ISSN: 2458-8989

Natural and Engineering Sciences

NESciences, 2026, 11 (3): 588-598 doi: 10.28978/nesciences.263047

Environmental Drivers of Amphibian and Reptile Diversity in a Tropical Canal Ecosystem: Evidence from Lam Takhong, Thailand

Dr. Alongkot Chukaew[1*], Tristan Kanjanapas[2]

[1]Director of Environmental and Social Foundation, Thailand.
E-mail: alongkot@esfthailand.org

[2]Youth Project Member, Marine Endangered Species ConservationEnvironmental and Social Foundation, Thailand. E-mail: tristan.esf@gmail.com

Abstract

Herpetofaunal diversity in tropical canal ecosystems remains understudied, particularly in Thailand, where extensive networks of artificial waterways modify natural habitats. This study examined amphibian and reptile diversity along the Lam Takhong Canal, Pak Chong District, Nakhon Ratchasima Province, Thailand, and investigated relationships between environmental drivers and species diversity using Visual Encounter Surveys at six stations (twelve sampling points) spanning upstream, midstream, and downstream zones. Environmental parameters, including air temperature, water temperature, soil temperature, relative humidity, pH, ammonia, and nitrate, were measured concurrently, and relationships were analyzed using Pearson correlation, multiple regression, and one-way ANOVA. A total of 463 individuals representing 45 species were recorded (326 amphibians from 19 species; 137 reptiles from 26 species), including the Thailand-endemic Khorat snail-eating turtle (Malayemys khoratensis). Water pH and ammonia were significantly and positively correlated with species richness and abundance ($r = 0.741$ and 0.795, respectively; $p < 0.05$), while water temperature showed a marginally significant negative correlation with richness ($r = -0.531$, $p = 0.075$). Air temperature and humidity showed no significant associations. A multiple regression model incorporating environmental predictors explained 75% of the variance in species richness ($R^2 = 0.749$). These findings indicate that water quality, rather than microclimatic conditions, is the principal determinant of herpetofaunal diversity in this tropical canal ecosystem, with implications for water-quality management and habitat conservation in irrigation canals across rapidly developing agricultural landscapes in Southeast Asia.

Keywords:
amphibians and reptiles; herpetofaunal diversity; water quality; tropical canal ecosystem; environmental drivers; Lam Takhong

Available Online: 01/09/2026

1. Introduction

Amphibians and reptiles are often used to gauge how a tropical ecosystem is doing, since their physiology and behavior respond so directly to temperature, humidity, and habitat quality (Zhu et al., 2024). Climate change and habitat modification are usually named as the two biggest pressures on herpetofaunal populations, and ectotherms feel this more than most groups because their metabolism and reproduction depend directly on ambient conditions (Lourenço-de-Moraes et al., 2019; Bofill & Blom, 2024). Both pressures act on species with biphasic life histories: many amphibians need both

**Corresponding Author: Dr. Alongkot Chukaew, E-mail: alongkot@esfthailand.org*

aquatic and terrestrial habitat within a single life cycle, so a disruption to either environment, whether thermal, hydrological, or chemical, can limit population persistence in ways a single-habitat study would miss (Campbell et al., 2024). Most ecological research on these groups still comes from forests and protected areas, though, and comparatively little is known about how amphibians and reptiles fare in the artificial waterways that increasingly dominate tropical agricultural landscapes (Smith et al., 2021).

This gap shows up clearly in Thailand, where a large network of irrigation canals reshapes natural hydrology across much of the country's agricultural heartland, yet few studies have looked at how these systems support herpetofaunal biodiversity (Aguilar et al., 2025; Grismer et al., 2022). Part of why this matter is that Thailand's protected areas are themselves projected to undergo real climatic shifts in the coming decades, and amphibians and reptiles are expected to respond differently to changing thermal regimes than other vertebrate groups do (Pomoim et al., 2022). Irrigation canals may increasingly work as secondary habitat and dispersal routes for species pushed out of more heavily altered surrounding land (Matos et al., 2021). As agricultural intensification keeps expanding the footprint of these engineered waterways across Southeast Asia, understanding what currently lets herpetofauna persist in them, and what limits that persistence, matters for anticipating how these systems hold up under future climatic and land-use pressure, even though answering that longer question properly would need more than one field season of data.

The Lam Takhong Canal, in Nakhon Ratchasima Province, is a good place to look at this question. It starts in the forested watershed of Khao Yai National Park and runs through a mix of agricultural and semi-urban land before reaching the Lam Takhong Reservoir, so it moves from relatively intact to heavily modified habitat over a short distance (Harianja et al., 2024). The canal's upstream, midstream, and downstream reaches differ in canopy cover, water chemistry, and surrounding land use, so this same stretch also works as a natural gradient for comparing how microclimatic, thermal, and water-quality drivers influence herpetofaunal diversity within one study system.

2. Research Objectives

This study surveyed amphibian and reptile diversity along the Lam Takhong Canal and measured a suite of environmental variables at each station, with three specific objectives:

(1) To document the species diversity, composition, and relative abundance of amphibians and reptiles along the canal;

(2) To characterize how microclimatic conditions, habitat thermal conditions, and water quality vary spatially along the canal's upstream-to-downstream gradient; and

(3) To test which of these environmental drivers, individually and in combination, best explain patterns in species richness, diversity, and abundance.

The results are intended to provide baseline ecological data to support water-quality management and biodiversity conservation in irrigation canals more broadly across tropical Southeast Asia.

3. Hypotheses

Four hypotheses guided the analysis:

H1: Microclimatic conditions (air temperature, relative humidity) significantly influence species richness and diversity.

H2: Habitat thermal conditions (water and soil temperature) significantly affect species occurrence and distribution.

H3: Water quality parameters (pH, ammonia, nitrate) are significantly associated with species diversity.

H4: Environmental drivers collectively explain significant variation in species diversity across sampling stations.

4. Literature Review

4.1 Climate Change and Biodiversity Loss

Climate change ranks among the biggest drivers of global biodiversity decline, and ectotherms such as amphibians and reptiles are especially exposed: even small increases in ambient temperature can push them toward their critical thermal limits, disrupting growth, reproduction, and immune function (Ruthsatz et al., 2024; Pottier et al., 2025). Rising global temperatures, altered precipitation, and more frequent climate extremes are projected to intensify these pressures over the coming decades (Pörtner et al., 2023; Fei et al., 2026; Duffy et al., 2022), and species already living near their thermal ceiling,

often true of tropical populations, have the least room left to absorb further warming (Doucette et al., 2023). Several authors, though, push back against treating climate change as the dominant driver of biodiversity loss on its own. Habitat destruction and land-use change remain the primary pressure in most regions, and it's the interaction between climatic stress and habitat modification, not either one alone, that tends to do the most damage (Caro et al., 2022; Jaureguiberry et al., 2022). This matters especially for regulated freshwater systems, where altered flow regimes can throw amphibian breeding out of sync with favorable environmental windows and pile onto the effects of thermal stress on larval survival (Teixeira et al., 2022).

4.2 Ecological Sensitivity of Amphibians and Reptiles

Amphibians and reptiles sit at an important point in the food web, acting as both predator and prey, and their biphasic life histories plus permeable, water-dependent skin make them unusually responsive to environmental change. Amphibians in particular are considered the most imperiled vertebrate class on the planet (Campbell et al., 2024; Hopkins et al., 2024). Because they depend on ambient conditions for thermoregulation, metabolism, and hydration, habitat simplification or contamination tends to hit them faster and harder than better-buffered groups (Alagador, 2022; Crnobrnja-Isailović et al., 2021). Vegetation structure and microhabitat availability matter a great deal here: losing structural complexity cuts off chances for thermoregulation and shelter, and tends to favor a small set of disturbance-tolerant generalists over the wider community of habitat specialists (Băncilă et al., 2023; O'Sullivan et al., 2023).

4.3 Environmental Drivers in Freshwater Ecosystems

In freshwater systems, hydrological regime, water chemistry, and riparian vegetation together shape herpetofaunal communities, balancing what a species physiologically needs, thermoregulation and hydration, against what it ecologically needs, shelter and prey (Karami et al., 2023; Puig-Gironès et al., 2024). Water availability and quality are consistently reported among the strongest predictors of amphibian abundance and diversity, and landscape-scale factors, meaning surrounding land use and vegetation cover, often carry more weight than local, site-level variables (Cervantes-López et al., 2025; Channuwong et al., 2026; Vehkaoja et al., 2023). Agricultural expansion and urbanization wear these systems down through habitat fragmentation, altered hydrological connectivity, and shifts in water chemistry and temperature, and the effects tend to stack up rather than stay isolated (Awkerman et al., 2024).

4.4 Freshwater Canals as Modified Habitats

Artificial waterways have shaped landscapes for millennia and now exceed 63,000 km worldwide (Bergman et al., 2021), yet they remain understudied relative to natural streams and rivers. Canals typically face a recurring set of stressors: agricultural runoff, wastewater discharge, and water abstraction all degrade water quality and simplify physical habitat, even as the channels themselves create new corridors for movement and, potentially, invasive species spread (Kaijser et al., 2025; Lettoof et al., 2023). Growing flow intermittence tied to drought and water demand adds another threat for species adapted to perennial conditions (Datry et al., 2022), and nutrient loading and other contaminants tend to build up during low-flow periods, so aquatic organisms often face a pulse of physiological stress once flow resumes (Awkerman et al., 2024).

4.5 Research Gap and Study Rationale

Most herpetofaunal research in Southeast Asia has focused on forested or protected habitats. Canal and reservoir-linked systems, despite their ecological and social importance, remain comparatively unstudied, especially where biodiversity surveys are paired with concurrent environmental measurements (Tantipisanuh et al., 2023; Grismer et al., 2022). This gap limits the evidence base available for managing biodiversity in the region's rapidly expanding irrigation networks. The Lam Takhong Canal, which spans a gradient from protected forest headwaters to agricultural and semi-urban reaches, offers a natural opportunity to close part of that gap and to test which environmental drivers most strongly shape herpetofaunal community structure in a regulated tropical waterway.

5. Conceptual Framework

This study frames environmental variability as the primary driver of habitat suitability, and therefore of herpetofaunal diversity, in the canal ecosystem (Figure 1). Because amphibians and reptiles are ectotherms, their physiology and behavior respond directly to ambient conditions. Three groups of

environmental drivers are treated as independent variables: microclimatic conditions (air temperature, relative humidity), habitat thermal conditions (water and soil temperature), and water quality (pH, ammonia, nitrate). These are hypothesized to act on habitat suitability and microhabitat quality, which in turn shapes the ecological response measured here: species richness, diversity, and occurrence. The framework treats the drivers as acting jointly rather than independently, which is what Hypothesis 4 tests.

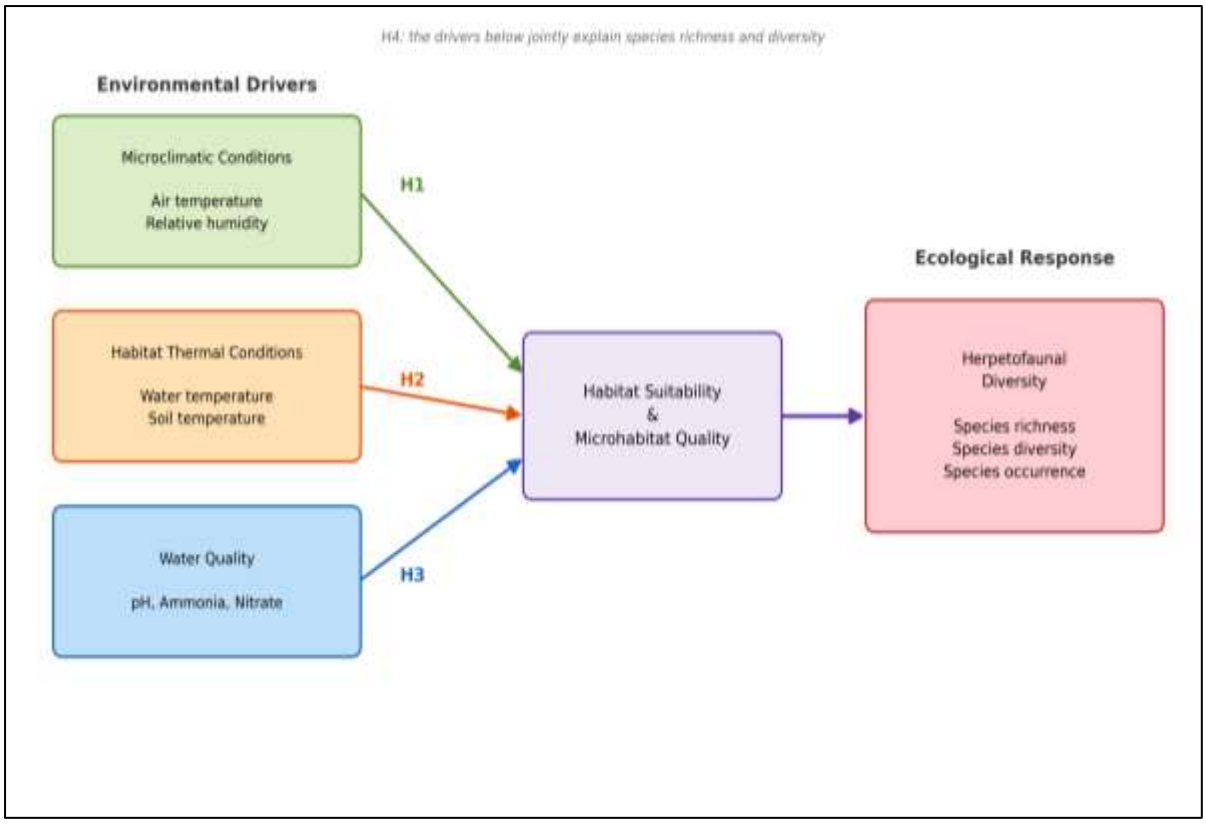

Figure 1. Conceptual framework linking environmental drivers, habitat suitability, and herpetofaunal diversity

6. Research Methodology

6.1 Study Area

The study was conducted along roughly 2–3 km of the Lam Takhong Canal in Pak Chong District, Nakhon Ratchasima Province, at an elevation of about 300 m. The canal originates in the forested headwaters of Khao Yai National Park, Thailand's first national park and a UNESCO World Heritage Site, and flows through a mix of riparian vegetation, agricultural land, and semi-urban development before entering the Lam Takhong Reservoir, which supplies water for irrigation, hydropower, and domestic use in the province. Six stations were established along this gradient and grouped into upstream, midstream, and downstream zones, with two sampling points per station (twelve points in total), covering a range of canopy cover and human disturbance.

6.2 Field Survey and Sampling

Amphibians and reptiles were surveyed using the Visual Encounter Survey (VES) method, conducted between 18:00 and 20:00, when herpetofaunal activity is highest. Surveys were restricted to favorable weather to cut down on detection bias, since activity tends to drop off during heavy rain or temperature extremes (Anunciação et al., 2023), and observers recorded species identity, time, location, and microhabitat for every individual encountered along fixed transects at each station (Griffin et al., 2025). Sampling effort was kept consistent across stations to reduce detection differences between sites (Baumgardt et al., 2021), and artificial cover objects were used alongside active searching, since they are a cheap and effective way to catch cryptic, ground-dwelling species that active searches tend to miss (Liberman et al., 2024; Hodges et al., 2022).

6.3 Environmental Data Collection

At each station, air temperature and water temperature were measured with digital thermometers, soil temperature with an infrared thermometer, and relative humidity with a handheld hygrometer. Water pH was measured with a portable pH meter, and ammonia and nitrate concentrations were determined using colorimetric test kits. These variables were chosen because each is a known determinant of habitat suitability and physiological performance in ectothermic organisms: thermal variables constrain metabolism and activity, humidity governs evaporative water loss in amphibians, and water chemistry affects both direct physiological tolerance and the productivity of the aquatic food base that larval and adult stages both depend on (Hopkins et al., 2024; Mahan et al., 2022).

6.4 Data Analysis

Species richness, abundance, and diversity indices (Shannon–Wiener H′, Pielou's evenness J′, Simpson's D) were calculated for each station. Relationships between environmental variables and species richness, diversity, and abundance were tested using Pearson correlation and simple linear regression for Hypotheses 1–3, and multiple linear regression for the combined test in Hypothesis 4. One-way ANOVA was used to compare richness, diversity, and abundance across the three longitudinal zones, and a preliminary correlation screen was used to check for multicollinearity among predictors before regression (Atanacković et al., 2023). Data were checked for normality prior to parametric testing, and statistical significance was evaluated at the conventional 0.05 threshold, with a Bonferroni adjustment applied where multiple pairwise comparisons were involved (Xia et al., 2025).

7. Results

7.1 Species Composition and Abundance

A total of 463 individuals from 45 species were recorded across the twelve sampling points (Figure 2). Amphibians accounted for 326 individuals from 19 species, and reptiles for 137 individuals from 26 species. The assemblage was strongly right-skewed: four species, Hylarana erythraea (n = 86), Fejervarya limnocharis (n = 65), Calotes versicolor (n = 60), and Rana nigrovittata (n = 28), together made up just over half of all records, while 21 of the 45 species were represented by a single individual. This pattern, where a handful of habitat generalists dominate numerically while many specialists persist at low abundance, is typical of disturbed or transitional freshwater habitats. The reptile assemblage also included the Khorat snail-eating turtle (Malayemys khoratensis), a species endemic to Thailand, recorded as a single individual.

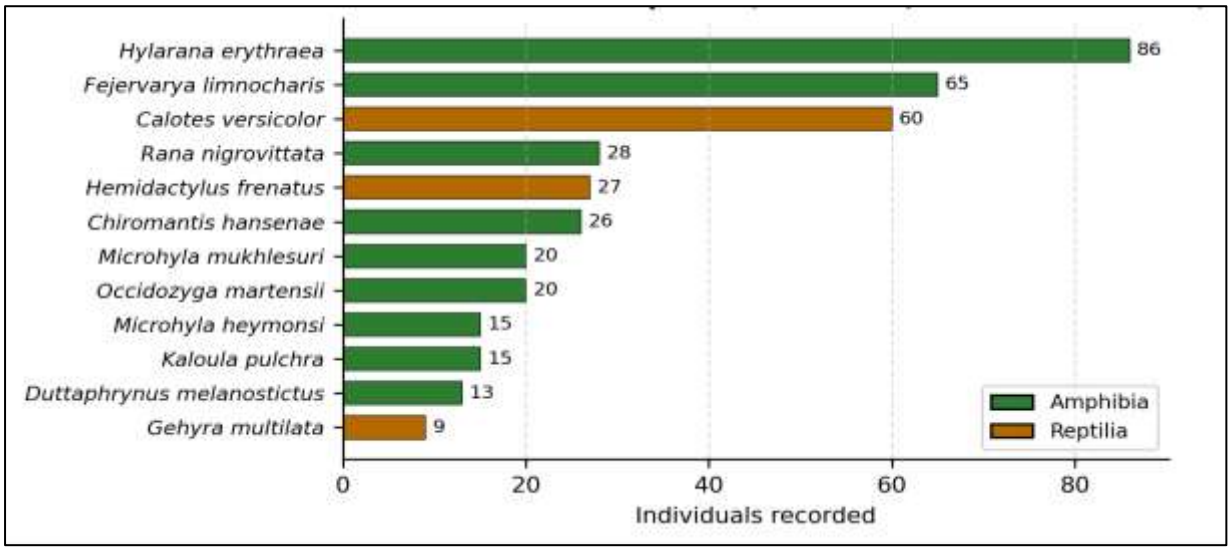

Figure 2 The twelve most abundant species recorded (of 45 total), colour-coded by Class. (n = 463 individuals)

7.2 Environmental Characteristics of Sampling Stations

Air temperature (23.0–28.5 °C) and relative humidity (66–89%) varied without a clear longitudinal trend, but water temperature rose from a mean of 20.0 °C upstream to 25.9 °C downstream, consistent with reduced canopy cover in the lower reaches. Water pH was highest upstream (mean 8.4) and declined toward midstream and downstream stations (means 7.5 and 7.7). Nitrate was elevated at

upstream stations and the first midstream station (12.5 mg L^{-1}) before dropping to a stable baseline of 1.25 mg L^{-1} elsewhere, suggesting a localized nutrient source near the headwaters rather than a gradual downstream trend. Ammonia remained low and fairly uniform throughout (0–0.25 mg L^{-1}).

7.3 Spatial Patterns in Richness and Diversity

Station level richness ranged from 6 to 16 species, and Shannon diversity from 1.456 to 2.576 (Table 1). At the zone level, richness and diversity were highest upstream ($\bar{S}$ = 12.25, $\bar{H}'$ = 2.081) and lowest midstream ($\bar{S}$ = 8.50, $\bar{H}'$ = 1.650), while mean abundance increased from upstream (30.0) to midstream (33.75) and downstream (52.0). None of these zonal differences reached statistical significance in one-way ANOVA (richness: $F_{2,9} = 1.67$, $p = 0.241$; H′: $F_{2,9} = 1.48$, $p = 0.278$; abundance: $F_{2,9} = 3.17$, $p = 0.091$), though the abundance comparison came noticeably closer to the conventional threshold than the other two metrics, suggesting station-to-station variation within zones still outweighed, but not by as wide a margin, the variation explained by zone identity.

Table 1. Species richness (S), abundance (N), and diversity indices at each sampling station

Station	Zone	S	N	H′	J′	D
S01-1	Upstream	16	37	2.571	0.927	0.909
S01-2	Upstream	11	36	1.693	0.706	0.730
S02-1	Upstream	6	13	1.484	0.828	0.710
S02-2	Upstream	16	34	2.576	0.929	0.908
S03-1	Midstream	6	11	1.594	0.890	0.760
S03-2	Midstream	11	38	1.953	0.814	0.792
S04-1	Midstream	8	33	1.598	0.769	0.713
S04-2	Midstream	9	53	1.456	0.663	0.612
S05-1	Downstream	11	39	1.849	0.771	0.774
S05-2	Downstream	13	51	2.085	0.813	0.834
S06-1	Downstream	11	57	2.033	0.848	0.838
S06-2	Downstream	11	61	1.815	0.757	0.764

7.4 Hypothesis Testing

Air temperature and relative humidity showed no significant relationship with richness or diversity (H1 not supported), though air temperature trended in the expected direction ($r = 0.427–0.546$). Water temperature was negatively correlated with richness and diversity, approaching significance ($r = −0.531$ and $−0.534$, $p < 0.10$), which gives partial support to H2; soil temperature showed no relationship at all. Water quality produced the clearest results by far: pH correlated positively with richness ($r = 0.741$, $p = 0.006$) and diversity ($r = 0.642$, $p = 0.024$), ammonia correlated positively with both richness ($r = 0.683$, $p = 0.014$) and abundance ($r = 0.795$, $p = 0.002$), and nitrate correlated negatively with abundance ($r = −0.714$, $p = 0.009$). H3 was strongly supported. A multiple regression combining air temperature, humidity, pH, and ammonia explained 75% of the variance in richness ($R^2 = 0.749$), with pH and ammonia contributing the largest effects, which supports H4 (Table 2).

Table 2. Summary of hypothesis testing

Hypothesis	Key predictor(s)	Result	Support
H1	Air temperature, humidity	$r = 0.43–0.55$, $p > 0.06$	Not supported
H2	Water temp., soil temp.	Water temp.: $r = −0.53$, $p = 0.075$	Partially supported
H3	pH, ammonia, nitrate	pH & NH_3 vs. richness: $p < 0.05$; NO_3^- vs. abundance: $p = 0.009$	Supported
H4	Combined drivers	$R^2 = 0.75$ (richness)	Supported

8. Discussion

8.1 Patterns of Herpetofaunal Diversity

That the Lam Takhong Canal supports 45 species despite being a heavily modified waterway fits with findings from other artificial waterways around the world, which can sustain meaningful biodiversity even in disturbed form (Bergman et al., 2021; Bowen et al., 2024). The dominance of a few generalist species alongside many low-abundance specialists' lines up with the idea of biotic homogenization under habitat disturbance (Dehling & Dehling, 2023). The endemic Khorat snail-eating turtle showing up here, even as a single record, is a reminder that modified waterways can still hold conservation value for range-restricted species (Cox et al., 2022).

8.2 The Role of Water Quality

Water quality, and pH and ammonia specifically, turned out to be the strongest correlates of richness and abundance in this study, which fits the general pattern of amphibians being sensitive to aquatic chemistry through their permeable skin (Hopkins et al., 2024). The positive ammonia relationship is worth pausing on, since it runs against the toxic effects usually reported for ammonia exposure (Zambrano-Fernández et al., 2021). But ammonia levels here stayed well below acutely toxic thresholds throughout, so a more likely explanation is that ammonia was tracking nutrient-rich, productive water rather than acting as a stressor in its own right; this would line up with reports that primary productivity can positively predict anuran abundance (Sheridan & Kendrick, 2024). The negative relationship between nitrate and abundance probably reflects localized eutrophication near the headwater stations instead (Timalsina et al., 2025). Put together, the multiple regression result ($R^2 = 0.78$) suggests these drivers work jointly rather than separately, which matches frameworks that treat freshwater biodiversity as shaped by interacting hydrological, chemical, and structural factors (Karami et al., 2023; Kaijser et al., 2025).

8.3 Temperature and Humidity

Air temperature and humidity had no significant effect here, and the most likely reason is that the thermal range sampled (23.0–28.5 °C) sits well within the broader tolerance window typical of tropical ectotherms (Filho et al., 2022), unlike studies that cover wider elevational or seasonal gradients (Oliveira et al., 2024). Water temperature told a different story. Its marginally significant negative relationship with richness makes ecological sense given its direct role in amphibian larval development and reptile thermoregulation (Ruthsatz et al., 2024; Youthao et al., 2026), and it may explain why the warmer, more exposed downstream reach had higher abundance but lower diversity. That pattern broadly matches how amphibians have been shown to respond to warming elsewhere (Pottier et al., 2025).

8.4 Linking These Results to Climate Change

These findings are relevant to the climate change literature, but only in a limited way. The negative relationship between water temperature and both richness and diversity fits the broader expectation that warming hits ectotherms hardest when they are already close to their thermal limits (Ruthsatz et al., 2024; Pottier et al., 2025), and it lends some indirect support to the concern that continued warming of shallow tropical waterways could further erode herpetofaunal diversity in systems like this one (Pörtner et al., 2023). However, this study cannot show a climate change effect directly. Sampling was cross-sectional and mostly confined to a single season, so what the data actually show is a correlation between current thermal conditions and diversity at one point in time, not a trend caused by warming over time. It is also worth pointing out that air temperature and humidity, the two variables most directly tied to regional climate rather than local canal structure, were exactly the predictors that showed no significant relationship with any diversity metric. Not every plausible climate-linked variable produces a detectable signal within the narrow range a single study happens to sample (Filho et al., 2022). This fits with arguments that climate change should be treated as one interacting driver among several rather than the default explanation (Caro et al., 2022; Jaureguiberry et al., 2022): the clearer result here was that water quality, not thermal or climatic variables, carried the strongest explanatory power. None of this makes climate change irrelevant to this system. Warmer water downstream, changing rainfall patterns, and shifting canal hydrology are all plausible long-term pressures on the assemblage documented here. But confirming that link properly would take repeated, multi-season monitoring of the kind proposed in Section 7.7, not the single baseline survey this study is built on.

8.5 Longitudinal Spatial Patterns

Although the zonal differences did not reach statistical significance, the trend toward higher diversity upstream near the forested Khao Yai watershed, and lower diversity in the more disturbed midstream and downstream reaches, fits with evidence that landscape-level factors often outweigh local variables in shaping herpetofaunal communities (Cervantes-López et al., 2025). The small number of stations per zone probably limited the statistical power needed to detect this pattern formally.

8.6 Conservation Implications

These results point to two practical takeaways. First, water-quality monitoring, not just thermal or hydrological management, should be a core part of biodiversity planning for irrigation canals. Second, keeping riparian vegetation in place to buffer water temperature in downstream reaches would likely help amphibian diversity specifically, which matches findings on riparian buffers elsewhere in Southeast Asia (Harianja et al., 2024). More broadly, finding a nationally endemic species in a working irrigation canal is a good argument for folding biodiversity surveys into routine water-management planning instead of treating them as a separate exercise (Ljustina et al., 2022; Tantipisanuh et al., 2023).

8.7 Limitations and Future Research

This study has some real limits. Sampling was conducted mostly in one season and once per station, so it cannot capture seasonal variation in either herpetofaunal activity or environmental conditions (Anunciação et al., 2023), and twelve sampling points may simply not be enough to detect smaller spatial effects with confidence. The VES method itself, while standard, is also known to under-detect cryptic species (Baumgardt et al., 2021). Extending sampling across both wet and dry seasons, adding more stations, and pairing visual surveys with eDNA metabarcoding would likely give a fuller picture of diversity along canals like this one (McDevitt et al., 2019; Quilumbaquin et al., 2023).

9. References

1. Aguilar, F. F., Velo-Antón, G., Tarroso, P., & Segurado, P. (2025). Fine-scale habitat preferences of riparian ectotherms in a human-influenced landscape: insights from two herptiles endemic to the Iberian Peninsula. Biodiversity and Conservation, 34(6), 2227. https://doi.org/10.1007/s10531-025-03073-2
2. Alagador, D. (2022). Effective conservation planning of Iberian amphibians based on a regionalization of climate-driven range shifts. Conservation Biology, 37(2). https://doi.org/10.1111/cobi.14026
3. Anunciação, P. R., Ernst, R., Martello, F., Vancine, M. H., Carvalho, L. M. T. de, & Ribeiro, M. C. (2023). Climate-driven loss of taxonomic and functional richness in Brazilian Atlantic Forest anurans. Perspectives in Ecology and Conservation, 21(4), 274. https://doi.org/10.1016/j.pecon.2023.09.001
4. Atanacković, A., Popović, N., Marinković, N., Tomović, J., Đuknić, J., Stanković, J., & Paunović, M. (2023). Effects of Environmental Factors on the Distribution and Diversity of Aquatic Oligochaetes. Water, 15(22), 3873. https://doi.org/10.3390/w15223873
5. Awkerman, J. A., Glinski, D. A., Henderson, W. M., Meter, R. V., & Purucker, S. T. (2024). Framework for multi-stressor physiological response evaluation in amphibian risk assessment and conservation. Frontiers in Ecology and Evolution, 12. https://doi.org/10.3389/fevo.2024.1336747
6. Băncilă, R. I., Lattuada, M., & Sillero, N. (2023). Distribution of amphibians and reptiles in agricultural landscape across Europe. Landscape Ecology, 38(3), 861. https://doi.org/10.1007/s10980-022-01583-w
7. Baumgardt, J. A., Morrison, M. L., Brennan, L. A., Thornley, M., & Campbell, T. A. (2021). Variation in herpetofauna detection probabilities: implications for study design. Environmental Monitoring and Assessment, 193(10), 658. https://doi.org/10.1007/s10661-021-09424-0
8. Bergman, J. N., Beaudoin, C., Mistry, I., Turcotte, A., Vis, C., Minelga, V., Neigel, K. L., Lin, H., Bennett, J., Young, N., Rennie, C. D., Trottier, L., Abrams, A. E. I., Beaupre, P., Glassman, D., Blouin-Demers, G., Garant, D., Donaldson, L., Vermaire, J. C., … Cooke, S. J. (2021). Historical, contemporary, and future perspectives on a coupled social–ecological system in a changing world: Canada's historic Rideau Canal. Environmental Reviews, 30(1), 72. https://doi.org/10.1139/er-2021-0026
9. Bofill, S. I. H., & Blom, M. P. K. (2024). Climate change from an ectotherm perspective: evolutionary consequences and demographic change in amphibian and reptilian populations. Biodiversity and Conservation, 33(3), 905. https://doi.org/10.1007/s10531-023-02772-y

10. Bowen, J. C., Wahyudio, P. J., Anshari, G. Z., Aluwihare, L. I., & Hoyt, A. M. (2024). Canal networks regulate aquatic losses of carbon from degraded tropical peatlands. Nature Geoscience, 17(3), 213. https://doi.org/10.1038/s41561-024-01383-8
11. Campbell, K. S., Baltensperger, A. P., & Kerby, J. L. (2024). Random Frogs: using future climate and land-use scenarios to predict amphibian distribution change in the Upper Missouri River Basin. Landscape Ecology, 39(3). https://doi.org/10.1007/s10980-024-01841-z
12. Caro, T., Rowe, Z. W., Berger, J., Wholey, P., & Dobson, A. P. (2022). An inconvenient misconception: Climate change is not the principal driver of biodiversity loss. Conservation Letters, 15(3). https://doi.org/10.1111/conl.12868
13. Cervantes-López, M. de J., Alves-Ferreira, G., & Morante-Filho, J. C. (2025). Landscape predictors are more important than local factors in determining multiple dimensions of amphibian and reptile diversity in shaded cocoa agroforests. Landscape Ecology, 40(1). https://doi.org/10.1007/s10980-024-02032-6
14. Channuwong, S., Bangbon, P., Rodloytuk, P., Phanniphong, K., & Wang, X. (2026). Transformationalleadership and strategic management affecting sustainable development of Thai higher education institutions. *Social Sciences & Humanities Open, 14,* 103618. https://doi.org/10.1016/j.ssaho.2026.103618
15. Cox, N. A., Young, B. E., Bowles, P., Fernández, M., Marin, J., Rapacciuolo, G., Böhm, M., Brooks, T. M., Hedges, S. B., Hilton-Taylor, C., Hoffmann, M., Jenkins, R. K. B., Tognelli, M. F., Alexander, G. J., Allison, A., Ananjeva, N. B., Auliya, M., Ávila, L. J., Chapple, D. G., … Xie, Y. (2022). A global reptile assessment highlights shared conservation needs of tetrapods. Nature, 605(7909), 285. https://doi.org/10.1038/s41586-022-04664-7
16. Crnobrnja-Isailović, J., Jovanović, B., Ilić, M., Ćorović, J., Čubrić, T., Stojadinović, D., & Ćosić, N. (2021). Small Hydropower Plants' Proliferation Would Negatively Affect Local Herpetofauna. Frontiers in Ecology and Evolution, 9. https://doi.org/10.3389/fevo.2021.610325
17. Datry, T., Truchy, A., Olden, J. D., Busch, M. H., Stubbington, R., Dodds, W. K., Zipper, S. C., Yu, S., Messager, M., Tonkin, J. D., Kaiser, K. E., Hammond, J. C., Moody, E. K., Burrows, R. M., Sarremejane, R., Delvecchia, A., Fork, M. L., Little, C. J., Walker, R. H., … Allen, D. C. (2022). Causes, Responses, and Implications of Anthropogenic versus Natural Flow Intermittence in River Networks. BioScience, 73(1), 9. https://doi.org/10.1093/biosci/biac098
18. Dehling, D. M., & Dehling, J. M. (2023). Elevated alpha diversity in disturbed sites obscures regional decline and homogenization of amphibian taxonomic, functional and phylogenetic diversity. Scientific Reports, 13(1), 1710. https://doi.org/10.1038/s41598-023-27946-0
19. Doucette, L. I., Duncan, R. P., Osborne, W., Evans, M., Georges, A., Gruber, B., & Sarre, S. D. (2023). Climate warming drives a temperate-zone lizard to its upper thermal limits, restricting activity, and increasing energetic costs. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-35087-7
20. Duffy, K., Gouhier, T. C., & Ganguly, A. R. (2022). Climate-mediated shifts in temperature fluctuations promote extinction risk. Nature Climate Change, 12(11), 1037. https://doi.org/10.1038/s41558-022-01490-7
21. Fei, Z., Channuwong, S., Bangbon, P., Siripap, P., & Jia, Y. (2026). Socioeconomic and adaptive determinants of sustainable agricultural development (SDG 2) in Thailand. *Natural and Engineering Sciences, 11*(2), 140-152. https://doi.org/10.28978/nesciences.262012
22. Filho, L. M. C., Gomes, L., Katzenberger, M., Solé, M., & Orrico, V. G. D. (2022). There and back again: A meta-analytical approach on the influence of acclimation and altitude in the upper thermal tolerance of amphibians and reptiles. Frontiers in Ecology and Evolution, 10. https://doi.org/10.3389/fevo.2022.1017255
23. Griffin, R., Lewis, T. R., Tzanopoulos, J., & Griffiths, R. A. (2025). Natural history traits influence winners and losers for herpetological communities in disturbed tropical habitats. Oecologia, 207(3), 52. https://doi.org/10.1007/s00442-025-05691-7
24. Grismer, L. L., Rujirawan, A., Yodthong, S., Stuart, B. L., Lê, M. Đ., Le, D. T., Chuaynkern, Y., Wood, P. L., & Aowphol, A. (2022). The taxonomy and phylogeny of the Cyrtodactylus brevipalmatus group (Squamata: Gekkonidae) with emphasis on C. interdigitalis and C. ngati. Vertebrate Zoology, 72, 245. https://doi.org/10.3897/vz.72.e80615
25. Harianja, M. F., Luke, S. H., Barclay, H., Khen, C. V., Aldridge, D. C., Foster, W. A., & Turner, E. C. (2024). The impacts of within-stream physical structure and riparian buffer strips on semi-aquatic bugs in Southeast Asian oil palm. Frontiers in Forests and Global Change, 6. https://doi.org/10.3389/ffgc.2023.1203513

26. Hodges, C. W., Marshall, B. M., Hill, J. G., & Strine, C. T. (2022). Malayan kraits (Bungarus candidus) show affinity to anthropogenic structures in a human dominated landscape. Scientific Reports, 12(1), 7139. https://doi.org/10.1038/s41598-022-11255-z
27. Hopkins, C. L., Lesbarrères, D., Claunch, N. M., Emmenegger, E. J., Hardy, B. M., Torres-Sánchez, M., Stark, T., Julian, A., McGrath-Blaser, S., Parker-Graham, C. A., Haman, K., Morgan, A., & Miller, D. L. (2024). Balancing the Scales: Including Under-represented Herptile Species in a One Health Approach. Research Directions One Health, 1. https://doi.org/10.1017/one.2024.14
28. Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D. E., Coscieme, L., Golden, A. S., Guerra, C. A., Jacob, U., Takahashi, Y., Settele, J., Díaz, S., Molnár, Z., & Purvis, A. (2022). The direct drivers of recent global anthropogenic biodiversity loss. Science Advances, 8(45). https://doi.org/10.1126/sciadv.abm9982
29. Kaijser, W., Musiol, M., Schneider, A. R., Prati, S., Brauer, V. S., Bayer, R., Birk, S., Brauns, M., Dunne, L., Enss, J., Farias, L., Feld, C. K., Feldhaus, L., Gillmann, S. M., Hupało, K., Osakpolor, S. E., Olberg, S. L. M., Pimentel, I. M., Schäfer, R. B., … Hering, D. (2025). Meta-analysis-derived estimates of stressor–response associations for riverine organism groups. Nature Ecology & Evolution. https://doi.org/10.1038/s41559-025-02884-4
30. Karami, P., Tavakoli, S., & Esmaeili, M. (2023). Evolution of seasonal land surface temperature trend in pond-breeding newt (Neurergus derjugini) in western Iran and eastern Iraq. Ecological Processes, 12(1). https://doi.org/10.1186/s13717-023-00426-z
31. Lettoof, D. C., Parkin, T., Jolly, C. J., Laive, A. de, & Takach, B. von. (2023). Snake life history traits and their association with urban habitat use in a tropical city. Urban Ecosystems, 26(2), 433. https://doi.org/10.1007/s11252-023-01327-x
32. Liberman, Y., Ben-Ami, F., & Meiri, S. (2024). Artificial cover objects as a tool for the survey and conservation of herpetofauna. Biodiversity and Conservation, 33(5), 1575. https://doi.org/10.1007/s10531-024-02840-x
33. Ljustina, O., Crother, B. I., Doody, J. S., & Fontenot, C. L. (2022). Canal structure influences watersnake assemblage structure in an urban environment. Research Square (Research Square). https://doi.org/10.21203/rs.3.rs-2062579/v1
34. Lourenço-de-Moraes, R., Campos, F. S., Ferreira, R. B., Solé, M., Beard, K. H., & Bastos, R. P. (2019). Back to the future: conserving functional and phylogenetic diversity in amphibian-climate refuges. Biodiversity and Conservation, 28(5), 1049. https://doi.org/10.1007/s10531-019-01706-x
35. Mahan, L. B., Bassett, L. G., Duarte, A., Forstner, M. R. J., & Mali, I. (2022). Effects of salinization on the occurrence of a long-lived vertebrate in a desert river. Scientific Reports, 12(1). https://doi.org/10.1038/s41598-022-20199-3
36. Matos, L. R. A. de, Ramalho, W. P., Arruda, F. V. de, Ceron, K., Luna, P., Virgílio, L. R., & Vieira, L. J. S. (2021). Environmental Drivers and Network Structure of Hylid Anurans in Floating Meadows From Amazonian Oxbow Lakes. Research Square (Research Square). https://doi.org/10.21203/rs.3.rs-748588/v1
37. McDevitt, A. D., Sales, N. G., Browett, S. S., Sparnenn, A. O., Mariani, S., Wangensteen, O. S., Coscia, I., & Benvenuto, C. (2019). Environmental DNA metabarcoding as an effective and rapid tool for fish monitoring in canals. Journal of Fish Biology, 95(2), 679. https://doi.org/10.1111/jfb.14053
38. Oliveira, A. F. de S., Zuquim, G., Martins, L. F., Bandeira, L. N., Diele-Viegas, L. M., Cavalcante, V. H. G. L., Baccaro, F. B., Colli, G. R., Tuomisto, H., & Werneck, F. P. (2024). The role of environmental gradients and microclimates in structuring communities and functional groups of lizards in a rainforest-savanna transition area. PeerJ, 12. https://doi.org/10.7717/peerj.16986
39. O'Sullivan, J., Foster, C. N., Blanchard, W., Florance, D., Michael, D., & Lindenmayer, D. B. (2023). Reversing habitat loss: An experimental test of the interactive effects of grazing exclusion and surface rock restoration on reptile conservation. Journal of Applied Ecology, 60(9), 1778. https://doi.org/10.1111/1365-2664.14452
40. Pomoim, N., Hughes, A. C., Trisurat, Y., & Corlett, R. T. (2022). Vulnerability to climate change of species in protected areas in Thailand. Scientific Reports, 12(1). https://doi.org/10.1038/s41598-022-09767-9
41. Pörtner, H., Scholes, R. J., Arneth, A., Barnes, D. K. A., Burrows, M. T., Diamond, S. E., Duarte, C. M., Kiessling, W., Leadley, P., Managi, S., McElwee, P., Midgley, G. F., Ngo, H. T., Obura, D., Pascual, U., Sankaran, M., Shin, Y., & Val, A. L. (2023). Overcoming the coupled climate and biodiversity crises and their societal impacts. Science, 380(6642). https://doi.org/10.1126/science.abl4881

42. Pottier, P., Kearney, M., Wu, N. C., Gunderson, A. R., Rej, J. E., Rivera-Villanueva, A. N., Pollo, P., Burke, S., Drobniak, S. M., & Nakagawa, S. (2025). Vulnerability of amphibians to global warming. Nature, 639(8056), 954. https://doi.org/10.1038/s41586-025-08665-0
43. Puig-Gironès, R., Bel, G., Cid, N., Cañedo-Argüelles, M., Fernández-Calero, J. M., Quevedo-Ortiz, G., Fortuño, P., Vinyoles, D., Real, J., Pujol-Buxó, E., & Bonada, N. (2024). Water availability and biological interactions shape amphibian abundance and diversity in Mediterranean temporary rivers. The Science of The Total Environment, 953, 175917. https://doi.org/10.1016/j.scitotenv.2024.175917
44. Quilumbaquin, W., Carrera-Gonzalez, A., heyden, C. V. der, & Ortega-Andrade, H. M. (2023). Environmental DNA and visual encounter surveys for amphibian biomonitoring in aquatic environments of the Ecuadorian Amazon. PeerJ, 11. https://doi.org/10.7717/peerj.15455
45. Ruthsatz, K., Dahlke, F., Alter, K., Wohlrab, S., Eterovick, P. C., Lyra, M., Gippner, S., Cooke, S. J., & Peck, M. A. (2024). Acclimation capacity to global warming of amphibians and freshwater fishes: Drivers, patterns, and data limitations. Global Change Biology, 30(5).
https://doi.org/10.1111/gcb.17318
46. Sheridan, J. A., & Kendrick, M. R. (2024). Relationships of primary productivity with anuran abundance, richness, and community composition in tropical streams. PLoS ONE, 19(5). https://doi.org/10.1371/journal.pone.0303886
47. Smith, S. N., Jones, M. D., Marshall, B. M., Waengsothorn, S., Gale, G. A., & Strine, C. T. (2021). Native Burmese pythons exhibit site fidelity and preference for aquatic habitats in an agricultural mosaic. Scientific Reports, 11(1). https://doi.org/10.1038/s41598-021-86640-1
48. Tantipisanuh, N., Chutipong, W., Kamjing, A., Dachyosdee, U., & Ngoprasert, D. (2023). Assessing effects of landscape modifications and identifying priority areas for two Asian otters in coastal wetlands. Global Ecology and Conservation, 48. https://doi.org/10.1016/j.gecco.2023.e02760
49. Teixeira, C. D. C., Trevelin, L. C., Santos-Costa, M. C. dos, Prudente, A. L. da C., & Silva, D. P. (2022). Synergistic effects of climate and landscape change on the conservation of Amazonian lizards. PeerJ, 10. https://doi.org/10.7717/peerj.13028
50. Timalsina, R., Acharya, S. K., Đurin, B., Awasthi, M. P., Pant, R. R., Joshi, G. R., Byanju, R. M., Panthi, K. P., Joshi, S., Kumar, A., Thakur, T. K., & Saqr, A. M. (2025). An Assessment of Seasonal Water Quality in Phewa Lake, Nepal, by Integrating Geochemical Indices and Statistical Techniques: A Sustainable Approach. Water, 17(2), 238. https://doi.org/10.3390/w17020238
51. Vehkaoja, M., Thompson, S., Niemi, M., & Väänänen, V. (2023). Connectivity, land use, and fish presence influence smooth newt (Lissotriton vulgaris) occurrence and abundance in an urban landscape. Frontiers in Ecology and Evolution, 11. https://doi.org/10.3389/fevo.2023.1157297
52. Xia, Y., Yin, X., Liu, X., Xu, M., Weng, D., Liu, Q., Chi, W., & Wu, H. (2025). One-year assessment and predictive modeling of macrobenthic communities under thermal discharge and environmental influences near the preoperational YanTai HY-Nuclear Power Plant in the Yellow Sea. Frontiers in Marine Science, 12. https://doi.org/10.3389/fmars.2025.1637335 53.
53. Youthao, S., Channuwong, S., Weerachareonchai, P., Dhammahansakul, N., Sun, R., &
Jia, Y. (2026). An AI-Driven framework for smart micro-housing and sustainable urban development (SDG 11). *Natural and Engineering Sciences, 11*(2), 242-252.
https://doi.org/10.28978/nesciences.262022
54. Zambrano-Fernández, S., Zamora-Camacho, F. J., & Aragón, P. (2021). Direct and indirect effects of chronic exposure to ammonium on anuran larvae survivorship, morphology, and swimming speed. Chemosphere, 287, 132349. https://doi.org/10.1016/j.chemosphere.2021.132349
55. Zhu, W. S., Wang, B., & Jiang, J. (2024). Evolution, Diversity, and Conservation of Herpetofauna. Animals, 14(13), 2004. https://doi.org/10.3390/ani14132004