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Assessing the Prevalence, Diversity, and Evolutionary Rate Estimation of Endoparasites and Ectoparasites in *Oreochromis Niloticus* (Nile Tilapia) from Lake Sebu, South Cotabato

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ABSTRACT

An underestimated issue in fisheries are parasites that pose a public health risk through consuming undercooked or raw fish, which leads to harmful pathogen exposure. Therefore, this study aimed at determining the prevalence and diversity of endo- and ectoparasites present in *Oreochromis niloticus* (Nile tilapia) from Lake Sebu and to estimate the evolutionary rates of identified parasites by constructing an evolutionary rate phylogenetic tree. Moreover, a descriptive cross-sectional design was used with 27 mature tilapia collected through stratified random sampling through the littoral, inflow, and outflow zones. Then, parasites were identified using standard parasitological methods and the diversity and evolutionary rate were determined using MEGA and PAST software. The results then showed a common infection of the ectoparasite *Ichthyobodo* (33.33%) and a heavy infection of the endoparasite *Capillaria* (100%). Furthermore, parasite diversity had the highest relative rate in the littoral zone ($H' = 1.245$; $D' = 0.615$) compared to the inflow and outflow zones. Lastly, the evolutionary rate revealed that *Trichodina* (2.36) and *Digeneans* (2.15) evolved the fastest. Overall, the findings suggested the presence of parasites in Nile tilapia from Lake Sebu, therefore needing better management. To add, greater parasite diversity in the littoral area is likely due to favorable conditions brought by human activities. Moreover, most ectoparasite species showed faster evolutionary rates which suggests a more focused control as it may indicate fast adaptation to environmental changes and develop new infection which is difficult to eradicate.

INTRODUCTION

Parasites are an underestimated issue in fisheries, putting public health at great risk. Specifically, endoparasites, such as nematodes and trematodes, infect the internal organs of fish, whereas ectoparasites like anchor worms and fish lice infest the external fish body. Both parasite types can be transferred to humans by the consumption of raw or undercooked fish, leading to harmful pathogen exposure (Jennings *et al.*, 2016; Shamsi, 2019; Ziarati *et al.*, 2022). Moreover, lakes, being mostly enclosed with limited water exchange, can retain pathogens longer, increasing fish vulnerability to the spread of parasite (Falkenberg *et al.*, 2024). In particular, Lake Sebu, a key tourist destination in Lake Sebu, South Cotabato, covers 354 hectares and produces an estimated 2,000 to 2,500 metric tons of *Oreochromis niloticus* (Nile tilapia) annually which not only supports local livelihoods and serve neighboring regions but also meet high demands from tourists (Beniga, 2024). Finally, since research shows fish infection rates in Mindanao can reach 77.8% (Paglinawan *et al.*, 2022), the need for initiation in determining parasitic prevalence in Lake Sebu was a priority.

Studies conducted in different countries have reported significant prevalence of endoparasites and ectoparasites in freshwater fish, particularly tilapia. These parasites cause tissue damage, poor body condition, and mortality, with infection rates varying depending on species, habitat, and environmental conditions. Parasitic infections in

tilapia have been recorded with 40% tapeworms, 24% protozoa, and 22% amoebae (Acosta-Perez *et al.*, 2022). Moreover, in Egypt, 82% of tilapia were found with internal and 41% external parasites such as *Cichidogyrus*, *Gyrodactylus*, and *Trichodina* (Salwa *et al.*, 2023). While in Nigeria, infections included 32% tapeworms and 40.47% roundworms (Awosolu *et al.*, 2018) and in Ethiopia, 73% of tilapia were reported to host both internal and external parasites (Marshet *et al.*, 2019). These showcase a global widespread parasitic prevalence affecting one of the world's favored fish species.

In the Philippines, endoparasite prevalence in fish species ranges from 30% to over 60%, depending on location and species. For instance, 62% of tilapia in Las Piñas City were infected with Monogenean parasites affecting the gills, intestines, and other parts (Thessa 2016), 45% from other areas with *Acanthogyrus* spp (Munda, 2020), and 38% of wild Nile tilapia from Lake Mainit with *Neoechinorhynchus* spp. (Aninon & Paylangco, 2025). Furthermore, in Lake Taal, more than 40% of tilapia were infected with *Neoechinorhynchus* spp. These findings highlight the high and varied prevalence of parasites in Philippine tilapia populations, underscoring the need for continued assessment in local aquatic environments.

Despite the reported high infection rates of parasites in Tilapia, there is still a significant research gap in not only knowing the prevalence and diversity of endoparasites and ectoparasites but also their evolutionary patterns.

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Although the presence of parasites has been documented in the literature, very few studies have explored the evolution of the parasites over time, especially in a major aquaculture area like Lake Sebu. The lack of evolutionary rate estimation limits current knowledge on parasite adaptation, transmission dynamics, and the potential risks they pose to fish health and food safety. To address this gap, the study aimed to assess the prevalence and diversity of parasites infecting tilapia and to estimate their evolutionary rates using molecular sequence data providing insights that can help improve aquaculture management and protect public health.

Specifically, this study (1) determined the prevalence of endoparasites and ectoparasites in *Oreochromis niloticus* (Nile tilapia) from Lake Sebu; (2) assessed the diversity of the identified parasites present in the samples; (3) estimated the evolutionary rates of the identified endoparasites and ectoparasites by analyzing molecular sequence data and constructing phylogenetic trees; and (4) provided a policy brief discussing the food safety risks associated with parasitic infections in Nile tilapia and the implications of parasite evolution for aquaculture management and public health in Lake Sebu. The results supported the Sustainable Development Goals, SDG 3 Good Health and Well-being that promotes safe fish consumption, SDG 14 Life Below Water which protects aquatic ecosystems, SDG 2 Zero Hunger that supports stable fish supply for food, and SDG 1 No Poverty to help fishers maintain income through safe and marketable products.

MATERIALS AND METHODS

Materials

Twenty-seven Nile tilapia specimens were used which were the only tilapia species farmed in Lake Sebu, introduced in the 1970s for aquaculture (Pouder *et al.*, 2019), captured and transported using fishing nets, 27 plastic ziplock bags, and two large containers with ice. Laboratory equipment included light compound microscopes for parasite identification, sterile scalpels, scissors, tweezers, glass slides, cover slips, and dissecting pans. Parasite identification followed a guide (Cummings, 2018) on common freshwater fish parasites. Microsoft Excel was used to organize parasite counts, calculate parasite prevalence, mean intensity, and mean abundance while PAST software for biodiversity indices. Phylogenetic tree construction used the MEGA software.

Research Design

The design used was the descriptive cross-sectional which is non-experimental and involved collecting data at a single time period to describe existing conditions without changing any variables (Couillard *et al.*, 2017). This approach was appropriate because it allowed the researchers to assess the current parasitic condition of Lake Sebu Nile tilapia. The study focused on the presence, prevalence, and diversity of the endoparasites and ectoparasites. It was conducted from November

to December 2025, with samples collected from three sampling sites and three replicates per site to improve data reliability and represent parasite prevalence more accurately.

Procedure

Ocular Visit and Regulatory Compliance

An ocular visit was done in Lake Sebu, South Cotabato in order to evaluate the general condition and accessibility. It assessed the presence of the target fish and secured the designated sites for fish sampling. Furthermore, the study's regulatory compliance was taken from the Local Government Unit (LGU) and the Provincial Department of Environmental and Natural Resources Office (PENRO).

Site Selection and Stratification

The sampling design used was the stratified random sampling design which was used for choosing the sites shown in figure 1. The lake was stratified into three major ecological zones (strata) that influence parasite prevalence and diversity. These zones included the (1) inflow zone, where incoming streams can introduce parasites; (2) littoral zone, which is the main area for fish farming located near human settlements that can increase waste discharge leading to parasite prevalence; (3) outflow zone, where water movement may concentrate pathogens (Jovani & Tella, 2006). Within each zone (stratum), the sampling site was randomly selected using a Grid-Cell method that overlays a grid onto the map area with a number to each cell seen with fish pens. A number generator then randomly selected a number that correlates to a cell which ensures unbiased site allocation. Each site has a standardized dimension, 100 m² in both inflow and outflow zones, and a 15.2 m² radius plot in the littoral zone. Furthermore, 9 Tilapia were collected at each stratum, totaling for 27 fish hosts examined for optimal balance of effort and precision (Bertaglia *et al.*, 2023).

Fish Capture and Handling

Matured tilapia specimens were captured early with supervised by trained fishermen. Specifically selected with a normal size range of 20 to 30 centimeters, weighed 300 to 500 grams, as adult fishes are more susceptible to parasites (Peterson, 2025). Specifically, the specimens were humanely slaughtered through spiking, a method of inserting a small object to the brain for instant and painless death (World Health Organization, 2010). Furthermore, the specimens were separated based on their respective sampling sites using labeled ziplock bags before placing in a container with ice and water and underwent a one-hour transportation to the laboratory for dissection and parasite identification (Noga, 2010).

Ectoparasites Collection

All ectoparasite sample procedures followed standard parasitology dissection guidelines (Tesfay *et al.*, 2024). The collection involved placing the external scrapings

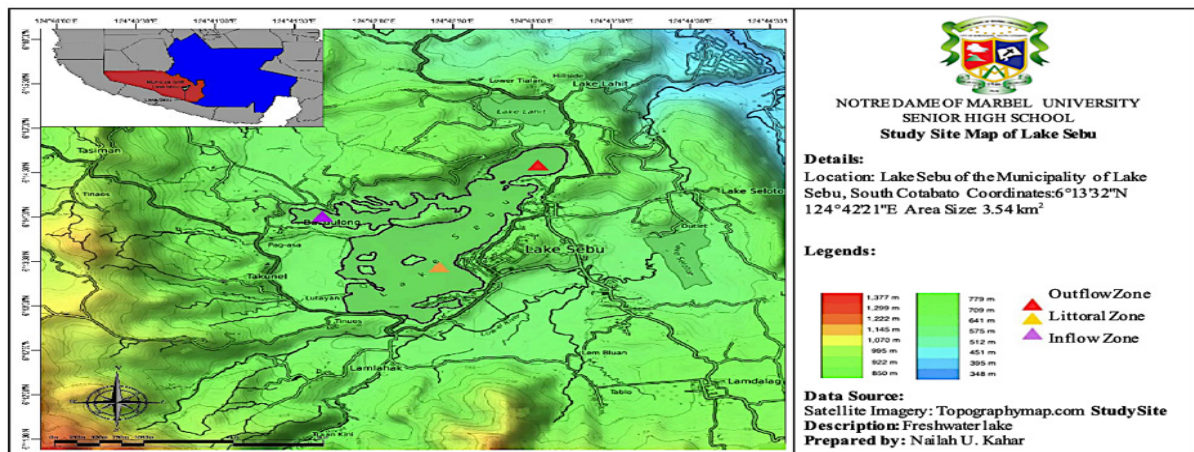


Figure 1: Study Site Map of Lake Sebu

on a glass slide and compressed with a coverslip. (1) The skin and fin were scraped from areas with mucus or any signs of swelling, bleeding, and skin lesions. (2) As for the gills, the operculum was lifted, and mucus from the gill surfaces was scraped.

Endoparasite Collection

All endoparasite sample procedures followed standard parasitology dissection guidelines (Tesfay *et al.*, 2024). Organs were removed from each fish and placed in a petri dish for examination. The collection involved placing a sliced section from the organ onto a glass slide and compressed with a coverslip. (1) The GIT was removed at both ends from the abdominal cavity, opened along the ventral midline, starting from the anus to the base of the operculum. A scraping from the lining was collected. (2) In the muscle tissue, 5-10 μ m slices of muscle tissue were taken at the epaxial muscle. The swim bladder was sliced among the viscera and removed by detaching it at the anterior and posterior ends. (3) The gonads were sliced from the dorsal body wall. (4) The liver was sliced from the cranial region of the abdominal cavity, positioned ventrally and behind the heart. (5) The heart was sliced

from the sinus venosus to the bulbus arteriosus.

Endoparasite and Ectoparasite Preservation

The slides were preserved by sealing the edges of the coverslips with nail polish. Each slide was labeled with the fish sample number and sampling location to maintain proper identification and record-keeping. Slides were examined under a microscope and the identification used a pictorial guide along with expert (Cummings, 2018).

Parasite Prevalence

The parasite prevalence (Eq 1.) was calculated to identify how widespread the infection were. The mean intensity (Eq 2.) was used to calculate the average number of parasites per infected host, while the mean abundance (Eq. 3) was used to show the average number of parasites per host with both the infected and uninfected. These were then classified using a unified Standardized Framework (Na, 2008) (Table 1) to ensure consistency in parasitology reporting across studies (Aacl, 2024; Battistuzzi, 2011). Where N is the total number of hosts examined, H+ is the number of infected hosts, and P is the total number of parasites counted.

$$\frac{H^+}{N} \times 100$$

Eq. 1: Parasite Prevalence

$$\frac{P}{H^+}$$

Eq. 2: Mean Intensity of Infection

$$\frac{P}{N}$$

Eq. 3: Mean Abundance of Infection

Where N is the total number of hosts examined, H+ is the number of infected hosts, and P is the total number of parasites counted.

Table 1: Standardized Classification of Parasite Prevalence, Mean Intensity, & Mean Abundance

Metric	Value range	Classification	Description
Prevalence (%)	90-100	Very High	Parasites are present in almost all examined hosts, indicating widespread infection in the population.
	70-89	High	A large proportion of hosts are infected, suggesting strong parasite presence in the environment.
	50-69	Moderate	More than half of the hosts are infected, showing a common but not universal occurrence.
	30-49	Low	Infection occurs in a considerable minority of hosts, indicating limited distribution.
	10-29	Very Low	Only a small portion of the population is infected.
	<10	Rare	Parasites are infrequently detected and occur sporadically.

Mean Intensity (Parasites per infected host)	<1	Very low	Infected hosts carry very few parasites, indicating minimal infection severity.
	1-5	Low	Hosts exhibit light infections with limited potential impact on health.
	6-50	Moderate	Parasite load is noticeable and may cause subclinical effects.
	51-100	High	Hosts carry heavy parasite burdens that may impair normal physiological functions.
	>100	Very High	Severe infection with a high risk of stress, disease, or mortality.
Mean Abundance (Parasites per examined host)	<1	Very low	Parasites are rarely encountered across the examined population.
	1-5	Low	Parasites are present at low levels within the population.
	6-50	Moderate	Parasites occur at moderate levels, reflecting sustained transmission.
	>50	High	Parasites are abundant across hosts, indicating intense environmental exposure.

Parasite Diversity Assessment

Parasite diversity was assessed using the identified number of parasite genus per zone. The Shannon-Weaver Diversity (H') was used to indicate the presence of more parasite genera, including less common types, while the

Simpson's Diversity Index (D') suggested a more even distribution of parasites with less dominance by any single genus. The metrics then followed a standardized interpretation in table 2.

Table 2: Biodiversity Metrics & Interpretation

Shannon-Weaver Diversity (H')	Simpson's Diversity Index (D')	Interpretation
≥ 1.80	≥ 0.75	Very High
1.40-1.79	0.60-0.74	High
1.00-1.39	0.40-0.59	Moderate
0.50-0.99	0.25-0.39	Low
<0.50	<0.25	Very Low

Parasite Evolutionary Rate Estimation

The evolutionary rate of the identified parasites was examined by downloading the corresponding FASTA sequences from the NCBI bank, particularly using 16 ribosomal RNA and a uniform length of approximately 1,000 base pairs per taxon. A Molecular Clock Test using the Maximum Likelihood method was performed to determine whether the parasite lineages evolved at a constant rate (EMBL-EBI, 2025) while a phylogenetic time tree was generated using the RelTime method, which allows variable estimates of divergence times (Sanderson, 2002; Reyes & Cando, 2019):

time shows that they can adapt, which makes regular monitoring and policy action necessary.

Data Analysis

The parasite prevalence was analyzed in Microsoft Excel, while the diversity was quantified using PAST (Paleontological Statistics), a scientific data analysis computer software. The Molecular Clock Test and phylogenetic time tree were constructed using the MEGA (Molecular Evolutionary Genetics Analysis), a computer software. The overall findings were then summarized and presented through descriptive tables and figures.

Policy brief on food safety risks associated with parasite prevalence, diversity, & evolution in Nile tilapia

A policy brief was made to turn the study's findings into useful actions for DENR-XII, BFAR, the Lake Sebu LGU, and the communities. The study showed three core insights: (1) the high number of parasite infections can harm public health, fish production, and the livelihood of fisherfolk; (2) the presence of many parasite species shows patterns in parasite variety and how they spread within the lake; and (3) the rate of parasite change over

Ethical Consideration

The collected data by the researchers were strictly used for its academic purposes to bring objective results. Furthermore, no plagiarism and use of Artificial Intelligence (AI) was involved for any information and results in the study was ensured by the researchers.

RESULTS AND DISCUSSION

Nile Tilapia Parasite Prevalence in Lake Sebu

Table 3 shows Capillaria was the most common endoparasite, with a (100%) prevalence, the highest mean

Table 3: Parasite Distribution, Prevalence, Mean Abundance, & Mean Intensity in *O. niloticus* from Lake Sebu (n=27)

Parasite	Phylum	Infections Site(s)	Host infected	Parasites recovered	Prevalence (%)	Mean Abundance	Mean Intensity	Range
Ectoparasite								
Ichthyobodo	Euglenozoa	Sc	9	29	33.33%L	1.07L	3.22L	0-5
Trichodina	Ciliophora	G, Sc	5	12	18.52%VL	0.44VL	2.4L	0-6
Dactylogyrid	Platyhelminthes	G	4	4	14.81%VL	0.15VL	1L	0-1
Argulus	Arthropoda	Sc	1	1	3.71%R	0.04VL	1L	0-1
Endoparasite								
Capillaria	Nematoda	Liv, GIT, SB	27	166	100%VH	6.15M	6.15M	0-5
Camallanus	Nematoda	MT, Gon, Liv Hrt, GIT	7	7	26%VL	0.26VL	1L	0-1
Digeneans	Platyhelminthes	Sc	11	16	40.74%L	0.60VL	1.45L	0-2
Cryptobia iubilans	Euglenozoa	GIT	3	5	11.11%VL	0.19VL	1.67L	0-3

Note: 1 Location Abbreviations: Sc=scales; G=gills; Sk=skin; GIT=gastrointestinal tract; Liv=liver; Hrt=heart; Gon=gonads; SB=swim bladder; MT=muscle tissue.

Note: 2 Classification codes: Superscript letters indicate infection levels based on standardized categories

abundance, and the highest mean intensity (both 6.15), that indicated significant infection. In contrast, *Cryptobia iubilans* had the lowest parasitic values, with a prevalence of (11.11%), a mean abundance of 0.19, and a mean intensity of 1.67. *Ichthyobodo* was the most prevalent ectoparasite (33.33%). It had a low mean abundance of 1.07 and a low mean intensity of 3.22. In comparison, ectoparasite, contrasting with the present findings where digenean trematodes were most abundant (David, 2016). This difference suggests that parasite composition varies across lake environments. The dominance of *Capillaria* in Lake Sebu may indicate increased infection pressure that impair overall fish health as chronic nematode infections are known to cause intestinal damage, ultimately lowering fish productivity (Paperna, 1996). Moreover, high nematode burdens are commonly associated with

Argulus had the lowest ectoparasite prevalence (3.71%), very low mean abundance (0.04), and low mean intensity (1.00). All of these findings suggest that Nile tilapia from Lake Sebu may be vulnerable to parasite pressure, posing a threat to public health.

In comparison, pond-reared Nile tilapia in Pampanga reported *Trichodina* spp. as the most prevalent and intense environmentally stressed freshwater systems (Abiyu *et al.*, 2020; Taal, *et al.*, 2017). Compared with other tropical lakes where endoparasite prevalence typically ranges from 10–40% (Esch *et al.*, 1990) the unusually high occurrence of *Capillaria* in Lake Sebu suggests the need for improved management and routine parasitological monitoring to support sustainable tilapia production.

Figure 2 shows ectoparasites isolated from *O. niloticus*. *Ichthyobodo* (A) is a pear-shaped protozoan with a

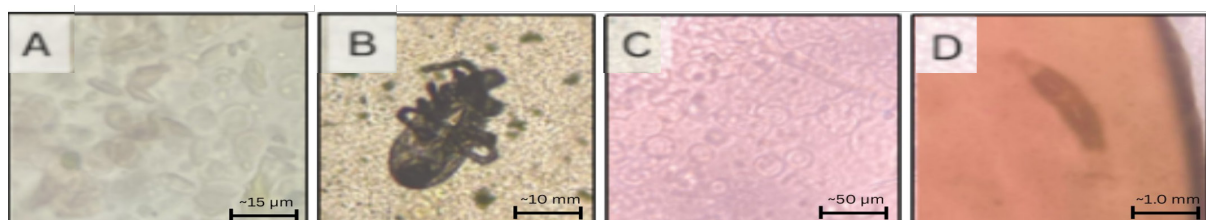


Figure 2: Representative Ectoparasites Isolated from *O. niloticus*. (A) *Ichthyobodo*, (B) *Argulus*, (C) *Trichodina*, (D) *Dactylogyrid*

flagellum. *Argulus* (B) is a vertically flattened crustacean with a broad carapace. *Trichodina* (C) is a circular, disc-shaped ciliate. *Dactylogyrid* (D) is a monogenean flatworm with an elongated body and a posterior

opisthaptor bearing hooks. Each parasite was identified based on these morphological characteristics following the literature of Noga (Tesfay *et al.*, 2024).

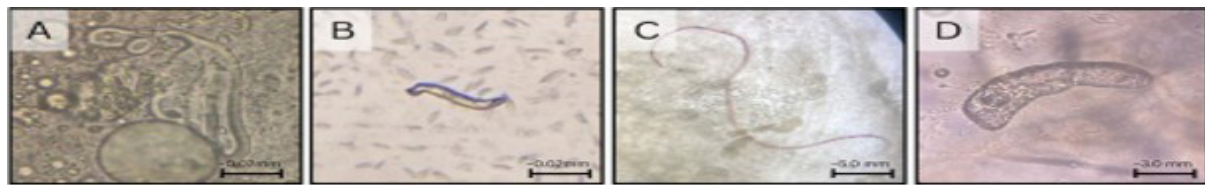


Figure 3: Representative Endoparasites Isolated from *O. niloticus*. (A) *Capillaria*, (B) *Cryptobia iubans*, (C) *Camallanus*, (D) *Digeneans*

Figure 3 shows representative endoparasites isolated from *O. niloticus*. *Capillaria* (A) is a long, slender, thread-like nematode with a smooth, uniform body, which is typical of this genus. *Cryptobia iubans* (B) is a small, slightly curved protozoan with a flagellum-like structure that helps it attach to the host's tissues. *Camallanus* (C) appears as a thicker, coiled nematode with visible

surface structures along its body, distinguishing it from the thinner *Capillaria*. Lastly, *Digenean* (D) is a flatworm with a broad, flattened body and a distinct oral sucker, allowing it to attach to host organs, which is characteristic of trematodes. Each parasite was identified based on these morphological features following the literature of Noga²³.

Table 4: Parasite Diversity Indices of *O. niloticus* Across Sampling Zones in Lake Sebu

Sampling Zone	No. of Genera	Parasite Present	Total Parasites Recovered	Shannon-Wiener Diversity Index (H')	Simpson's Diversity Index(D')
Littoral	7	Dactylogyrid, Digenean, Camallanus, Capillaria, Cryptobia Iubans Ichthyobodo, Trichodina	118	1.24M	0.61H
Inflow	5	Digenean, Dactylogyrid, Capillaria, Camallanus, Trichodina	66	0.75L	0.36M
Outflow	5	Argulus, Digenean, Dactylogyrid, Capillaria, Camallanus	60	0.74L	0.34L

Note: VL=Very Low, L=Low, M=Moderate, H=High, VH=Very High

Nile Tilapia Parasite Diversity in Lake Sebu

Table 4 shows differences in parasite diversity of Nile tilapia in Lake Sebu among the sampling zones. Overall, the littoral zone has the highest diversity indices with 7 parasite genera having a moderate Shannon–Wiener value ($H'=1.24$) and a high Simpson value ($D'=0.61$). This provides a clearer picture that the littoral zone may possibly support both greater diversity and balance of parasite genera than the other zones. To add, this suggests that the littoral zone, closest to the residential and tourist area, should have better management control and focus. Several studies have shown that littoral zones often support higher parasite and species diversity than other

parts of freshwater systems due to their complex habitats and higher biological activity. Littoral areas typically contain more vegetation, organic matter, and shelter, which can support a greater number of hosts, creating conditions ideal for parasite survival and transmission (Marcogliese, 2004 & Kennedy, 2009). Increased host availability and stable environmental conditions in areas near the shore have also been linked to higher parasite diversity in freshwater fish (Abdelkhalek, *et al.*, 2018). These findings support the pattern observed in Lake Sebu, where the littoral zone showed higher parasite diversity compared to inflow and outflow areas.

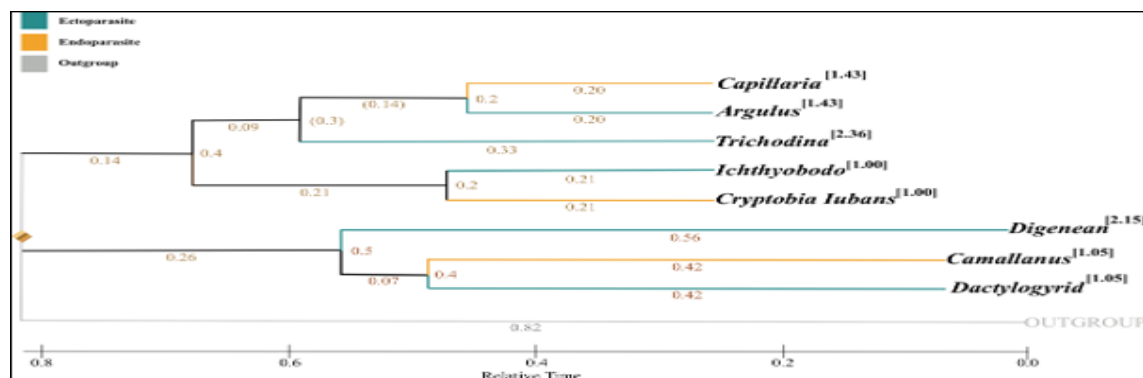


Figure 4: Estimated Evolutionary Rate Phylogenetic Tree of Parasite Taxa Identified from *O. niloticus*

Lake Sebu Parasite Evolutionary Rate Estimation

Figure 4 shows the estimated evolutionary rate of the phylogenetic tree under the Without Clock model as analysis showed that the evolution rates of the parasites varied, with branch values representing genetic change over time. The x-axis time shows the relative timeline of evolution for each parasite, indicating how long each existed and evolved compared to each other. The values in brackets above each parasite are the solved estimated evolutionary rates that show ectoparasite Trichodina having the highest relative evolutionary rate (2.36) which means more genetic change and adaptation. In contrast, Camallanus and Dactylogyrid showed lower rates (1.05) that relatively means minimal and slower evolutionary processes. These differences in evolutionary rates may pose alarming implications for the Lake Sebu management and public health. For instance, faster-evolving parasites can adapt to new infection strategies against tilapia immune defenses which leads to diseases harder to control. To add, as the ectoparasites mostly showed higher rates than the endoparasites, this shows that they may rapidly adapt to fluctuating water quality and overstocking in Lake Sebu (Koniyo *et al.*, 2020 & D'Bastiani *et al.*, 2021).

Similarly, Trichodina sp. was found to evolve effectively to overcome the immune defense of Nile tilapia leading to severe threats to the gills and scales (Cable *et al.*, 2017). Furthermore, it was also identified to be a dominant ectoparasite on red tilapia with high intensity and prevalence attributing to its rapid multiplication (Mendoza-Palmero *et al.*, 2015). Furthermore, ectoparasites host-switch more intensely than endoparasites which risks diversification, this supports the results of most ectoparasites evolving faster (Lymbery *et al.*, 2020). In ecological studies, the differences in evolutionary rates significantly makes diseases difficult to control as parasites have shorter generation times and higher mutation rates than hosts leading to increased virulence and resistance to treatments in fisheries that can undermine long-term disease control efforts (Aacl, 2024).

monitoring and proper fish management are essential for protecting public health and sustaining tilapia production in Lake Sebu.

Recommendations

Based on the results, there are many actions that are recommended in order to decrease the risks of parasitic infections in Lake Sebu and ensure safe and sustainable tilapia production. (1) The monitoring of parasite levels should be concentrated in the littoral area, which is where the diversity and intensity of infection are highest. (2) Improving water quality, for example by reducing organic waste, avoiding overstocking, and improving lake sanitation, should also be considered a priority because poor water conditions can facilitate faster parasite development. (3) Aquaculture managers are advised to observe proper stocking density, regular pond cleaning, and regular health checks to avoid transmission among

Policy Brief on Food Safety Risks Associated with Parasite Prevalence, Diversity, and Evolution

A policy brief presented the background on food safety and aquaculture risks and summarized key findings showing high parasite prevalence, including a 100% infection rate of Capillaria, and higher parasite diversity in littoral zones, particularly in tourist and nearby residential areas. These findings were linked to food safety risks, parasite transmission, and adaptive evolution, and were translated into practical recommendations for LGUs, BFAR, DENR, and fisherfolk communities. The policy brief recommends that monitoring and management activities should focus on littoral areas, particularly tourist sites and residential areas, because of the higher parasite diversity found in these areas, which indicates a higher risk of transmission and a greater threat to public health, fish quality, and livelihood sustainability emphasizing the importance of monitoring, better aquaculture practices, and food safety education. The policy brief is attached in the appendices.

CONCLUSION

This study concludes that the ectoparasite Digenean show more common infection rates and the endoparasite Capillaria show more heavy infection rates. While ectoparasite Argulus occasionally infects Nile Tilapia. Furthermore, the level of parasite diversity varied with the littoral zone showing low to moderate diversity but relatively higher compared to the inflow and outflow zones. The estimated evolutionary rate analysis revealed that Trichodina and Digenean are evolving more rapidly than Dactylogyrid and Camallanus which relatively evolved the slowest. These indicate that high levels of parasite infection, high parasite diversity, and the difference of evolving species, threaten fish health, food safety, and the sustainability of tilapia farming. These findings relate to SDG 3 by highlighting potential health risks, SDG 14 by emphasizing freshwater ecosystem health, SDG 2 through threats to food security, and SDG 1 by affecting livelihoods dependent on aquaculture. Therefore, regular fish. (4) Policymakers, including the Municipality of Lake Sebu, DENR, and BFAR, should include these findings in long-term management plans to ensure that rapidly changing parasites are closely monitored. (5) Future research should compare across more, use a single molecular marker such as the 16S rRNA, include seasonal observations, and study parasite–host immune interactions to improve predictions of parasite spread and adaptation in Lake Sebu.

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