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Research Article

Abundance and Distribution of Snail Intermediate Hosts of *Fasciola* spp. a High-Risk Fascioliasis Ecosystem in Western Kenya

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Abstract

Trematode infections are still one of Africa's most common and pervasive tropical diseases, especially in areas near freshwater bodies. *Fasciola gigantica* transmission in East African wetlands is shaped by the ecology of its freshwater snail hosts, yet fine-scale dynamics remain poorly resolved. This study quantified spatial, temporal, and spatio-temporal patterns of snail populations in Kingwal Wetland, in western Kenya, through monthly surveys of the snail host from January–December 2023 at seven ecologically distinct sites. A total of 8,754 snails belonging to eight different species were collected; dominant taxa were *Biomphalaria sudanica* (21.0%), *B. pfeifferi* (17.9%), *Lymnaea auricularia* (13.6%), *Bulinus globosus* (12.8%), and *Radix natalensis* (6.0%). The confirmed *F. gigantica* vectors, *L. auricularia* and *R. natalensis*, the snails showed distinct spatial patterns, with *R. natalensis* reaching a peak infection prevalence of 29.3% in June. Species abundance differed significantly across the sites ($\chi^2 = 3{,}284.77$, df = 42, $p < 0.001$): Sites 1–3 exhibited the highest snail species diversity and abundance, whereas Site 7 exhibited consistently the lowest, likely reflecting anthropogenic disturbance and seasonal desiccation. Snail populations peaked during the long rains (May–August), with the highest monthly count in May (n = 1,383), and were lowest in January (n = 230) and December (n = 316), confirming strong seasonal effects ($\chi^2 = 839.27$, df = 77, $p < 0.001$) and a significant spatio-temporal variation (CMH = 1,192.37, df = 11, $p < 0.001$). These findings indicate that fasciolosis transmission potential is greatest in wet months within stable, vegetation-rich habitats. The identification of a seasonal transmission window highlights a key timeframe for implementing targeted snail control measures, habitat management, and enhanced surveillance to disrupt *F. gigantica* transmission in wetlands.

Keywords

Freshwater Snails, *Fasciola Gigantica*, Spatial-temporal Variation, *Lymnaea Auricularia*, *Radix Natalensis*, Kingwal Wetland

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1. Introduction

Freshwater snails play indispensable roles in trematode life cycles as obligatory intermediate hosts, enabling asexual amplification and release of infective cercariae that subsequently infect definitive hosts. Consequently, snail ecology, behaviour, and population dynamics are central to understanding transmission potential and designing control strategies [1-5]. Among trematode–snail systems, the interaction between *Fasciola* spp. (Digenea: Fasciolidae) and lymnaeid snails is particularly important for veterinary and public health: miracidia infect snails, develop through sporocyst–redial stages, and produce cercariae that encyst as metacercariae on vegetation or in water, later ingested by grazing mammals thus linking aquatic habitats to terrestrial grazing systems and shaping where and when transmission occurs [3, 6].

Globally, a relatively narrow set of lymnaeids are competent hosts, yet their distributions are broad and local abundances fluctuate in space and time. In temperate regions, *Galba truncatula* predominates for *F. hepatica*, whereas in tropical and subtropical zones *Radix natalensis*, *Lymnaea auricularia*, and related taxa more commonly transmit *F. gigantica*. Field studies consistently show strong microhabitat heterogeneity: slow-flowing channels, marsh margins, and floodplain pastures often harbour higher snail densities and infection rates than fast-flowing or shaded waters patterns shaped by physicochemical gradients and biotic interactions [2, 7-9].

Across sub-Saharan Africa, *R. natalensis* is widespread from large lakeshores to inland wetlands and is frequently implicated as a dominant intermediate host for *F. gigantica* in livestock systems, while *L. auricularia* is a recognised vector in parts of East Africa. Infection prevalence varies with season, site conditions, and livestock–water contact, reflecting both snail population biology and the intensity of parasite egg contamination [10-14].

In East Africa and Kenya, wetlands are transmission hotspots owing to hydrological stability, abundant macrophytes, and regular livestock use, which foster persistent snail populations and recurrent parasite exchange between intermediate and definitive hosts. Recent studies clarify seasonal ecology, spatial distribution, and cercarial shedding patterns across riverine and agricultural landscapes [7-9, 15-19]. Emerging syntheses further quantify thermal constraints on snail life-history traits and link temperature variability to *Fasciola* transmission dynamics [16, 20-23].

Nevertheless, fine-scale longitudinal studies that jointly quantify snail abundance, spatial distribution, and infection prevalence across wetland microhabitats and relate these indices to fascioliasis in sympatric herds remain scarce. Many surveys are cross-sectional, limited in spatial/seasonal scope, and seldom integrate malacological with veterinary data, constraining risk mapping, seasonal forecasting, and targeted interventions. This study addresses that gap by delineating spatial and seasonal patterns in the abundance and infection prevalence of *R. natalensis* and *L. auricularia* in a Kenyan wetland and examining associations with fascioliasis occurrence in nearby livestock [20-25].

2. Materials and Methods

2.1. Study Area

The study was conducted in Kingwal Wetland, located in Nandi County, Kenya, approximately 6 km west of Kapsabet town along the Kapsabet–Kaimosi road. The wetland lies between latitudes 0°11′ and 0°13′ N and longitudes 35°06′ and 35°08′ E, at an altitude of approximately 2,020 metres above sea level. It forms part of the Yala River catchment within the Lake Victoria basin and is sustained by the Kingwal River and several seasonal streams.

Kingwal Wetland covers an estimated area of 15–20 km ^{2} during peak flooding and is characterised by a mosaic of ecological zones, including permanent open-water channels, papyrus (*Cyperus* papyrus) stands, seasonally flooded grasslands, marshes with emergent sedges, and riparian fringes. The hydrology is strongly seasonal, with expansion during the long rains (March–June) and contraction during the dry months (December–February).

The surrounding landscape is dominated by smallholder mixed farming, where households cultivate maize, beans, and horticultural crops, and rear livestock primarily cattle and sheep. Livestock graze both on upland pastures and within the wetland margins, with direct access to open water for drinking. Livestock movement into the wetland is especially common during dry periods when upland forage is scarce, resulting in concentrated grazing and faecal deposition near water bodies.

Seven sampling sites within the wetland were selected based on habitat type, water permanence, degree of livestock access, and vegetation structure. These sites represented a gradient from permanently inundated, high-vegetation-density zones to seasonally flooded, open-grass areas. Site accessibility and security for repeated sampling throughout the year were also considered during selection.

2.2. Description of Sampling Sites

The sampling sites in Kingwal Wetland were purposefully selected to reflect ecological variation across hydrological, vegetative, and land use gradients. This stratified approach aimed to capture the spatial-temporal distribution, abundance, and infection risk of freshwater snails, particularly those acting as intermediate hosts for *Fasciola* species.

Site 1 was located in the northwestern edge of the papyrus swamp, an area characterized by dense macrophyte vegetation and permanent waterlogging. This zone provides an ideal

breeding ground for lymnaeid snails due to its stable moisture and abundant organic matter, making it suitable for observing natural, undisturbed snail populations. Site 2 was located along a midsection of the stream traversing the wetland. This flowing water habitat allowed for the assessment of snail species influenced by current velocity, oxygenation levels, and sediment transport, which are known to affect both snail survival and cercarial release patterns. Site 3 was situated on the northern floodplain, an area subject to seasonal inundation. This site was selected to monitor snail colonization and abundance under fluctuating hydrological conditions. Such intermittently wet habitats can serve as temporary breeding grounds for snails and may amplify fascioliasis transmission risk during peak flooding periods. Sites 4 and 5 were located in the central and western zones of the papyrus swamp, where livestock frequently access water points and graze along swamp edges. These locations were chosen to assess the impact of human–livestock interactions on snail population dynamics and cercarial infection rates. Site 4, in particular, was near a livestock crossing point, while Site 5 represented a relatively less disturbed reference area within the same vegetative zone.

Sites 6 and 7 were set within the southern and southeastern grazing zones, which are heavily utilized for cattle and sheep rearing. These sites were selected to evaluate the potential role of nutrient-rich runoff, fecal contamination, and physical habitat disturbance on snail density and infection prevalence. Prolonged exposure of these areas to livestock pressure increases the likelihood of *Fasciola* transmission through contaminated habitats.

Overall, this site selection design provided a comprehensive spatial representation of the diverse ecological and land use features in Kingwal Wetland, thereby supporting the study's objectives on snail ecology and fascioliasis transmission risk.

2.3. Study Design

This was a longitudinal ecological survey carried out over a continuous 12-month period from January to December. The design allowed assessment of spatial (between sites) and temporal (monthly/seasonal) variations in snail species composition, abundance, and *Fasciola* spp. infection prevalence.

At each of the seven sites, monthly malacological surveys were conducted, yielding a total of 84 site-month observations. The repeated-measures approach enabled detection of trends related to seasonal hydrology, livestock access, and potential snail habitat stability.

Each monthly survey involved two main stages: Snail collection and species identification (see section 2.4) and Laboratory examination for *Fasciola* spp. infection (see section 2.5).

Data from all sites and months were compiled for analysis of spatial patterns, seasonal trends, and species-specific infection rates.

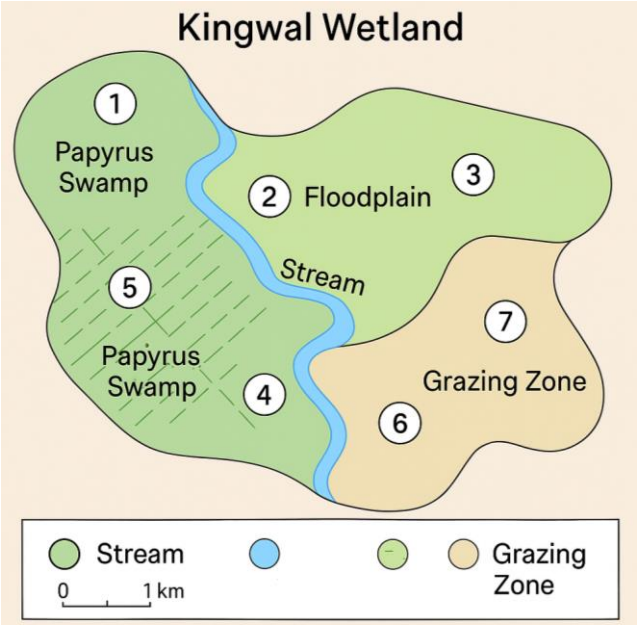

Figure 1. *Sampling sites selected within Kingwal Swamp.*

2.4. Snail Sampling and Identification

Snail sampling was conducted monthly over a continuous 12-month period to capture seasonal and intra-seasonal variation in their abundance and infection rates. Surveys covered representative ecological zones of Kingwal Swamp, spanning open-water margins, emergent macrophyte belts, flooded pasturelands, seep-fed channels, and shallow backwaters used by livestock. Sites were selected *a priori* to represent the dominant landscape units and grazing interfaces, and were retained throughout the study to permit repeated measures through wet and dry phases. Snail sampling followed standard timed-search and scoop-netting protocols for freshwater malacology [2, 3, 8]. At each site, sampling was conducted once per month for the full 12-month study period.

A stratified, effort-standardized design was used. Within each site and visit, three 10-m linear transects were established per available selected microhabitat (where space allowed). Transect start points were positioned using a random offset along the wetland bank or margin, with a ≥5 m buffer between neighboring transects to avoid double sampling. The 0-m and 10-m endpoints were georeferenced (GPS; ±3–5 m) and photographed to ensure relocation consistency across sampling months. To reduce diel bias in detectability, all fieldwork was undertaken between 09:00 and 15:00 hours under comparable light conditions, and postponed during unsafe high-flow flood events. At each transect, basic environmental covariates were recorded at 0, 5, and 10 m (water depth, substrate class, % macrophyte cover, canopy openness) together with spot water-quality profiles (temperature, pH, electrical conductivity, dissolved oxygen, and turbidi-

ty/visibility using a Secchi disk or handheld meter). A brief log of antecedent weather (24–48 h rainfall, storm inflows) was also recorded to contextualize the snail counts.

Each transect was surveyed using a standardized 30 person-minute timed-search protocol to equalize survey effort among sites and months. Where two collectors were available, each searched for 15 minutes respectively to total 30 person-minutes. Search effort combined two complementary collection methods:

1) *Scoop netting:* A long-handled D-frame/scoop net (1-mm mesh) was swept through submerged and floating vegetation, the upper 2–5 cm of soft sediment, and along stem bases. A consistent sweep rhythm was maintained (e.g., five strokes per 2-m segment), with the net inverted and rinsed into a white tray after each set to facilitate visual detection of small or cryptic snails.
2) *Manual hand-picking:* Snails attached to stems, undersides of floating leaves, exposed plant roots, or submerged litter were detached using blunt forceps or gloved fingers. The collector advanced slowly along the ransect line, inspecting both waterward and landward faces of macrophyte stands.

To minimize cross-contamination (transfer of eggs, miracidia, or other propagules) among sites, nets, trays, and forceps were decontaminated between sites in using a 10% household-bleach bath for ≥10 minutes and rinsed thoroughly with ambient water, following standard public-health field guidance [3]. Personnel wore waders and nitrile gloves; all team members were trained in safe wading and handling to avoid slips, cuts, or contact with sharp debris.

Specimens from each transect were placed immediately into clean, ventilated, labeled plastic containers (wide-mouth) partially filled with ambient habitat water. Labels included site code, transect ID, date/time, microhabitat code, and collector initials. To prevent hypoxia and stress, snail stocking density was limited (rule-of-thumb ≤50 small or ≤20 large snails per liter); a handful of site macrophytes was added for substrate, and lids were punctured/mesh-covered for gas exchange. Containers were kept shaded in an insulated field crate and transported to the temporary field laboratory within two hours of collection.

At the field station, snails were sorted, counted, and provisionally identified to genus/species using regional keys. For each species, a subset (e.g., first 30–50 individuals where available) was measured (shell length to the nearest mm) to track size-structure shifts across seasons. Specimens were then allocated to downstream analyses as follows: Shedding set (live)—individuals were rinsed gently and placed singly or in pairs into clear 30–50 mL vials or multi-well plates with filtered site water for cercarial shedding assays scheduled the same day (details in §3.4.2). Snails were held at ambient temperature (target 22–26 ℃), under diffuse light, and not overcrowded to avoid stress-induced mortality that could depress shedding.

Representative individuals of each taxon and site were preserved in ≥95% ethanol (fresh: specimen ratio ≥3:1, changed after 24 h) for later molecular confirmation of identification (DNA barcoding) and to archive a voucher series. All vials carried a unique specimen ID linked to field metadata (site, transect, microhabitat, date, collector, photograph).

Species identification was conducted under a stereomicroscope using morphological keys [2, 8]. Diagnostic features considered included shell shape, spire length, aperture proportion, whorl number, and shell coloration. The identification process placed particular emphasis on detecting and distinguishing lymnaeid species—*Radix natalensis* and *Lymnaea auricularia*—given their established role as intermediate hosts of *Fasciola* spp. in East Africa [10, 13, 19]. For quality assurance, 10% of specimens from each sampling session were re-examined by a second experienced malacologist to confirm identifications.

2.5. Examination for *Fasciola* Spp. Infection in Snails

Infection status was determined using the cercarial shedding method [1-3]. Each live snail was placed individually into a transparent shedding vial containing 5–10 mL of dechlorinated water and exposed to artificial light for 2–4 hours to stimulate cercarial emergence.

The shedding water was examined under a compound microscope (×40 magnification) for Fasciola-type cercariae, which were identified morphologically by their rounded body and short, unbranched tail. Snails that did not shed cercariae on the first examination were held in aquaria and re-examined after 48 hours. Infected snails were recorded by species, site, and month for subsequent analysis of infection prevalence.

2.6. Data Management and Statistical Analysis

Snail abundance was expressed as the number of individuals collected per 30-minute timed search per site per month. Infection prevalence was calculated as the proportion of examined snails shedding *Fasciola* cercariae.

Differences in abundance and infection prevalence between sites and months were assessed using Chi-square (χ^2) tests for proportions. All statistical analyses were conducted in R statistical software (version 4.2.2), with significance set at $\alpha = 0.05$.

3. Results

3.1. Spatial Variations of Snail Intermediate Hosts of *Fasciola* Spp

A total of 8,754 freshwater snails representing eight different species were collected from various landscapes within Kingwal Wetland. Of the eight snail species examined, only *L.*

auricularia and *Radix natalensis* were found to be positive for cercarial shedding attributed to *Fasciola* spp. This was confirmed during the study. The snail abundance varied spatially and temporally (Figure 2).

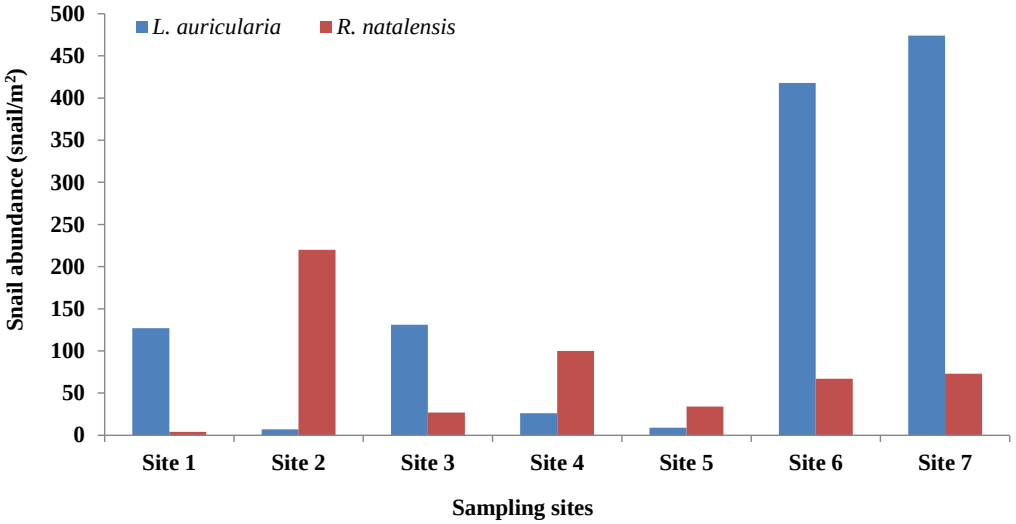

Figure 2. *Spatial Variations of Snail Intermediate Hosts of Fasciola spp.*

A total of 1,192 *L. auricularia* individuals and 525 *Radix natalensis* were collected from seven distinct ecological zones within Kingwal Wetland. Their infection rates with *Fasciola* species are shown in Table 1. Of these, 98 *L. auricularia* and 91 *R. natalensis* individuals tested positive for *Fasciola* infection, translating to an overall prevalence of 8.2% and 17.3% respectively. Infection prevalence in *R. natalensis* showed significant ($P < 0.001$) spatial heterogeneity. The highest prevalence was recorded at Site 6 (31.3%) and Site 7 (24.7%), both situated in the southern and southeastern livestock grazing zones. These areas experience extensive livestock activity, frequent fecal contamination, and standing water all conducive to *Fasciola* transmission. Site 1, though low in *R. natalensis* density (n=4), recorded a high individual prevalence of 25.0%, suggesting that even low-density habitats can maintain transmission potential under favorable ecological conditions. In contrast, *L. auricularia* infection was highest in Site 7 (9.7%), followed by Site 3 (8.4%) and Site 6 (7.7%). These sites share traits of periodic inundation, sediment accumulation, and organic-rich substrates, which support survival of both snails and parasite larvae. Sites 2 and 5 exhibited the lowest or no observed snail infection, likely due to faster water flow and reduced livestock fecal contamination, which limits the viability of *Fasciola* eggs and miracidia. A chi-square test for association between infection rates and site yielded significant results ($\chi^2 = 46.21$, df = 12, $P < 0.001$), confirming non-random spatial distribution of infection.

Table 1. *Spatial Distribution of Fasciola Infection rates in Snails in Kingwal Wetland.*

Site	*R. natalensis*			*L. auricularia*		
	Count	**Infected**	**Prevalence (%)**	**Count**	**Infected**	**Prevalence (%)**
1	4	1	25.0	127	6	4.7
2	220	29	13.2	7	0	0.0
3	27	3	11.1	131	11	8.4
4	100	15	15.0	26	2	7.7
5	34	4	11.8	9	1	11.1
6	67	21	31.3	418	32	7.7
7	73	18	24.7	474	46	9.7
Total	525	91	17.3	1,192	98	8.2

3.2. Temporal Variations in Abundance of Snail Intermediate Hosts of *Fasciola* Spp

Over the course of the year, the monthly abundance of *Lymnaea auricularia* and *Radix natalensis* in Kingwal Wetland exhibited distinct seasonal fluctuations. *L. auricularia* numbers were lowest between February and April, including complete absence in March (Figure 3). From June, a sharp increase was observed, peaking at 199 individuals in September. High abundance were maintained through October (185 individuals) before gradually declining towards December (100 individuals). In contrast, *R. natalensis* abundance showed a more modest but steady increase starting in March. Its abundance peaked in October at 87 individuals and remained relatively high in November (82) and December (64). This pattern suggests a delayed but sustained rise in *R. natalensis* compared to *L. auricularia*. To assess whether these monthly differences in abundance between the two species were statistically significant, a Two-way Chi-square test of independence was conducted. The analysis revealed a highly significant association between snail species and month of collection ($\chi^2 = 83.69$, df = 11, $p < 0.001$), indicating that the seasonal distribution patterns of *L. auricularia* and *R. natalensis* were not uniform. Specifically, *L. auricularia* demonstrated a more pronounced and concentrated peak during the second half of the year, whereas *R. natalensis* exhibited a more gradual and sustained increase in abundance during the same period.

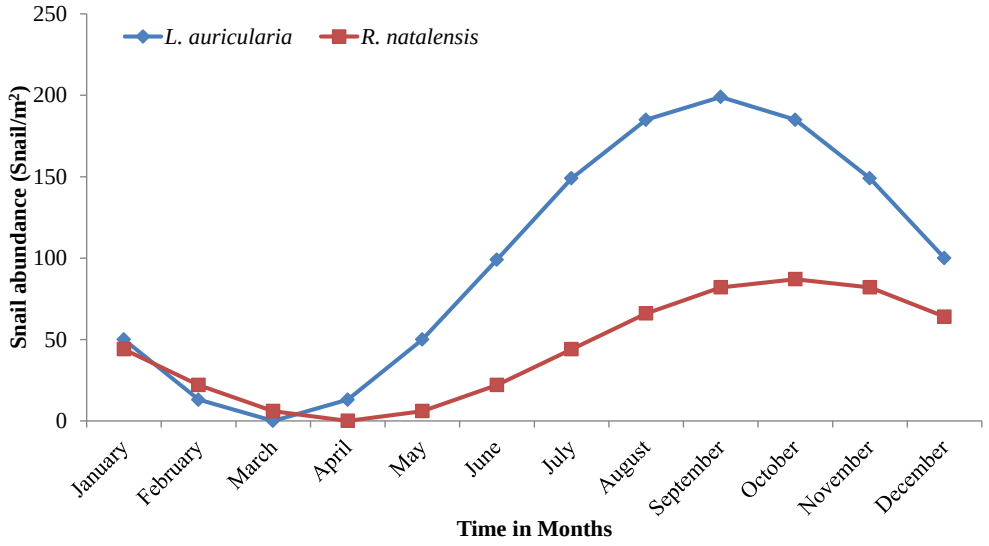

Figure 3. *Temporal Variations of Snail Intermediate Hosts of Fasciola species in Kingwal Swamp.*

A total of 1,342 *L. auricularia* and 154 *R. natalensis* snails were examined for *Fasciola* spp. infection over the 12-month period (Table 2). Infection prevalence varied significantly by month and by snail species. *R. natalensis* consistently exhibited higher infection rates than *L. auricularia*, with values ranging from 11.9% in January to a peak of 29.3% in June. Other high-prevalence months included May (28.4%), August (29.1%), and April (24.6%), aligning with the rainy season when ecological conditions likely favored snail breeding and parasite transmission. The lowest infection rates occurred during the drier months, particularly in December (12.1%) and January (11.9%). *L. auricularia* also exhibited monthly variation in parasite infection, though at lower overall rates than *R. natalensis*. Its infection prevalence ranged from a minimum of 4.0% in January to a maximum of 12.2% in June. Other months with relatively high infection levels included May (11.3%) and August (12.0%). Similar to *R. natalensis*, the infection rates in *L. auricularia* tended to rise with the onset of the long rainy season and gradually declined as the dry season approached.

Statistical analysis confirmed these temporal trends. The monthly variation in infection prevalence for both snail species was statistically significant. For *R. natalensis*, infection prevalence showed strong monthly variation, with an average prevalence of 22.8% and a standard deviation of ±6.6%. In contrast, *L. auricularia* had a mean infection rate of 8.5%, with a standard deviation of ±2.6%. The highest infection levels for both species occurred between May and August, coinciding with periods of increased rainfall which provided suitable environmental conditions for both snail reproduction and parasite development. Comparatively, *R. natalensis* appears to be more susceptible to infection by *Fasciola species* than *L. auricularia*. This difference may be attributed to species-specific ecological preferences or physiological factors that make *R. natalensis* a more competent intermediate host.

Table 2. Monthly Infection Data for Snails by Fasciola spp. in Kingwal Wetland.

Month	*R. natalensis*			*L. auricularia*		
	Sampled	Infected	Prevalence (%)	Sampled	Infected	Prevalence (%)
January	42	5	11.9	101	4	4.0
February	38	6	15.8	98	6	6.1
March	49	10	20.4	112	9	8.0
April	61	15	24.6	135	14	10.4
May	67	19	28.4	141	16	11.3
June	58	17	29.3	123	15	12.2
July	52	14	26.9	109	13	11.9
August	55	16	29.1	117	14	12.0
September	47	13	27.7	114	11	9.6
October	44	9	20.5	106	8	7.5
November	39	6	15.4	98	6	6.1
December	33	4	12.1	88	5	5.7
Total	585	154	26.3	1,342	121	9.0

3.3. Spatio-temporal Variations of Snail Intermediate Hosts of Fasciola Spp

The abundance of *Lymnaea auricularia* and *Radix natalensis* varied across both space (site) and time (month), although statistical analysis using the chi-square test revealed that these variations were not significant. For *L. auricularia*, the chi-square test yielded a value of $\chi^2 = 1.123$ with a p-value of 0.812, and a similar result was obtained for *R. natalensis* ($\chi^2 = 0.566$, $p = 0.874$). These results indicate that the observed fluctuations in snail abundance across the different sites and months were not statistically significant at the 5% confidence level. Nonetheless, descriptive analysis reveals several notable patterns in their distribution.

Both snail species exhibited distinct temporal trends in abundance. For *L. auricularia*, the highest abundance was recorded at Site 1 in May, with 95 individuals. *R. natalensis* followed a similar trend, peaking in May at the same site with 48 individuals. In general, the early months of the year (January to July) were characterized by higher snail counts, suggesting favorable environmental conditions during this period. Conversely, the lowest abundance for both species occurred in December at Site 5, where only 45 *L. auricularia* and 19 *R. natalensis* were recorded. These findings suggest that snail populations are influenced by seasonal environmental factors, potentially including rainfall patterns, temperature, and vegetation cover.

Spatially, Site 1 consistently supported the highest densities of both species throughout the year. Abundances remained above 83 individuals for *L. auricularia* from January to August and ranged between 39 and 48 individuals for *R. natalensis* during the same period. This pattern suggests that Site 1 may offer optimal habitat conditions, such as suitable water quality, vegetation structure, or reduced levels of disturbance or predation. On the other hand, Sites 5 and 7 typically recorded the lowest monthly averages for both species. These two sites showed gradual declines in snail numbers toward the end of the year, possibly reflecting less favorable or more variable environmental conditions. For instance, at Site 7, *L. auricularia* declined from 70 in May to just 46 in December, while *R. natalensis* declined from 35 to 20 over the same period.

Certain site-month combinations stood out due to relatively high or low snail counts. At Site 1, *L. auricularia* remained consistently high from April (90 individuals) to July (89), while *R. natalensis* also showed peaks in April (45), July (44), and August (41). These months likely reflect optimal ecological conditions perhaps increased aquatic vegetation, stable water levels, or ideal temperatures for reproduction and growth.

Although not statistically significant, the descriptive patterns point to ecological consistency in the timing of peak snail abundance across sites, and a gradient of site quality, with Site 1 being most suitable and Sites 5 and 7 less so. These patterns merit further investigation with larger sample sizes or finer-resolution ecological data to determine the specific environmental drivers of snail population dynamics.

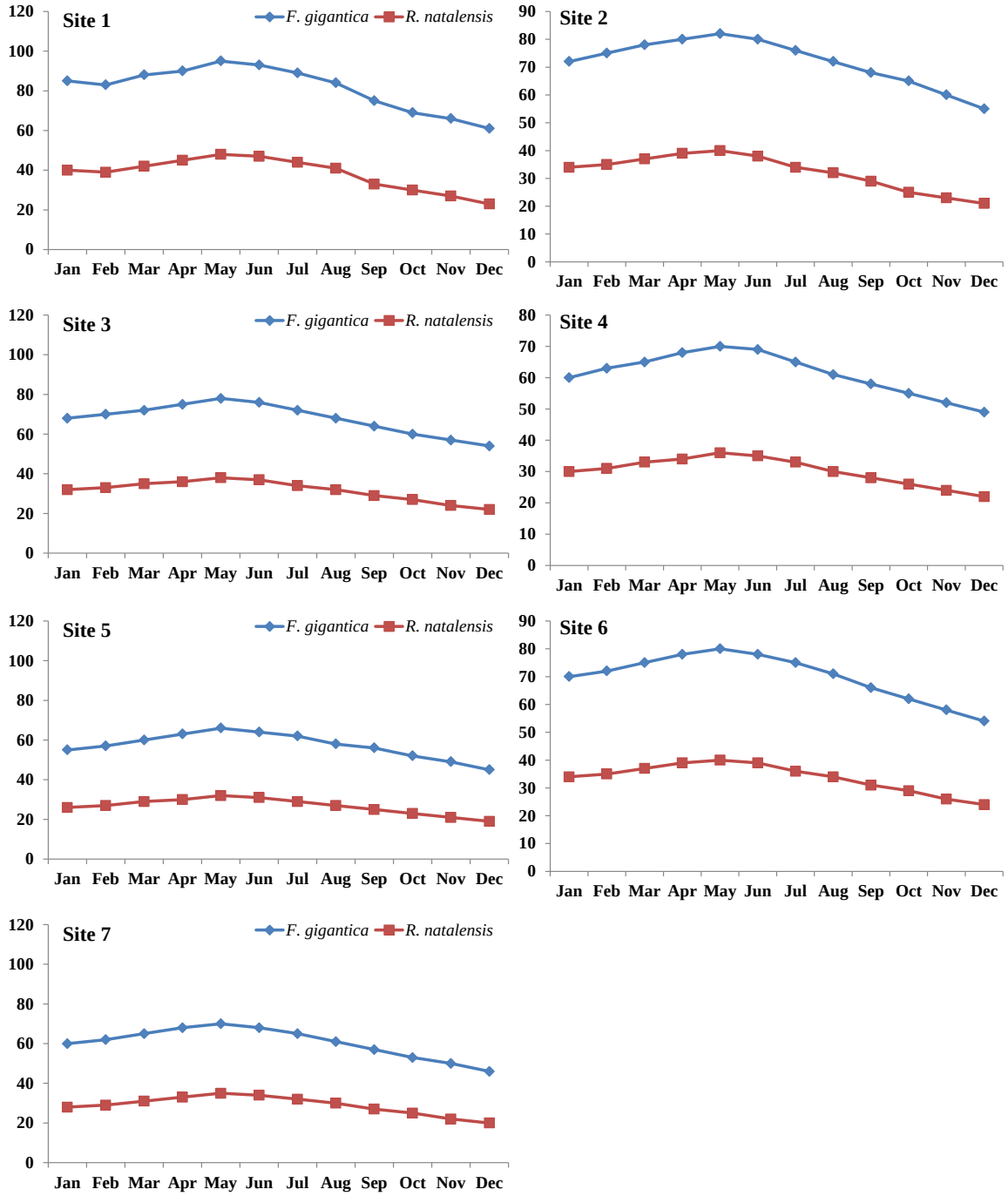

Figure 4. *Spatio-temporal Variations of Snail Intermediate Hosts of* Fasciola *spp.*

4. Discussion

Across the Kingwal Wetland mosaic, spatial patterns in fascioliasis infection emphasize that transmission is driven less by overall snail richness than by the presence and infection status of a few competent lymnaeid hosts—principally *Radix natalensis* and *Lymnaea auricularia*—whose ecology dovetails with the *Fasciola* life cycle; this aligns with long-standing evidence that fascioliasis in tropical Africa is sustained where these lymnaeids occur in stable or seasonally inundated, nutrient-rich waters with livestock access and slow flow that favor miracidia encounter and cercarial shedding [2, 7-9, 10, 12, 13, 19-21]. In East and North-East Africa, *R. natalensis* repeatedly emerges as the most epidemiologically important vector of *F. gigantica* in flood-prone water bodies, irrigation channels, and backwaters—a pattern first quantified at landscape scale using GIS risk models and later corroborated by site-level parasitology (e.g., Yilma & Malone's

Ethiopia model and subsequent East African extensions), and by country studies in Zimbabwe, Algeria, and the Lake Victoria basin showing higher infection foci in shallow, organic-laden habitats used by cattle [4-7, 9, 11, 18]. The concentration of infected snails at a subset of sites that combine stable hydrology, detrital food, vegetation structure, and pastoral use is consistent with observations that microhabitat quality and contamination rate can outweigh raw host density in determining focal transmission; thus even low-density *R. natalensis* populations can sustain high local infection where faecal inputs seed eggs into calm margins where miracidia locate lymnaeids efficiently [1, 2, 7, 9, 17, 21]. Conversely, reaches with higher current or periodic flushing are poorer transmission habitats, as increased velocity, turbidity, and reduced macrophytes suppress both snail settlement and parasite stages [1, 2, 7, 9, 17]. Collectively, these spatial signals support the operational value of lymnaeid-centred surveillance: mapping and monitoring *R. natalensis* and *L. auricularia* in nutrient-rich, low-flow pockets (and near cattle access points) functions as an early-warning system for fascioliasis risk in livestock and, where human exposure occurs, in people; targeted habitat management—e.g., fencing of watering margins, intermittent drainage, or vegetation management in small foci—aligns with WHO-endorsed principles for snail-borne trematode control and is most defensible where site-specific ecology, rather than whole-wetland averages, governs transmission potential [3, 10, 20, 21].

The contrasting seasonal trajectories of *L. auricularia* and *R. natalensis*—the former exhibiting brief, pronounced pulses and the latter sustaining broader, later-season plateaus—mirror species-specific life-history strategies that shape transmission windows: *L. auricularia* often surges around the wet-to-dry transition in shallow, vegetated margins where reproduction and survival spike in residual pools, whereas *R. natalensis* maintains activity across a wider temporal niche and peaks later, consistent with tolerance of drier or more variable hydrology and frequent occupancy of sun-exposed pools used by livestock [6, 7, 9, 12, 13, 15, 19, 21, 22]. Multi-month series from East and southern Africa show similar asynchrony, with *R. natalensis* extending the fascioliasis season beyond peak rains by remaining abundant (and frequently infected) into late post-rain months; analyses from Zimbabwe, Lake Victoria tributaries, and North Africa report that residual standing water, organic enrichment from grazing, and moderate temperatures sustain both snail populations and intramolluscan development, prolonging cercarial output into the latter half of the year [6, 7, 9, 11, 15-17, 19]. Such temporal structuring is epidemiologically important because it broadens the alignment between snail infectivity and livestock exposure at water points—precisely when herds congregate at shrinking pools—thereby elevating risk during "shoulder season" months. From a control standpoint, the data argue for season-aware interventions: surveillance and molluscicide (or non-chemical habitat actions) synchronized to early wet-season rises for *L. auricularia* foci, and extended into late post-rain months where *R. natalensis* persists; strategic veterinary actions (e.g., timing herd management around high-risk margins) likewise benefit from these host-specific phenologies [10, 15-17, 20-23].

Even where formal tests detect no significant site × month interaction for total counts, the descriptive spatio-temporal patterning—stable "source" sites that retain water and vegetation, peripheral "sinks" that desiccate or flush, and species-specific responses to those regimes—reveals biologically coherent structure typical of wetland metapopulations of trematode-hosting snails. Perennial or frequently inundated nodes act as refugia for *L. auricularia* and *R. natalensis*, reseeding transient patches as conditions improve, while grazing intensity and faecal inputs overlay an anthropogenic signal that can decouple abundance from transmission by concentrating parasite stages in a few high-use pools [6, 7, 9, 18, 21, 22]. Comparable source–sink and seasonality effects have been described along East African rivers and wetlands, where lymnaeid abundance peaks during habitat expansion and declines with contraction, and where the highest *Fasciola* transmission is often recorded not at the numerically richest sites but at livestock-dominated margins with persistent shallow water, macrophytes, and organic detritus [6, 7, 9, 18, 19, 21, 22]. Integrating this spatio-temporal mosaic into control means privileging place-and-time targeting: map perennial nodes (candidate reservoirs), identify repeatedly positive foci (hotspots), and schedule actions when host populations and intramolluscan development most overlap. At program level, this argues for risk maps that weight (i) perenniality/flow class, (ii) macrophyte structure, and (iii) documented livestock access more heavily than raw site-wide snail counts; regionally validated GIS frameworks and African reviews support this weighting and show that incorporating these landscape and use variables improves fascioliasis risk prediction—transforming non-significant omnibus tests into actionable micro-stratification for surveillance and environmental management [4, 5, 10, 20-22].

5. Conclusion and Recommendations

This study presents the first comprehensive study of fascioliasis transmission in Kingwal Wetland primarily sustained by two competent lymnaeid snail species *Radix natalensis* and *Lymnaea auricularia* out of the eight identified snail species thatshed *Fasciola* cercariae.. *R. natalensis* exhibited higher infection prevalence (mean 17.3%) than *L. auricularia* (mean 8.2%), with peaks occurring during the long rains and early post-rain periods, especially in nutrient-rich, slow-flowing, livestock-accessible habitats such as Sites 6 and 7. Distinct seasonal patterns were observed, with *L. auricularia* showing short, intense abundance peaks at the wet-to-dry transition, while *R. natalensis* maintained moderate but prolonged populations into the dry season, extending the transmission window. Although site–month abundance interactions were not statistically significant, stable "source" habitats with

permanent water and dense vegetation emerged as critical refugia for infected populations, underscoring that habitat quality and livestock–water contact drive transmission risk more than overall snail density.

Targeted, site-specific, and seasonally timed control measures are recommended, focusing surveillance and intervention on *R. natalensis* and *L. auricularia* populations in high-risk habitats identified through GIS-based mapping that prioritises water permanence, vegetation cover, and livestock access over raw snail counts. Snail control interventions such as molluscicide, vegetation clearance, or intermittent drainage should be implemented early in the wet season for *L. auricularia* habitats and extended into late post-rain months for *R. natalensis* areas. Livestock management should include restricting or rotating access to infested watering points during peak transmission months (May–August) and promoting off-site watering facilities. These efforts should be embedded within a One Health framework that integrates malacological, veterinary, and public health surveillance with community awareness programmes, while further research should investigate environmental predictors of snail infection dynamics to improve predictive modelling and long-term control planning.

Abbreviations

CMH	Haenszel (Test Statistic)
DF	Degree of Freedom
DNA	Deoxyribonucleic Acid
GIS	Geographic Information System
GPS	Global Positioning System
HClO	Sodium Hypochlorite Solution

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Author Contributions

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Moses Ngeiywa: Supervision, Validation, Visualization, Writing – review & editing

Judith Makwali: Supervision, Validation, Visualization, Writing – review & editing

Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

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