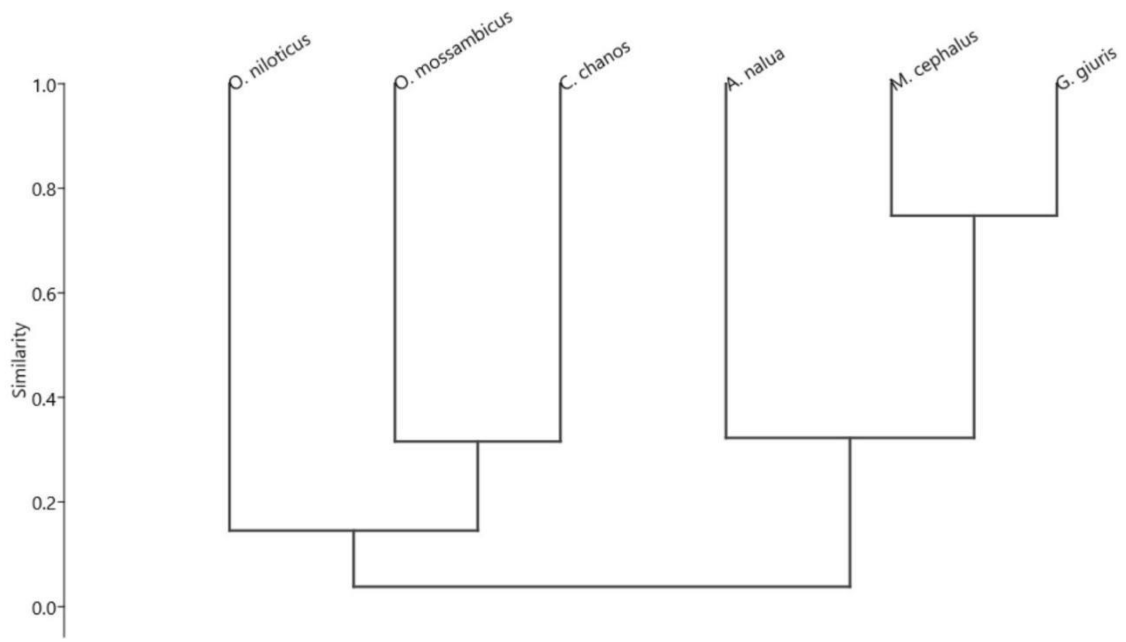

Figure 3. Cluster analysis of the distribution of brackish water fishes in Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Philippines

Physicochemical parameters

The physicochemical parameters of the three sampling sites, particularly water pH, water temperature, and salinity, were tested to examine their effects on species diversity and abundance (Table 4). Barangay Margos recorded the highest water pH, followed by Barangay Lapinig and Barangay Taguitic. All three sites are within the standard set by the Philippines Department of Environment and Natural Resources (DENR) regarding water quality suitable for waters designated as sanctuaries (pH = 7.0-8.5). Regarding the water temperature, it is Barangay Taguitic that had the highest value, and Barangay Margos and Barangay Lapinig have the same temperatures lower than that of Barangay Taguitic. These values are also within the standard water temperature DENR (2016) set, which is 26°C to 30°C. Meanwhile, Barangay Taguitic has the highest salinity level, followed by Barangay Lapinig, and the site with the least salinity level is Barangay Margos. Salinity levels vary among water types. Freshwater and marine waters have salinity levels of <0.5 ppt and >30 ppt, respectively (DENR 2016), while brackish water can be classified based on their salinity level ranging from 0.5 ppt to 30 ppt.

Concerning the study of Basavaraja et al. (2014), pH fluctuations are viewed as an indicator of general productivity as they impact the Ichthyofaunal habitats. A pH level of less than 5.0 (pH<5.0) can reduce aquatic diversity (Goldman and Horne 1983) as cited in Basavaraja et al. (2014) due to an increase of heavy metal solubility that also causes an increase in toxicity affecting the growth and development of fish species. On the other hand, a pH level of more than 10.0 (pH>10.0) damages their skin and gills. Classifying all three sites within the optimum pH range positively affects the species' diversity and abundance.

Water temperature is another critical factor in the abundance and diversity of species. It directly affects the metabolic rate of the fish and the ecosystem's production, which is necessary for these organisms to survive. A study by O'Connor and Booth (2021) on the response of estuarine fishes toward elevated temperatures highlighted the relationship between water temperature changes and species' productivity, dominance, and migration. When the temperature exceeds its optimal range, only those species with broad thermal tolerance will most likely be present in the area or survive (Booth et al. 2014). With this, it can be depicted that the abundance and diversity of brackish water fishes in Tamala Fish Sanctuary may be influenced by its water temperature values, which are within the ideal range.

Similarly, the changes in water salinity affect various fish species depending on their tolerance. Considering that Barangay Margos is classified as a freshwater environment while Barangay Taguitic and Barangay Lapinig are brackish water, this explains the differences in their accommodated species. In addition, the salinity gradient may also affect other physicochemical parameters, such as the dissolved oxygen concentration, which is vital for other organisms' survival, impacting the habitats' overall ecological balance.

Canonical Correspondence Analysis (CCA) indicates the significance of the environmental parameters and the presence of brackish water fishes (Figure 4). In particular, *O. niloticus* and *O. mossambicus* occurred to be associated with pH level that is close to neutrality (pH = 7) as these species are reported to grow in water ranging from 5-9 pH level for *O. niloticus* (Abd El-Hack et al. 2022), and 3.7-10.3 pH level for *O. mossambicus* (Froese and Pauly 2018) thus suggesting that both species are generally tolerant to different pH levels. Species such as *A. nalua*, *G. giuris*, and *M. cephalus* also correlate with salinity levels. As observed, *G. giuris* and *M. cephalus* are present in environments with saline and fresh salinity status, while *A. nalua* is present only in saline water based on the classification by the Department of Water. This phenomenon could be because all three species are freshwater fish that can tolerate salinity at a certain level compared to other species. On the other hand, *C. chanos* appeared to be less impacted by any of the following environmental factors, indicating that they are generalist species. Moreover, as previously mentioned, the water temperature may have influenced the species diversity and abundance. However, its impact may not be as profound as the other environmental parameters of specific species.

Recovered endoparasites

Of the 174 fish samples collected, 31 (17.82%) were infected with endoparasites (Table 5). The samples accommodate endoparasites belonging to phyla Nematoda, Acanthocephala, and Metacercariae Trematode. However, only the acanthocephala were identified at the genus level, specifically *Acanthogyrus* (Figure 5). These infections were recorded based on the parameters of sites, species, and age to compare their prevalence rate and mean intensity.

Prevalence rate of endoparasites

Based on the laboratory analysis, Barangay Taguitic (42.86% CI 21.38-67.41) harbors the highest prevalence rate, followed by Barangay Margos (25.45% CI 15.81-38.3), while Barangay Lapinig (10.48% CI 5.95-17.79) recorded the lowest rate of infection. As mentioned in the diversity indices analysis, all sampling sites exhibit a low species diversity due to physicochemical limiting factors that disturbances may drive. These disturbances could be anthropogenic activities that contribute to domestic and tourism wastes, considering that there are human settlements near the sites. In a study conducted by Abd-ELrahman et al. (2023) in Egypt, the elevated infection rate can be linked to the rising pollution levels that impact the well-being of fish, rendering them more vulnerable to parasitic infections. This is also supported by the study of Munda and Estaño (2020), wherein the variability of infection per site indicates differences in water quality, inferring that there is indeed a relationship between the prevalence rate of infection and the quality of each site as habitats for brackish water fishes.

Table 4. Recorded environmental parameters in Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Mindanao, Philippines

Environmental parameter	Taguitic	Margos	Lapinig
Water pH	7.70-7.76	7.81-7.86	7.70-7.74
Water temperature (°C)	29-31	29-30	28-30
Salinity (ppt)	2.43-2.47	0.42-0.45	2.07-2.1

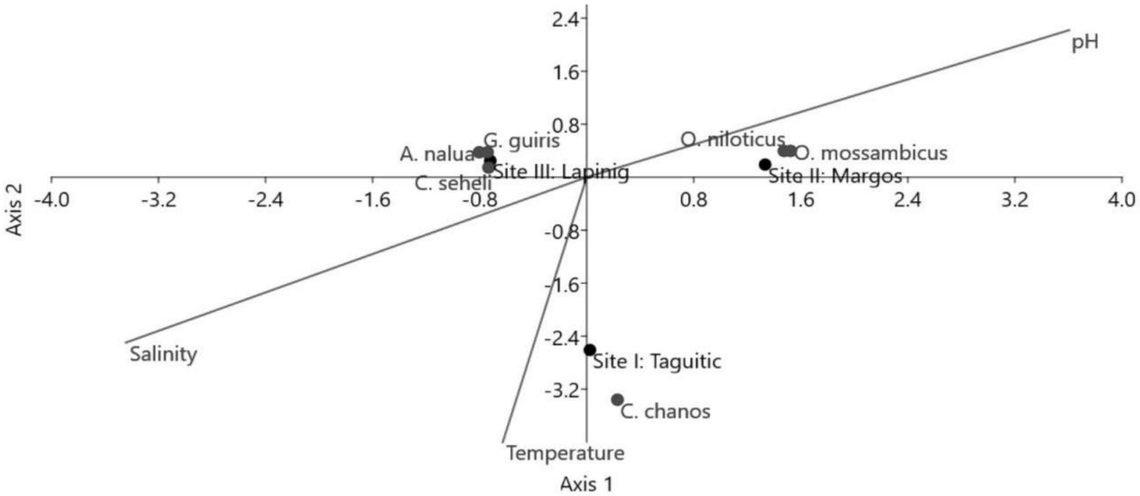

Figure 4. Canonical Correspondence Analysis of brackish water fishes and its associated environmental parameters in Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Philippines

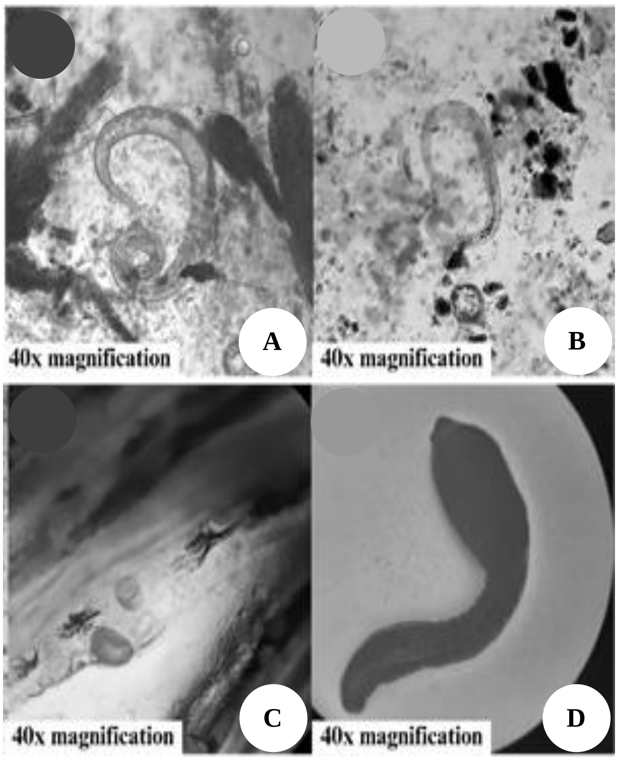

Figure 5. Endoparasites in brackish water fishes of Tamala Fish Sanctuary, Kapatagan, Lanao del Norte, Philippines at 40× magnification: A-B. Nematode; C. Trematode metacercariae; D. *Acanthogyrus*

In terms of species, *C. chanos* (35.71% CI 16.35-64.37) has the highest prevalence rate among all species. The presence of such parasites in *C. chanos* can be attributed to their feeding habits. They are reported to be herbivorous species but also consume a varied diet that includes omnivorous plankton, filamentous algae, and various types of detritus like worms and crustaceans (A'yun and Takarina 2019), which are said to be intermediate hosts for the larval stage of nematode species (Madsen and Stauffer Jr. 2024). *G. giuris* (29.73% CI 17.49-45.78) followed *C. chanos* regarding prevalence rate. Metacercariae of a trematode was present in the gills of this species, where samples collected were infected with trematode metacercariae on their gill filaments. Aside from their feeding habit's influence, which is similar to *C. chanos,* Mohan and Mamantha (2014) also highlighted how the complex life cycle of trematode can cause its prevalence. The life cycle of this organism involves multiple hosts: a bird or mammal, a first intermediate snail, and secondary intermediate host fish. Initially, it begins in the bird or mammal host. Eggs are defecated into the water, consumed by snails, and hatch into miracidium larvae. These larvae develop into cercaria larvae inside the snail and then shed into the water. Fish ingest these cercaria larvae, which develop into encysted metacercariae in the fish's gill filaments. This completes the life cycle, starting again with the consumption of infected fish by a bird or mammal host. *O. niloticus* (26.09% CI 15.6-40.26) is third among the highest prevalence rates and hosts the *Acanthogyrus*. The association between *O. niloticus* and *Acanthogyrus* can be linked to its food preferences, one of which is the arthropods, which is also an intermediate host for this species of the parasite during its larval stage until it finds a vertebrate definitive host during adulthood (Munda and Estaño 2020; Mathison et al. 2021). While parasites can be agents of zoonotic diseases, the sensitivity of *Acanthogyrus* to environmental changes makes them an efficient biological indicator. A study by Corpuz et al. (2016) describes the potential commensal relationship between the parasite species and their host as they exhibit metal sink capability that reduces the concentration of lead in the host, which may cause an adverse effect on its health. One of the species with the lowest prevalence rate is *M. cephalus* (1.61% CI 0.29-8.59), which is parasitized by a nematode. The low infection rate of this parasite in *M. cephalus* could be influenced by their preference to feed in the mid-water column (Ramos-Júdez and Duncan 2022), where most intermediate hosts cannot be found.

Table 5. Summary of infected brackish water fishes in Tamala Fish Sanctuary, Kapatagan, Lanao Del Norte, Philippines

Parameters	No. of samples	No. of infected individuals	Prevalence rate (%) (CI**)	Mean intensity
Sites*				
Taguitic	14	6	42.86 (21.38-67.41)	1.4
Margos	55	14	25.45 (15.81-38.3)	1.5
Lapinig	105	11	10.48 (5.95-17.79)	7.64
Species				
O. niloticus	46	12	26.09 (15.6-40.26)	1.42
O. mossambicus	5	0	0	0
C. chanos	14	5	35.71 (16.35-64.37)	1.6
M. cephalus	62	1	1.61 (0.29-8.59)	1
G. giuris	37	11	29.73 (17.49-45.78)	7.82
A. nalua	10	0	0	0
Age*				
Juvenile	63	7	10.44 (5.154-20.03)	1.41
Adult	85	24	28.24 (I19.77-38.5)	4.33

Note: *significant at $p<0.05$; **95% CI

Regarding host maturity based on size, 24 infected individuals are classified as adults (24.74% CI 17.23-34.18), while 7 are juveniles (9.09% CI 4.47-17.6). The collected data shows that adult species have a higher prevalence rate than juvenile species. Adult species have a higher infection rate because they are presumed to have a broader foraging and breeding range, which increases their vulnerability to picking up parasite infective stages from the environment (Munda and Estaño 2020).

Aside from the isolated parasites, microplastics were also retrieved from the visceral organs of the collected sample species, which were distinguished through their blue fiber-shaped composition. These species were found in *C. chanos*, *M. cephalus*, and *G. giuris,* species of fish primarily consumed by locals in the area. The particles inside these samples indicate that the area is polluted with plastic that may pose a risk to the environment, aquatic species, and humans when not regulated.

Contrary to the prevalence rate, the site that exhibits the highest mean intensity is Lapinig (7.64±0.23), followed by Margos (1.5±0.10) and Taguitic (1.4±0.17). The result from the Chi-square of independence test indicates that the infection per site is statistically significant ($p = 0.004$), inferring that variation of the site does influence the intensity of parasites. The mean intensity of both Taguitic and Margos are close to each other, which explains that their habitat compositions are also closely related to each other compared to Lapinig. The mean intensity per species was also compared, resulting in *G. giuris* (7.82±0.62) having the intensity rate, followed by *C. chanos* (1.6±0.17), *O. niloticus* (1.42±0.10), and *M. cephalus* (1±0.02). The Chi-square of independence analysis exhibits a significant difference among species. These differences can be explained by the varied life stages of the parasites present in the species that affected their infection mechanisms. Moreover, the different survival techniques of the host also affected the intensity of parasites in a way that they have varying responses to biotic and abiotic conditions, including those that are physical, resulting in a difference in intensity per species, which is also mentioned by El Assal and Mohamed (2018) in their study.

The variability of mean intensity based on age was also determined, which shows a significant difference between the mean intensity of juvenile and adult fish ($p = 0.009$). In this study, adult fish species (4.33±0.25) harbor a higher mean intensity than juveniles (1.41±0.04). This is due to adult foraging and breeding behaviors, which makes them susceptible to infection; they also have greater surface area and energy flux for parasite accumulation (Munda and Estaño 2020).

Overall, brackish water fishes in Tamala Fish Sanctuary are integral in providing ecosystem services to ensure food security. However, due to this function, they are often exploited and exposed to anthropogenic activities affecting their purpose in aquatic ecosystems. As they are subjected to different biotic and abiotic factors, they become vulnerable to parasitism, jeopardizing human health through the possible transmission of zoonotic diseases when consumed raw. The results of this study catalyze the urge for biodiversity conservation, environmental management, and public health awareness to ensure that there will be fewer threats and disturbances in the area and that different parasitic diseases will be regulated or inhibited. Since, human activities may change the natural function of the water system. Study of Hasan et al. (2023) suggested the protection of estuary ecosystem because many fish resources are used as a food source.

This study provides information about the diversity of brackish water fish species and their associated endoparasites in Tamala Fish Sanctuary, Kapatagan, Lanao del Norte. The presence of fish species can be influenced by environmental parameters and anthropogenic disturbances, similar to their associated endoparasites, making them vital for assessing one's health and the aquatic systems. Substantially, fish species are one of the most exploited species worldwide. Despite its importance in regulating food web dynamics and maintaining nutrient balances, it is often highly subjected to threats such as overfishing, by-catch, and habitat modification for food production, which causes a gradual decline in their population and an alteration in their biochemical and physiological, and behavioral aspects promoting an increase in parasitism. Though an integral part of human nutrition and food security, these species bring risks for zoonotic diseases caused by various parasites. With this, investigation of not only the diversity of fish species but also its associated endoparasites in a coastal area like Tamala Fish Sanctuary is necessary to contribute to its management practices and lessen the different parasitic diseases to protect and sustain biodiversity.

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