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[1]Department of Veterinary Pathology, Microbiology and Parasitology, Faculty of Veterinary Medicine, University of Nairobi, P.O. Box 29053-00625, Kangemi, Nairobi, Kenya

[2]Kenya Fisheries Service, Nakuru County, P.O. Box 12261-20100, Nakuru, Kenya

[3]Department of Veterinary Pathology, Microbiology and Parasitology, Faculty of Veterinary Medicine and Surgery, Egerton University, P.O. Box 536-20115, Egerton, Kenya

[4]WorldFish, Malaysia

[5]Norwegian Veterinary Institute, Fish Health Research Group, P.O. Box 64,1431 AS, Norway

[6]Department of Hydrobiology, Veterinary Research Institute, National Research Centre, Giza, 12622, Dokki, Egypt

Corresponding Author:
Finnan O Ageng'o
[1] Department of Veterinary Pathology, Microbiology and Parasitology, Faculty of Veterinary Medicine, University of Nairobi, P.O. Box 29053-00625, Kangemi, Nairobi, Kenya
[2] Kenya Fisheries Service, Nakuru County, P.O. Box 12261-20100, Nakuru, Kenya

Management practices and risk factors associated with parasitic infestations in farmed Nile tilapia in Bomet and Kericho counties, Kenya

[1, 2]Finnan O Ageng'o, [1]Robert M Waruiru, [1]Philip N Nyaga, [3]Daniel W Wanja, [1]Nicodemus M Kamuti, [1]Edith A Keya, [1]Jacob M Wainaina, [1]Paul G Mbuthia, [1]Mercy M Hamisi, [4]Mohan V Chadag, [4, 5, 6]Shimaa E Ali and [1]Beatrice M Munde

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Abstract
The aquaculture has surged in Kenya owing to dwindling wild stocks. However, this is coupled with challenges such as limited fish health knowledge and biosecurity measures. A cross sectional study was undertaken to determine risk factors and management practices associated with parasitic infestation of farmed Nile tilapia in Bomet and Kericho counties, Kenya. A total of 150 Nile tilapia (*Oreochromis niloticus*) were collected and subjected to standard parasitological examination. Potential risk factors associated with parasitic infestation in fish were assessed in 88 farms using pretested semi-structured questionnaires and on-site farm visit observations. Logistic regression analysis with the estimation of odds ratios (OR) was used to assess potential risks factors. Tilapia were dominant fish (>95%) and were farmed mainly in earthen ponds (> 61%). Most farmers (52.3%) used river water for ponds and 14% had experienced floods that introduced predators in the ponds. Farmers relied on fisheries department harvesting nets and only 12.5% sun dried the nets after use. Few farmers (37.5%) frequently cleaned and dried ponds before restocking, while 34.1% did not remove the pond bottom soil after fish harvesting. Approximately 3.4% of the farmers rated diseases as the main obstacle in fish farming and, 68.2% could not identify sick fish. Those who identified sick fish reported abnormal swimming (23.9%) and mortality (8%). Out of the 150 fish sampled, 62 (prevalence = 42%) were found to be infected with different genera of parasites including: *Dactylogyrus* spp. (21%); *Epistylis* spp. (7.3%); *Riboscyphidia* spp. (6.7%); *Trichodina* spp. (6%); *Paracamallanus* spp. (4.7%); *Camallanus* spp. (2%); *Diplostomum* spp. (2%) and *Contracaecum* spp. (1.3%). *Dactylogyrus* spp. were common in earthen ponds (91%) ($p<0.001$). Some management practices identified as possible risk factors for parasitic infestation in fish included; pond fertilization using livestock manure (OR=5.633), siting fish ponds in valleys/gullies (OR=2.028), use of river water for aqua farming (OR=1.654) and earthen pond types (OR=2.023). Farmers and extension workers should be trained on the importance of fish health and biosecurity. The authors recommend further detailed longitudinal controlled studies which consider myriad fish husbandry practices with parasitic infestations.

Keywords: Biosecurity, fish health, management practices, nile tilapia

1. Introduction

There has been surge in fish farming in Kenya, even in some areas where the local population is not native to fish-eating communities, such as those in Kericho and Bomet counties [1]. This surge was initiated by the previous government incentive, The Fish Farming Enterprise Productivity Program (FFEPP), under the economic stimulus program of 2010 [2]. Under the program, the government constructed ponds, subsidized fish feeds and seeds, and hired many fisheries extension officers [3]. The growth of fish farming continued for some time as farmers and consumers were sensitized through 'eat more fish' campaigns [1]. With increased awareness of the health benefits of fish, including the ability to supply essential nutrients, there is still a deficit in fish supply in Kenya. Therefore, there is a need to diversify economic activities to promote food security and nutrition in Kenya [2, 4].

Nile tilapia (*Oreochromis niloticus*) is the most commonly cultured fish species because of its ability to grow faster, reproduces easily in captivity under varying environmental conditions; additionally, this species has a low trophic level for feeding and can tolerate stress induced by handling and poor water conditions [3-5]. With increase in fish farming, the occurrence of fish diseases has drawn the attention of both farmers and researchers. For instance, emergence and intensification of cage farming in Lake Victoria, Kenya has led to fungal, bacterial and parasitic diseases resulting to losses [5]. In some parts of Kenya, fish parasites of economic importance (*Trichodina*, *Dactylogyrus*, *Gyrodactylus*, *Neascus*) as well as zoonotic ones (*Diplostomum*, *Clinostomum*, *Contracaecum*, *Acanthocephalus*) have been documented [7-11]. Researchers have also documented that the incidence and prevalence of parasitic infestations are influenced by management practices such as sharing farm tools, not treating ponds before stocking fingerlings and after harvesting fish. Others include, not monitoring water quality and lack of implementation of biosecurity measures in fish farms by farmers [8, 12]. Generally, high intensity of parasites in fish ponds may cause mass mortality, morbidity, stunted growth and infested fish may lose aesthetic value leading to massive economic losses [13, 14]. With the emergence of fish diseases, some with zoonotic potential and others causing economic losses, many farmers in Kenya still have little or no knowledge, attitude and practice necessary to control diseases and improve aquaculture productivity [15]. Risk factors associated with fish parasitic infestations has not been evaluated in Bomet and Kericho counties. Thus, this study was undertaken to assess aquaculture management practices that are potential risks factors for parasitic infestations in Nile tilapia in the two counties in Kenya.

2. Materials and Methods

2.1 Ethical clearance

Ethical clearance given by the Biosafety, Animal Use and Ethics Committee of the Faculty of Veterinary Medicine, University of Nairobi (REF: FVM BAUEC/2023/421), and National Commission for Science, Technology and Innovations (License No: NACOSTI/P/23/30841). Verbal agreements were given by respective directors of fisheries and selected farmers from the two counties. Handling and euthanasia of fish were in accordance with the international guidelines.

2.2 Study area

The study was carried out in Bomet and Kericho counties, Kenya between March and April 2023. Bomet County lies between latitudes 0º 29' and 1º 03' South and between longitudes 35º 05' and 35º 35' East. The county has an elevation of 2002 m above sea level and rainfall is highest in the lower highland zone with a recorded annual rainfall of between 75 mm and 245 mm. The rainfall is evenly distributed except during short dry season in January and February. The temperature ranges from 9.6 °C to 24.5 °C, with July and February being the coldest and hottest months, respectively [16].

Kericho County is located in the South Rift of the Great Rift Valley, approximately 256 km from Nairobi city. The county lies between longitude 35º 02’ and 35º 40’ East and between the equator and latitude 0º 23’ South with an altitude of 2002 m above the sea level. The county has a favourable climate and receives relief rainfall ranging from 1,400 mm to 2,125 mm, with moderate temperatures of 17 °C and low evaporation rates. The temperature ranges from 10 °C to 29 °C. The county experiences two rainy seasons: the long rainy season between April and June and the short rainy season between October and December [17].

2.3 Study design and data collection

A cross-sectional study that entailed fish sampling for parasitological examination and administration of semi-structured questionnaires was conducted in the two counties.

2.4 Administration of questionnaires

The questionnaire was initially pretested, revised and corrected accordingly, and a final set developed. The questionnaire was designed to gather data on fish farmer management practices which included: fish production systems, species and culture method, pond fertilization, fish feed, pond water source, sources of harvesting nets, pond drainage after harvesting and predation. Questionnaires were administered in 88 randomly selected fish farmers in Bomet (n=33) and Kericho (n=55) counties. The data generated were supplemented by researchers’ direct observations during farm visits. Global positioning systems (GPS) coordinates for individual farms within the study area were recorded.

2.5 Fish sampling, necropsy and parasitological examination

Following the owners’ consent, a total of 150 fish samples (Bomet n=60; Kericho n=90) were harvested from fish ponds from 15 randomly selected farms in Sotik, Bomet County (n=6), Ainamoi (n=5) and Belgut (4) in Kericho County. The three sub-counties were selected purposively owing to the high number of active fish ponds. Upon harvesting, the samples were transferred in buckets with source pond water and immediately transported to the laboratory for parasitological examination.

Fish were humanely killed by a sharp blow on the cranium and then pithed to sever the brain from the spinal cord, whilst covering the eyes with a moist cloth towel. The fish were then weighed and their lengths taken individually. The skin was grossly examined for ectoparasites and lesions such swellings, injuries and ulcers among others. For parasitological identification, wet mounts of skin scrapings and fin clippings, gill filaments, and eye and gut contents were collected and then placed on a glass slide with a drop of saline and examined under a light microscope at x10 and x40. The parasites recovered were characterized and identified using morphological features as described by Woo (2006) [18] and Robert (2012) [19].

2.5 Data analysis

The data was entered, validated and stored in a Microsoft Excel spreadsheet. Descriptive (Frequencies/proportions) and inferential statistics was performed using SPSS version 28.0 and Epi info statistical software version 7.0. Logistic regression analysis with estimation odds ratios (OR) was used to examine the significance of associations of risk factors with the outcome variable. Chi-square (X2) was used as a measure of significance, while Cramer’s V was used to measure the strength of association. Parasite distributions were described using prevalence as described by Margolis *et al*. (1982) [20] and Bush *et al*. (1997) [21]. The statistically significant associations were considered at P-values less than 0.05.

3. Results

3.1 Gender, age, role and experience in fish farming

Generally, gender was skewed towards males in both counties as 80.7% (71/88) of respondents were males, while 19.3% (17/88) were females. In Bomet, 75.8% (25/33) of the farmers interviewed were male, 24.2% (8/33) were female, and in Kericho, 83.6% (46/55) of the respondents were male, while 9/55 (16.4%) were female. Of these respondents, 38.5% were older than 56 years. In all, 81% of those famers had direct experience managing fish farms, while only 19% were employed. Seventy-six percent (25/33) and 84% (46/55) of the farmers directly managed their fishponds, whereas only 24% (8/33) and 16% (9/55) hired attendants in Bomet and Kericho counties, respectively. Over 60% of the respondents had been in fish farming for more than 7 years.

3.2 Purpose for doing fish farming

Overall, majority of the farmers (65.91%; 58/88) started fish for subsistence reasons with 69.7% (23/33) and 63.64% (35/55) of them from Bomet and Kericho, respectively. More than twenty-seven percent (24/88) of the respondents ventured into fish farming for business purposes with 24.24% (8/33) and 29.1% (16/55) of them from Bomet and Kericho, respectively. In both counties, a small number of respondents (6/88, 6.82%) started fish farming as a hobby (3/88, 3.41%) and for education (3/88, 3.41%).

3.3 Economic activities of fish farmers

Figure 1 shows the main economic/income generating activities of farmers in Bomet and Kericho counties. The majority (85.2%; 75/88) of the respondents were farmers followed by employed (11.4%; 10/88) and businesspersons (3.4%; 3/88).

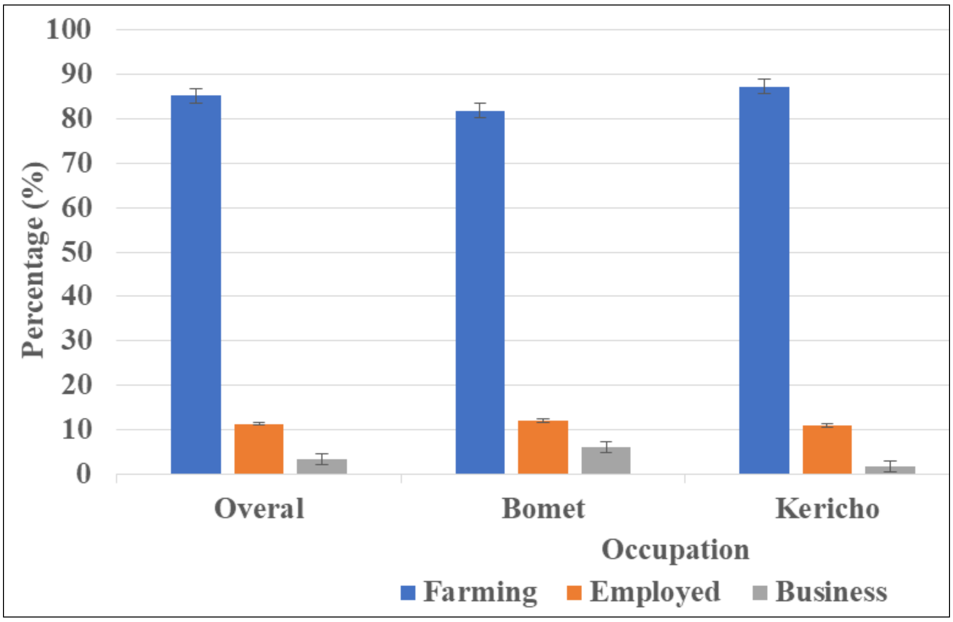

Fig 1: Economic activities of respondents in Bomet and Kericho counties, Kenya

3.4 Farmers' level of education

Figure 2 shows the level of education of respondents in Bomet and Kericho counties. In both counties, 12.5% of the respondents had no formal education, while 17.1%, 39.8% and 18.2% had attained primary, secondary and college (diploma) level of education, respectively. Over 9% of the respondents had attained undergraduate education and only 3.4% had post graduate degrees; all were from Kericho County (Fig. 2).

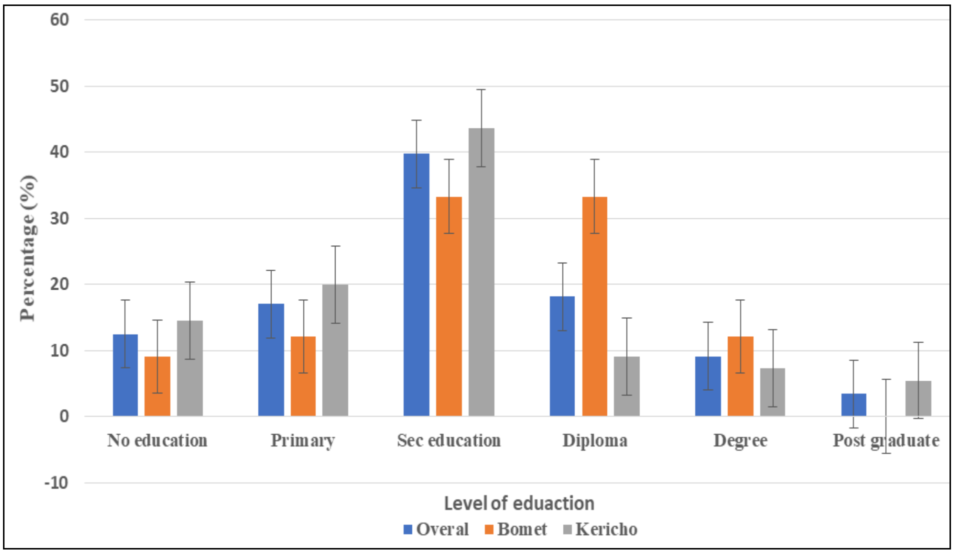

Fig 2: Farmers' level of education in Bomet and Kericho counties, Kenya

3.5 Farmed fish species

Nile tilapia (*Oreochromis niloticus*) was the most common fish species cultured by farmers in Bomet (97%; 32/33) and Kericho (95.45%; 84/88) counties. Polyculture of Nile tilapia and catfish (Clarias gariepinus) was also practiced by 3.4% (3/88) of the farmers, while only 1.1% of the farms reared catfish in both counties.

Overall, 53.4% (47/88) of the farms reared monosex male tilapia, while the rest (44.3%; 39/88) kept mixed sex tilapia. Bomet had 90.9% (30/33) and Kericho had 30.9% (17/55) male tilapia farms. Some farms (2.3%; 2/88) practice polyculture of catfish and tilapia to control prolific breeding of the latter in ponds (Table 1).

3.6 Farming system and pond types

Sixty-four percent (56/88) of the farmers in both counties practiced semi-intensive farming systems in earthen ponds; 61% (20/33) and 65% (36/55) of whom were from Bomet and Kericho, respectively. There was also semi-intensive farming using polyvinyl chloride dam-liners (26.1%; 23/88) and concrete ponds (8%; 7/88). Other systems recorded were intensive fish farming in aquaponics (1.1%; 1/88) and liner ponds inside a greenhouse (1.1%; 1/88) (Table 1).

3.7 Source of fingerlings

The majority of farmers (93%; 82/88) sourced fingerlings from government-owned hatchery under the Kenya Marine Fisheries and Research Institute, Kegati in Kisii County. The rest (7%; 6/88) sourced fingerlings locally from other farmers.

3.8 Source of feeds and pond fertilization

In both counties, commercial fish feeds were commonly used, constituting 51.1% (45/88) of the farms. Other feeds used were wheat bran (17%), "ochongaa" or white shrimp (12.5%), kales and Omena (3.4%), vegetables and ugali (3.4%), poultry feeds (2.3%) and duckweed (2.3%). Eight percent of the farmers did not feed fish in ponds. The feeding frequency was mainly twice a day (52.3%), once (31.8%), less frequently (6.8%) and four times a week (1.1%).

More than eighty one percent (81.8%) of the farmers were fertilizing their pond water mainly using cattle manure (67%), followed by chicken manure (13.6%), diammonium phosphate (DAP) fertilizer (1.1%) and pig manure (1.1%). Most farms preferred applying manure in dry form (76.1%; 67/88) than wet form (8%; 7/88).

3.9 Water source, drainage and quality

Fifty-two percent (46/88) of the farmers drew water for their ponds from rivers; where 60%; (33/55) and 39% (13/33) were from Kericho and Bomet, respectively. Other sources included; rainwater (11%), treated municipal water and wells (5.7% each), borehole water (4.5%) and spring water (3%). Water pans, dams and swamps each contributed 1.1% of the water sources for fish pond. In both counties, most farmers (65.9%) drained ponds into nearby agricultural land; 27% into rivers, 2.3% into earthen ponds and swamps, and 1.1% along the road. A few (1.1%) farmers did not drain water from their pond.

The majority of the farmers (88.6%) did not monitor pond water quality. Other farmers (11.4%) monitored ponds to determine the level of pond fertilization, with only one farmer monitoring pond water temperature.

Fifteen percent of the farmers had water shortage challenges while 14% experienced floods, which led to escape of fish from ponds in 4.5% of the farms. Floods were also reported to have introduced predators in ponds in 5.7% of the farms, and also led to outbreak of diseases in 3.4% of the farms.

3.10 Sharing of seine nets: All the farmers mostly relied on a borrowed seine net from the respective county fisheries, however, mosquito nets were also used by 63.6% of farms for harvesting fish for household consumption. Few farmers (12.5%) sun dried these nets before use.

3.11 Pond treatment before restocking and after fish harvesting

In both counties, 38% (33/88) of the farmers cleaned and dried fishponds frequently before restocking. Twenty-seven percent (24/88) of the farmers cleaned and dried their ponds but not frequently before restocking. One farmer (1.1%) never dried or cleaned ponds before restocking while the rest, only did so during the first stocking.

Thirty-four percent (30/88) of the farmers did not remove the pond bottom soil after harvesting of fish. Among these farmers, 36% (12/33) were in Bomet County, while 33% (18/55) were from Kericho County. Overall, 32% (28/88) of farms constituting 27% (9/33) and 35% (19/55) from Bomet and Kericho County, respectively, routinely removed pond sludge after harvesting the fish. In both counties, 33% (29/88) of the farmers removed pond sludge but not routinely (Table 1).

Table 1: Distribution of holding structures, pond treatments and fish species

County				
	Kericho		Bomet	
Pond type	**Number**	**Percentage (%)**	**Number**	**Percentage (%)**
Earthen	36	65.5	20	60.6
Liner	14	25.5	9	27.3
Concrete	4	7.3	3	9.1
Aquaponic	0	0	1	3
Liner pond in green house	1	1.8	0	0
Total	55	100	33	100
Fish species cultured				
Tilapia	52	94.6	32	97
Catfish	0		1	3
Tilapia and catfish	3	5.5	0	0
Total	55	100	33	100
Cleaning and drying pond before restocking				
First stocking	0	0	1	3
Never	0	0	1	3
Rarely/ never	19	34.6	10	30.3

Yes, sometimes	15	27.3	9	27.3
Yes, often	21	38.2	12	36.4
Total	55	100	33	100
Removing bottom soil after harvesting				
Never	18	32.7	12	36.4
Not yet	0	0	1	3.03
Yes, each time	19	34.5	9	27.3
Yes, sometimes	18	32.7	11	33.3
Total	55	100	33	100

3.12 Detection of sick fish by farmers

Diseases were reported to be a challenge to fish farming in 3.4% of the farmers. However, none of these farmers could specify the cause of these diseases. More than twenty-three percent (23.9%) of farmers detected sick fish depending on the gross observation of abnormal swimming behaviors while 8% relied on fish mortality (Fig. 4).

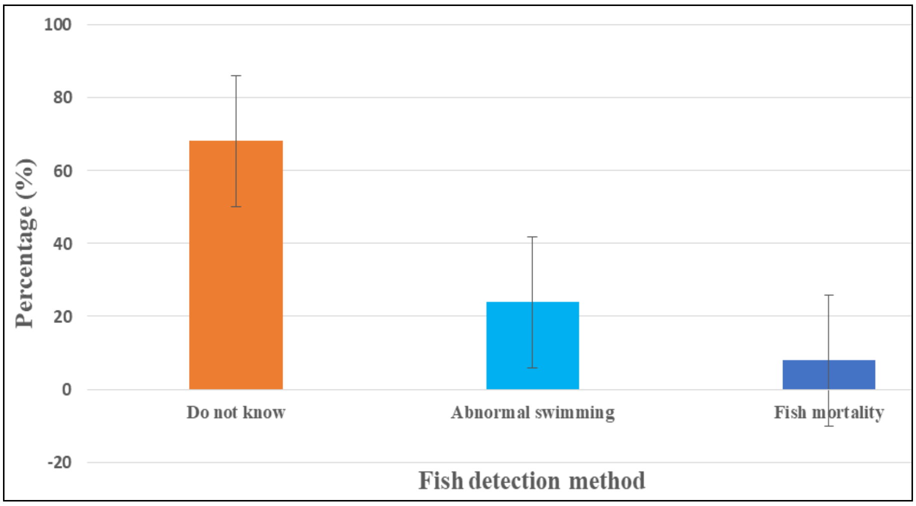

Fig 4: Farmers' methods of detecting sick fish in Bomet and Kericho counties, Kenya

3.13 Fish parasites recovered

Table 2 shows the prevalence and parasite genera isolated from Nile tilapia in Bomet and Kericho counties. Out of the 150 fish sampled, 62 (prevalence = 42%) were found to be infected with different parasites totaling 537. Additionally, a total of 51 (prevalence = 34%) fish were infected by single genera with recovery rate of 244 parasites, while 12 (prevalence = 8%) by mixed parasite genera with 293 parasites. The prevalence of parasitic infestations was found to be higher in earthen ponds (53%; 42/80) than in dam-liner ponds (35%; 21/60) and concrete ponds (10%; 1/10). Intestinal (*Para Camallanus* spp., 4.7%; *Camallanus* spp., 2%) and abdominal (Contracaecum spp., 1.3%) nematodes, digenean larval stages of *Diplostomum* spp. (2%), gill monogenean (*Dactylogyrus* spp. (21%), and ectoprotozoan parasites, *Epistylis* spp. (7.3%), *Riboscyphidia* spp. (6.7%) and *Trichodina* (6%) spp. were recovered and identified from different fish samples.

The prevalence of *Dactylogyrus* spp. was greater in earthen ponds (91%) relative to liner ponds (9%) and the difference was statistically significant ($p < 0.001$). Also, prevalence of this ectoparasite was significantly ($p < 0.05$) higher in Kericho County (28.9%) compared to Bomet County (10%). *Diplostomum* spp. and Contracaecum spp. were recovered in Kericho County only (Table 2). Figures 5 and 6 shows a fish eye fluke and a gill monogenean recovered from the study area.

Table 2: Prevalence and parasite genera recovered from different fish organs in Bomet and Kericho counties, Kenya

Genera	Infected organ	Class	Prevalence of infected fish (%)				
			Bomet County n=60	Kericho County n=90	Concrete n=10	Liner n=60	Earthen n=80
Dactylogyrus	Gills	Monogenea	10 (*6)	28.9 (*26)	0	5 (*3)	36.3 (*29)
Diplostomum	Eyes	Trematoda	0	3.3 (3)	0	3.33 (2)	1.3 (1)
Epistylis	Skin	Ciliophora	5 (3)	8.89 (8)	0	16.67 (10)	1.3 (1)
Trichodina	Skin	Ciliophora	8.3 (5)	4.4 (4)	0	5 (3)	7.5 (6)
Riboscyphidia	Skin	Ciliophora	8.3 (5)	5.6 (5)	0	10 (6)	5 (4)
Paracamallanus	Intestines	Nematoda	3.3 (2)	5.6 (5)	0	3.3 (2)	6.3 (5)
Camallanus	Intestines	Nematoda	1.7 (1)	2.2 (2)	10 (1)	1.7 (1)	1.3 (1)
Contracaecum	Abdominal cavity	Nematoda	0	2.2 (2)	0	0	2.5 (2)

*Number of parasites recovered from sampled Nile tilapia.

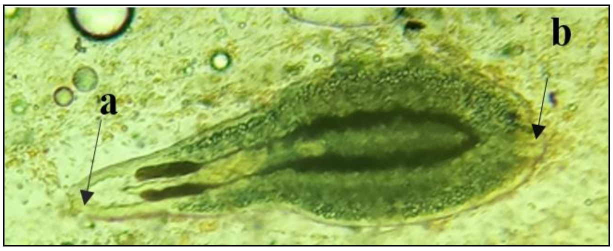

Fig 5: *Diplostomum* spp. metacercaria recovered from the eye of a Nile tilapia from Kericho County, Kenya. (Arrows showing the anterior end (a) and posterior end (b)

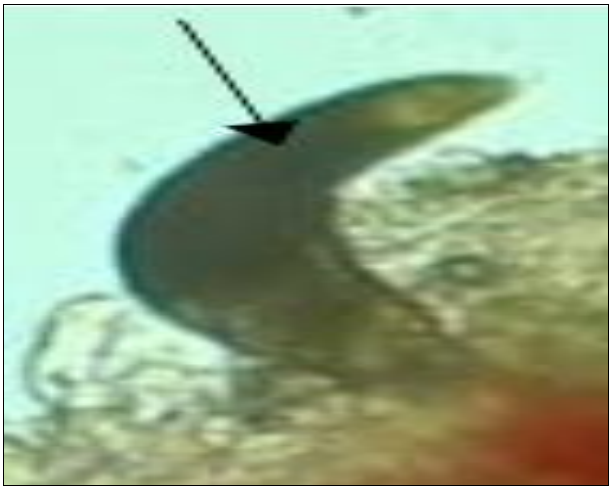

Fig 6: *Dactylogyrus* spp. (arrow) attached on a gill filament of a Nile tilapia from Bomet County, Kenya

3.14 Risks factors associated with parasitic infestations in fish: The association of management practices that predispose fish infestations to risk factors was done using univariate logistic regression [13]. The odd ratios were highest in the farms that used livestock manure (5.633), followed by pond sited in the valleys/gullies (2.028), earthen pond (2.023) and river water source (1.654) respectively. Other risk factors like removing pond bottom soil after harvesting and cleaning/drying pond before restocking had the lowest odd ratios (Table 3).

Table 3: Odd ratio for fish infestations against some farm practices

Risk factor	X^2 (df=1)	p<0.05	Cramer's	Odds ratio
Pond sited in valleys/gullies	0.368	0.544	0.329	2.028
Use of river water	0.058	0.809	0.405	1.654
Removing pond bottom soil after harvesting	0.279	0.597	0.401	0.226
Cleaning and drying pond bottom before restocking	1.201	0.273	0.306	0.214
Pond fertilization	0.413	0.520	0.380	5.633
Able to drain ponds	3.522	0.061	0.468	0.00
Earthen pond	0.448	0.503	0.322	2.023

4. Discussion

The main alternative economic activities of fish farmers in Bomet and Kericho counties were farming tea, coffee, maize and dairy animals. Salaried employee farmers (Working outside the farm) and farmers who were also business men/women were only 11.4% and 3.4%, respectively. This corroborates with findings of Mavuti *et al*. (2017) [12] where most of the fish farmers in Nyeri County, Kenya, were also involved in coffee and tea farming. Additionally, 69.7% of the farmers in Bomet and 63.6% in Kericho were farming fish for subsistence as a way of diversifying income and providing cheap protein to their family as reported elsewhere [2, 3].

A total of 3.4% of the farmers were undertaking fish farming as a hobby and for educational purposes. However, 27.3% were involved in fish farming for business, selling either fingerlings or market- sized fish. Majority of the farmers were male, most had attained secondary education, and the mean age was 56 years. Unlike what was reported in Nyeri County by Mulei *et al*. (2021) [22] where 49.7% of farmers had secondary level of education and were between 51-60 years of age. Farmers had little knowledge on fish health and biosecurity as was previously reported, which may be attributed to lack of sufficient fish extension officers and health providers [3, 15].

Tilapia fish culture was the most preferred in both counties, followed by polyculture of catfish and tilapia (3.4%) and catfish monoculture (1.1%). These findings corroborated with findings of other researchers who reported that tilapia was the most preferred fish under culture in Kenya [8, 9, 12, 13, 15]. Most of the tilapia farmed were male mono-sex (53.4%) because of high growth rate and controlled prolific breeding while 44.3% of the farmers had mixed sex tilapia as a result of poor aquaculture husbandry practices in the hatcheries where hormones used in sex reversal of tilapia were ineffective due to wrong application [3, 15]. The remaining farmers (2.3%) were practicing polyculture of mixed sex tilapia with catfish. The catfish were added to control tilapia breeding in ponds, a common practice by farmers in Kenya [2].

Most farmers (63.6%) in Kericho and Bomet counties were farming fish in earthen ponds, followed by liner ponds (26.1%), and concrete ponds (8%), while aquaponics and liner ponds inside a greenhouse accounted for 1.1% each. These findings agree with those of Mavuti *et al*. (2017) [12] who found that earthen ponds (58.1%) were the most popular holding system used in Nyeri County followed by liner ponds (33.9%) and concrete ponds (4%). This can be attributed to the fact that earthen ponds are relatively cheap to construct compared to other holding systems. In the study, earthen ponds were twice infested with parasites compared to other culture systems; earthen ponds can act as reservoirs for parasites because the plants growing within and inside the ponds can harbor snails, which are intermediate hosts for digenean trematodes of fish [9]. The present findings conflict with Wanja *et al*. (2020) [13], who showed that 68% of farmers used dam-liners as holding systems for fish, followed by earthen ponds (25%) in Kirinyaga County. The dam-liners are ideal for conserving water and preventing horizontal and underground water seepage.

The majority (93.2%) of the farmers in the current study sourced fingerlings from certified hatcheries with good biosecurity measures while 6.8% sourced locally from other farmers. The latter source could increase the rate of spread and occurrence of parasites to new farmers [8, 9, 13].

Most farmers fertilized their ponds to increase natural productivity with cattle manure being the most common (67%), followed by poultry droppings (13.6%). Similar findings were reported in other studies in Kenya by Mavuti *et al*. (2017) [12] and Wanja *et al*. (2020) [13]. Inorganic fertilizer (DAP) is not popular among farmers, as was also reported by Wanja *et al*. (2020) [13] in their study in Kirinyaga County. The over-use of fertilizers in ponds can negatively affect water quality, increasing fish susceptibility to pathogen infections [22]. Ponds manured with livestock wastes were five times infested with parasites compared to inorganic fertilizers. Organic manure has been documented as carriers of pathogens like bacteria; in dry form, manure consume dissolved oxygen during decomposition process compromising fish immunity making fish to be susceptible to pathogens [13].

More than half of the farmers used commercial feeds as was reported by Wanja *et al*. (2020) [13] in Kirinyaga County. Commercial feeds have high levels of crude protein, and when fed to fish, the growth rate increases considerably [3]. However, due to the market price of these feeds, 41% of farmers used locally available materials to formulate fish feed and 8% did not feed their fish at all. Though homemade rations help in reducing the cost of production, when farmers have no knowledge and skills in fish feed formulations, there is a chance that the feed may be imbalanced, resulting in nutritional deficiency in fish and hence weak immunity [2] and increased level of parasitism [23].

Rivers were the main source of water supplying 52.3% of the ponds. This was followed by underground water (13.6%), and rainwater (11.4%), with the rest of the ponds getting water from other sources. This finding is in agreement with that of Wanja *et al*. (2020) [13] who observed that 61% of ponds in Kirinyaga County sourced water from rivers. Ponds fed on river waters were twice infested by parasites compared to other water sources; farmers were not treating the water before use therefore, increased the chance of parasite infestations from the wild [24]. Ponds located in the valleys were twice infested with parasites compared to the ones located in the residential areas. In valleys, there is very minimal biosecurity measures and everyone can access [15].

In this study, farmers in Bomet (67%) and Kericho (53%) counties believed that water quality was influenced by the water source. All the participants felt that river water was the most suitable for fish farming because of presence of phytoplankton and the high volume of water. In Kericho County, all farmers were not monitoring water quality relative to 10 famers in Bomet County. These farmers mainly monitored pond fertilization and dissolved oxygen levels.

Water quality plays a major role in parasitic infestations as increase in water temperature, pH and electrical conductivity have been reported to have a positive correlation with infestation by parasites such as Amirthalingamia macracantha, *Euclinostomum* spp. and *Trichodina* spp. [25, 26]. *Trichodina* spp. also had a positive relationship with increase in organic load in water while parasites like Clinostomum spp. showed positive correlation with nitrogenous compounds [25, 26]. A study conducted in Kirinyaga County showed that the prevalence of Clinostomum cutaneum was positively correlated with water temperature and pH [11].

Only 13.6% of the farms in the current study reported to have experienced flood water into their ponds during the rainy season; that resulted in fish escape, introduction of predators and diseases. Unfortunately, farmers were incognizant of clinical signs associated with sick fish as was also reported by Opiyo *et al*. (2018) [15] and Mulei *et al*. (2021) [22].

All farmers in both counties depended on the fisheries department's seine net for full or partial harvesting. This was due to lack of purchasing power or not knowing where to source the nets. Mulei *et al*. (2021) [22] documented the significant association between sharing untreated nets and death of fish cultured in Kieni East Sub- County in Nyeri County. Untreated nets can act as vehicles for the transfer of pathogens from one farm to another, as reported in Alaska by Meyers *et al*. (2008) [27], where Aeromonas hydrophila infections in fish farms were positively correlated with use of shared nets. Over twelve percent (12.5%) of the farmers in Kericho treated sein nets by sun drying prior to use in their ponds. However, Mulei *et al*. (2021) [22] reported sun drying to be ineffective treatment and as such recommended use of safe chemicals and salting to minimize deaths of fish in farms.

The majority of farmers in both counties neither cleaned nor treated their ponds before restocking. Only 37.5% of the farms cleaned and dried their ponds frequently, 27.3% sometimes, 33% rarely, 1.1% never and another 1.1% had stocked fingerlings in the ponds for the first time. In addition, 34.1% of the farmers had never removed pond sediments after fish harvesting, 1.1% were yet to harvest fish, 33% sometimes removed the sediments and only 31.8% removed pond sediments frequently. These findings agree with those of Mavuti *et al*. (2017) [12] who stated that removing pond sediments followed by cleaning and drying help reduce the organic load in the ponds, thus improving dissolved oxygen levels in the pond water that could be utilized by decomposing materials. This practice also breaks the life cycles of parasites as they are killed together with intermediate hosts thereby preventing re-infections [12, 28].

During the study, 3.4% of farmers reported to be burdened by diseases and they farmed fish in concrete ponds at high stocking densities. Occurrence of disease may be associated with buildup of organic waste and fish feces and failure of farmers to replace pond water frequently leading to deterioration of water quality. Poor water quality creates conducive environment that favours the proliferation of pathogens [25]. More than half (68.2%) of farmers could not detect when the fish were sick, yet more than 70% had attained secondary education. The poor knowledge of fish health can be attributed to the fact that fish eating and farming were not undertaken in Kericho and Bomet counties, as the native are not fish-eating communities. Fish farming is a new enterprise that started during economic stimulus program hence providing additional training and capacity building on fish health are indicated [3, 15].

In this study, *Dactylogyrus* spp. was the only monogenean found. Poor sanitary conditions and overstocking in ponds, as tilapia were stocked 5 pieces per metre square and a good number of the fish were breeding in ponds creating conducive environment for infestation and proliferation of monogeneans [8, 9]. Overstocking was common for fish farmers who raised mixed sex Nile tilapia which are prolific breeders and this could lead to the loss of fish [29].

The prevalence of *Dactylogyrus* spp. was markedly higher in earthen ponds relative to liner and concrete ponds. This may have been attributed to poor water quality in earthen ponds and sharing of harvesting nets without treatment [8, 9, 13, 26]. Heavy infections by *Dactylogyrus* spp. can cause gill hyperplasia due to chronic irritation of the gills [13, 30].

Diplostomum spp. were found in the vitreous humour of the eyes of sampled tilapia from Kericho County with the prevalence being higher in liner ponds (3.3%) relative to earthen ponds (1.4%). However, the difference was not significant ($p>0.05$). This can be attributed to overgrown vegetation around liner ponds or torn liners that promotes the growth of aquatic weeds which attracts snails [9, 13]. The prevalence of nematodes, such as Contracaecum spp., *Camallanus* spp. and *Paracamallanus* spp. was slightly higher in earthen ponds than liner ponds. This difference might be caused by the presence of intermediate hosts such copepods, tubifex worms, or insect larvae in earthen ponds, and a good number of farmers were not able to remove pond sludge after harvesting or drying ponds before restocking to kill the intermediate hosts [9, 31]. However, the occurrence of Contracaecum spp. in liner ponds may be associated with the use of untreated shared harvesting nets and presence of piscivorous birds [8].

The recovered ectoprotozoans including *Trichodina*, *Epistylis* and *Riboscyphidia*. *Trichodina* spp. were found on the skin and fins of examined tilapia. The prevalence of ectoprotozoans was slightly higher in liner ponds, except for *Trichodina* spp., which had a higher prevalence in earthen ponds. This finding differed from that of Nyamete *et al.* (2020) [31] who showed that earthen ponds had a higher parasite prevalence because of siltation and vegetation.

Kericho and Bomet counties are neighbouring each other and have similar climatic conditions [16, 17]. Thus, the prevalence of parasites may mainly be attributed to aquaculture husbandry practices and presence of predators. The prevalence of *Epistylis*, *Trichodina*, *Riboscyphidia*, Paracamallunus and *Camallanus* species was generally the same in the two counties. However, prevalence of *Dactylogyrus* spp. was greater in Kericho County than in Bomet County. This could be attributed to the large sample size taken in Kericho and the fact that only 3% of fish from Bomet were under mixed sex tilapia. Mixed sex tilapia breed prolifically, resulting in high stocking densities in ponds and hence increasing contact between the fish thus, enabling spread of ectoparasites [13].

5. Conclusions and recommendations
This study revealed that aquacultural management practices and other risk factors such as type of ponds, sourcing untreated water from rivers for aquaculture, use of organic manures and pond site locations predispose Nile tilapia to both ecto- and endo-parasites in Bomet and Kericho counties. It is recommended that farmers be educated on proper aquaculture management practices with emphasis on the detection, prevention and control of fish parasites. Additionally, long term policy planning measures should be taken to enable large scale aquaculture production in Kenya.

6. Data Availability
The data are stored in cloud-based programs. The data used to support the findings of this study are available upon request.

7. Conflict of interest
The authors declare that there are no conflicts of interest.

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