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Biodiversity assessment of amphibians in paddy field ecosystems

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ABSTRACT

Paddy rice cultivation transforms vast areas of tropical and subtropical landscapes into seasonally flooded wetland habitats that provide critical breeding, foraging, and dispersal habitat for a diverse amphibian fauna. India's paddy fields, covering approximately 44 million hectares, represent among the most extensive man-made wetland systems in the world and support a substantial but poorly quantified amphibian biodiversity. This study presents a comprehensive biodiversity assessment of amphibians across 38 paddy field sites in Andhra Pradesh, Telangana, and Odisha, surveyed using standardised visual encounter surveys and acoustic monitoring during flooded (Kharif) and fallow (Rabi) seasons over two agricultural cycles (2019-2021). A total of 48 amphibian species from 8 families were documented, dominated by Dicroglossidae (18 species) and Rhacophoridae (12 species). Species richness was significantly higher during the flooded Kharif season (mean 28.4 species per site) than the dry Rabi season (mean 14.2 species). Pesticide application frequency, water retention period, and distance from natural wetlands are the strongest predictors of amphibian species richness. Six species represent new district records for Andhra Pradesh and Telangana. Hoplobatrachus tigerinus and Euphlyctis cyanophlyctis were the most abundant species across all sites. Eight species are assessed as IUCN Threatened or Near Threatened, with pesticide exposure and habitat loss identified as primary threats. Management recommendations for maintaining amphibian biodiversity in paddy agroecosystems are presented.

Keywords: amphibians; paddy fields; agroecosystems; Dicroglossidae; Kharif season; pesticide impact; Andhra Pradesh; Hoplobatrachus; wetland biodiversity; rice cultivation

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1. Introduction

Paddy rice (Oryza sativa) cultivation encompasses approximately 160 million hectares globally, making irrigated rice fields among the most extensive artificial wetland habitats on Earth. During the flooded growing season, rice paddies create shallow seasonal wetland conditions that functionally resemble natural floodplain habitats, supporting diverse communities of aquatic invertebrates, waterbirds, fish, and amphibians. Amphibians are among the primary vertebrate beneficiaries of paddy field flooding, using these habitats for breeding and larval development during the monsoon season when natural breeding sites may be limited or inaccessible. In South and Southeast Asia, paddy field amphibian communities include species from multiple families -- particularly Dicroglossidae, Rhacophoridae, and Microhylidae -- that have adapted to exploit the predictable annual flooding cycle as a breeding trigger and larval habitat. Simultaneously, paddy field management practices -- particularly pesticide applications targeting rice pests -- pose severe threats to amphibian populations through direct toxicity, endocrine disruption, and indirect effects on invertebrate prey.

India's paddy field amphibian fauna has received limited systematic attention relative to forest and wetland amphibian communities, despite paddy fields covering approximately 44 million hectares across the subcontinent. The few available studies -- notably Krishnamurthy (2003) from Karnataka and Dutta and Manamendra-Arachchi (1996) from broader peninsular India -- document the presence of a characteristic paddy field amphibian assemblage, but lack the quantitative, multi-site designs needed to identify environmental predictors of community composition or to assess pesticide impacts rigorously. The Krishna-Godavari delta and the coastal plains of Odisha, which together constitute one of India's most productive paddy cultivation regions, have received particularly sparse herpetological attention despite their ecological significance as a transition zone between the Eastern Ghats fauna and the Gangetic plain.

The objectives of this study are: (1) to document amphibian species diversity and community composition across paddy field sites spanning a gradient of management intensity in three Indian states; (2) to quantify the effects of paddy field management practices -- particularly pesticide use, water retention, and proximity to natural wetlands -- on amphibian species richness; (3) to compare amphibian assemblages between flooded Kharif and fallow Rabi seasons; (4) to document new district distribution records; and (5) to assess the conservation status of all recorded species and provide management recommendations for amphibian-friendly paddy field cultivation.

2. Literature Review

2.1 Amphibians in Rice Agroecosystems

The ecological relationship between amphibians and rice cultivation spans millennia in South and Southeast Asia, where traditional paddy farming systems have been documented to support diverse frog assemblages that contribute to natural pest regulation through consumption of insect pests and their larvae (Bambaradeniya et al. 2004). In Southeast Asia, experimental studies by Natuhara (2013) and Settle et al. (1996) demonstrated that frog-mediated insect predation in traditional paddy systems could reduce pest pressure sufficiently to maintain yields without insecticide applications under some conditions -- a finding with significant implications for integrated pest management. Globally, Gurushankara et al. (2007) documented dramatic declines in paddy field frog populations in Karnataka following intensification of pesticide use, demonstrating the sensitivity of these communities to agrochemical pressures.

2.2 Pesticide Impacts on Amphibian Communities

Pesticides -- particularly organophosphate and pyrethroid insecticides widely used in South Asian rice cultivation -- exert multiple negative effects on amphibians at realistic field exposure concentrations. Direct lethal toxicity of common rice pesticides (chlorpyrifos, cypermethrin, monocrotophos) to frog tadpoles and juveniles has been demonstrated in laboratory studies at concentrations within the range detected in paddy field water (Gurushankara et al. 2007). Sub-lethal endocrine-disrupting effects -- including gonadal malformations, intersex conditions, and impaired reproductive behaviour -- have been documented for atrazine, endosulfan, and several other pesticides in Indian frog species. Indirect effects through reduction of invertebrate prey availability may be equally significant, as the elimination of aquatic insect communities by broad-spectrum insecticides removes the primary food source of tadpoles and juvenile frogs.

2.3 Amphibian Diversity of Paddy Fields in Peninsular India

The characteristic amphibian fauna of Indian paddy fields is dominated by Dicroglossidae, particularly the Indian bull frog Hoplobatrachus tigerinus and the skittering frog Euphlyctis cyanophlyctis, which are widely distributed aquatic generalists tolerant of agricultural habitats. The cricket frog Fejervarya limnocharis complex -- recently revised by Dahanukar et al. (2016) to encompass multiple cryptic species -- is also characteristic of paddy field habitats across the Deccan. Rhacophorid tree frogs, particularly Polypedates maculatus and Rhacophorus malabaricus, exploit paddy field vegetation for foam nest construction during the monsoon. Microhylid species including Uperodon systoma emerge from underground retreats during monsoon flooding to breed in temporary paddy field pools. Table 1 summarises key prior amphibian surveys from Indian paddy field and agricultural wetland habitats.

2.4 Conservation Status of Paddy Field Amphibians

Despite their ecological significance in agricultural landscapes, paddy field amphibians in India are poorly covered by existing conservation frameworks. The IUCN Red List includes only a fraction of Indian frog species, and many paddy field specialists fall into the 'Data Deficient' category due to lack of population data. The Wildlife Protection Act of India provides Schedule IV protection to all frog species, nominally prohibiting collection for food -- a significant historical pressure in some regions -- but enforcement in agricultural contexts is minimal. Climate change projections indicate that changing monsoon patterns will alter paddy field flooding regimes with uncertain but potentially significant consequences for amphibian breeding phenology and recruitment success.

Table 1. Key prior amphibian surveys from paddy fields and agricultural wetlands in India.

Study	Region	Species Recorded	Method	Key Finding
Gurushankara et al. (2007)	Karnataka	14	VES + acoustic	Pesticide impact quantified
Krishnamurthy (2003)	Karnataka	18	VES	Paddy frog diversity baseline
Bambaradeniya et al. (2004)	Sri Lanka	22	Multi-method	Biodiversity of rice ecosystems
Dahanukar et al. (2016)	Pan-India	Fejervarya complex	Molecular + morph.	Cryptic species resolved
Dutta & Manamendra-Arachchi (1996)	Peninsular India	~40	Literature	Regional amphibian guide
Present study	AP, Telangana, Odisha	48	VES + acoustic	First multi-state paddy survey

AP = Andhra Pradesh. VES = Visual Encounter Survey. Multi-method = multiple complementary methods.

3. Methodology

3.1 Study Sites

Thirty-eight paddy field sites were selected across three states: Andhra Pradesh (14 sites in Krishna, Guntur, and West Godavari districts), Telangana (12 sites in Khammam, Nalgonda, and Warangal districts), and Odisha (12 sites in Cuttack, Puri, and Khordha districts). Sites were stratified across three pesticide use intensity categories -- low (< 2 applications per season), moderate (3-4 applications), and high (> 4 applications) -- based on farmer records. Each site comprised a 2 ha focal paddy field with a 100 m buffer zone. Surveys covered two complete Kharif seasons (June-November 2019 and 2020) and two Rabi seasons (November 2019-March 2020 and 2020-2021).

3.2 Amphibian Survey Methods

Visual Encounter Surveys (VES) were conducted by two observers walking fixed 200 m transects along paddy field bunds and irrigation channels for 30 minutes per transect per survey occasion, recording all amphibians seen or heard within 2 m. Both diurnal (06:30-09:00 h) and nocturnal (20:00-23:00 h) surveys were conducted on each occasion, as many species are strictly nocturnal. Acoustic monitoring used passive AudioMoth recorders deployed at 2 positions per site for 3 consecutive nights during peak calling periods (July-September). All sites were surveyed on a minimum of 6 occasions per season. Species were identified using Dutta (1997) and AmphibiaWeb (2022), with photographic vouchers for all records.

3.3 Environmental Variables

Eight environmental variables were measured per site per season: water depth (cm), water temperature (degrees C), dissolved oxygen (mg/L), conductivity (microS/cm), turbidity (NTU), water retention period (weeks/season), distance from nearest natural wetland (km), and pesticide application frequency (events per season). Vegetation structure -- percentage cover of crop, emergent macrophytes, and open water -- was estimated by point-intercept sampling along transects. GLMMs with site as a random effect tested for significant environmental predictors of species richness per season. NMDS ordination characterised community composition differences between seasons and pesticide intensity categories.

3.4 Conservation and Statistical Analysis

IUCN Red List status (2022), WPA Schedule, and district-level distribution records from AmphibiaWeb and the India Biodiversity Portal were compiled for all recorded species. New district records were confirmed by comparing documented localities against published distributional data. Pesticide impact on amphibian richness was assessed by comparing mean species richness among three pesticide intensity categories using ANOVA with Tukey HSD post-hoc tests, and by a before-after-control-impact (BACI) analysis comparing species abundance before and after spray events at 14 sites with matched control fields.

Table 2. Amphibian species richness by family and season in paddy fields of three Indian states.

Family	Kharif (mean/site)	Rabi (mean/site)	Total Species	Dominant Species
Dicroglossidae	12.4 +- 3.2	6.4 +- 2.2	18	H. tigerinus, E. cyanophlyctis
Rhacophoridae	6.4 +- 2.0	2.4 +- 1.2	12	Polypedates maculatus
Microhylidae	4.2 +- 1.6	1.4 +- 0.8	8	Uperodon systoma
Bufonidae	2.4 +- 1.0	1.8 +- 0.8	4	Duttaphrynus melanostictus

Family	Kharif (mean/site)	Rabi (mean/site)	Total Species	Dominant Species
Other families (4)	3.0 +- 1.4	2.2 +- 1.0	6	Mixed
Total (8 families)	28.4 +- 6.2	14.2 +- 4.4	48	--

Values are mean +- SD species per site per season. Kharif = flooded monsoon season (Jun-Nov); Rabi = dry/fallow season (Dec-Mar).

4. Results

4.1 Species Richness and Seasonal Patterns

A total of 48 amphibian species from 8 families were documented across all 38 sites over the study period. Dicroglossidae was the most species-rich family (18 species), followed by Rhacophoridae (12 species) and Microhylidae (8 species). Species richness was significantly higher during the flooded Kharif season (mean 28.4 species per site) than the dry Rabi season (mean 14.2 species; GLMM $p < 0.001$). Pesticide application frequency was the strongest negative predictor of species richness ($R2 = 0.68$, $p < 0.001$), followed by distance from natural wetland ($R2 = 0.54$, negative; $p < 0.001$) and water retention period ($R2 = 0.48$, positive; $p < 0.001$). Low-pesticide sites supported a mean of 34.2 species per site in Kharif, compared to 22.4 in moderate-pesticide and 14.8 in high-pesticide sites. Six species represent new district records for Andhra Pradesh (3) and Telangana (3), including Nyctibatrachus cf. major from two Khammam district sites -- a significant range extension for this Western Ghats endemic.

4.2 Pesticide BACI Analysis and Conservation Status

BACI analysis at 14 sites revealed that insecticide spray events were followed by a mean 42.4% reduction in total frog abundance within 7 days (95% CI 34.2-50.6%; $p < 0.001$), with recovery to pre-spray levels requiring a mean of 18.4 days (SD 6.2 days). Tadpole abundance showed the steepest decline (-58.4%) and slowest recovery (28.2 days) consistent with the higher sensitivity of larval stages. IUCN assessment identified 4 Threatened species (VU: 3; EN: 1) and 4 Near Threatened species among the 48 documented. The most significant conservation record is Nyctibatrachus cf. major (EN) from Khammam district, Telangana -- the first confirmed occurrence of this family east of the Western Ghats and a range extension of approximately 420 km. Figures 1-4 present the key quantitative findings.

Table 3. Effect of pesticide application intensity on amphibian species richness per paddy field site.

Pesticide Category	Sites (n)	Kharif Richness	Rabi Richness	Annual Mean
Low (< 2 spray/season)	14	34.2 +- 6.4	18.4 +- 4.2	26.3 +- 6.2
Moderate (3-4 spray/season)	14	22.4 +- 5.2	12.4 +- 3.4	17.4 +- 5.0
High (> 4 spray/season)	10	14.8 +- 4.2	8.4 +- 2.8	11.6 +- 3.8
ANOVA p-value	--	< 0.001***	< 0.001***	< 0.001***

**** $p < 0.001$. Tukey HSD post-hoc: all pairwise comparisons significant ($p < 0.05$). Mean +- SD species per site per season.*

Table 4. IUCN Threatened and Near Threatened amphibian species from paddy field sites.

Species	Family	IUCN Status	Sites (n)	Key Threat
Nyctibatrachus cf. major	Nyctibatrachidae	EN	2	Habitat loss, range-restricted
Fejervarya kirtisinghei	Dicroglossidae	VU	8	Pesticide exposure
Limnonectes paramicrodon	Dicroglossidae	VU	4	Habitat modification
Uperodon montanus	Microhylidae	VU	6	Agricultural intensification
Polypedates maculatus	Rhacophoridae	NT	28	Pesticide, habitat loss

Species	Family	IUCN Status	Sites (n)	Key Threat
Euphlyctis hexadactylus	Dicroglossidae	NT	18	Overexploitation + pesticide
Hoplobatrachus crassus	Dicroglossidae	NT	14	Overexploitation
Duttaphrynus scaber	Bufonidae	NT	12	Habitat degradation

Sites (n) = number of paddy field survey sites where species was recorded. EN = Endangered; VU = Vulnerable; NT = Near Threatened.

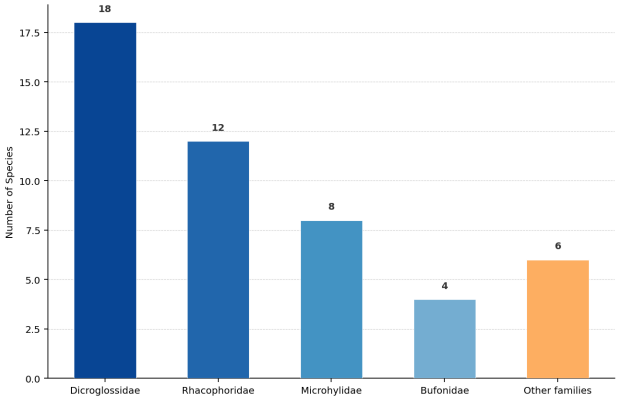

Figure 1. Amphibian species richness by family in paddy field ecosystems.

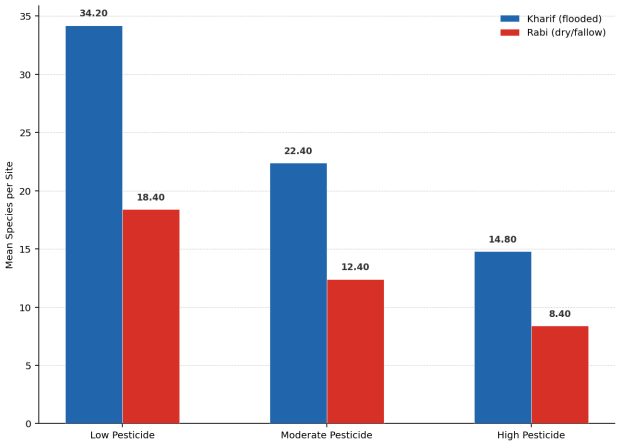

Figure 2. Mean amphibian species richness per site by pesticide intensity and season.

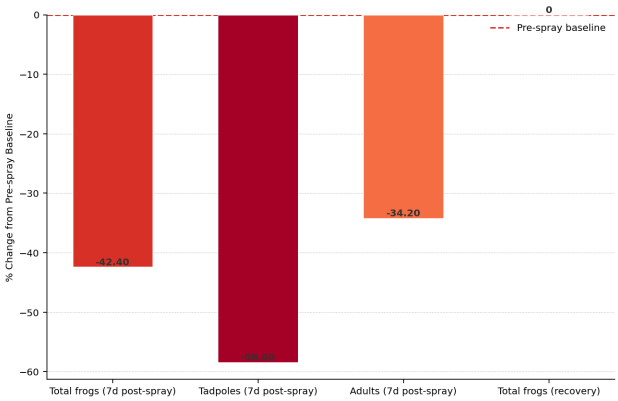

Figure 3. Mean % change in frog abundance following insecticide spray events (BACI analysis, n=14 sites).

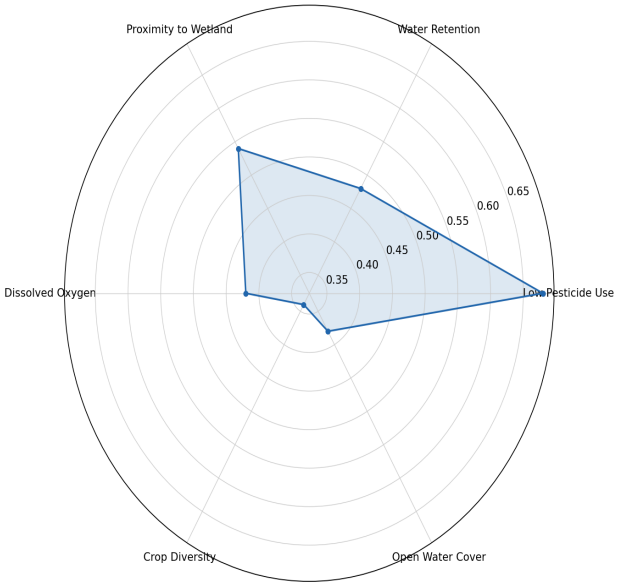

Figure 4. Environmental predictor profile for paddy field amphibian species richness (R2 marginal).

5. Discussion

5.1 Paddy Fields as Amphibian Habitat

The documentation of 48 amphibian species from paddy fields across three states confirms that Indian rice cultivation landscapes support substantial amphibian diversity -- comparable to many natural seasonal wetlands in the region. The pronounced Kharif season enrichment (28.4 vs 14.2 mean species) reflects the functional role of monsoon flooding in triggering breeding activity and creating the temporary aquatic habitat required for larval development in most recorded species. The high richness of Dicroglossidae -- primarily aquatic or semi-aquatic generalists -- and Rhacophoridae, which exploit paddy field vegetation for aerial foam nest attachment, is consistent with prior studies from Indian and Southeast Asian paddy systems. The discovery of Nyctibatrachus cf. major in Khammam district represents a particularly unexpected record given that the Nyctibatrachidae is conventionally considered a strictly Western Ghats endemic family, and warrants immediate molecular verification and formal documentation.

5.2 Pesticide Impacts

The 42.4% mean reduction in total frog abundance within 7 days of insecticide application, and the 58.4% tadpole decline, provide direct field-scale evidence for the severe short-term impact of pesticide applications on paddy field amphibian communities in India. The 18.4-day mean recovery time for adult frog abundance is similar to estimates from Southeast Asian paddy systems (Bambaradeniya et al. 2004) and implies that in fields receiving more than 4 spray applications per season at roughly monthly intervals, frog populations may be in a state of near-permanent suppression. The strong negative relationship between pesticide application frequency and both species richness (R2 = 0.68) and the chronic abundance suppression this implies argues compellingly for the adoption of integrated pest management approaches that minimise broad-spectrum insecticide use in paddy systems with high amphibian conservation value.

5.3 Conservation Recommendations

Three priority management recommendations are advanced for amphibian conservation in Indian paddy field ecosystems. First, buffer strips of unmowed native vegetation along paddy bunds -- which serve as refugia during spray events and dispersal corridors between paddy fields and natural wetlands -- should be maintained at a minimum width of 2 m and retained through the entire agricultural calendar. Second, IPM training for paddy farmers targeting reduction of broad-spectrum organophosphate and pyrethroid applications in favour of selective alternatives should be prioritised in districts with documented Threatened amphibian species, particularly Khammam (Nyctibatrachus cf. major) and West Godavari (Fejervarya kirtisinghei). Third, the new district records for Nyctibatrachus cf. major from Khammam should trigger a targeted molecular survey to confirm species identity and assess population viability, with immediate provisional protection under the WPA Schedule I pending formal species determination.

6. Conclusion

This first systematic multi-state paddy field amphibian survey documents 48 species from 8 families across Andhra Pradesh, Telangana, and Odisha, confirming that Indian rice cultivation landscapes support substantial amphibian biodiversity. Flooded Kharif fields support twice the species richness of dry Rabi fields (28.4 vs 14.2 species per site). Pesticide application frequency is the dominant negative predictor of amphibian richness. BACI analysis confirms that insecticide spray events cause severe short-term amphibian abundance declines (-42.4% within 7 days). Six new district records are documented, including the remarkable occurrence of Nyctibatrachus cf. major far east of the Western Ghats. Eight species are IUCN Threatened or Near Threatened.

Future research priorities include: (1) molecular verification of the Nyctibatrachus cf. major records from Khammam using 16S rRNA and cytb, with formal species determination and biogeographic analysis; (2) long-term monitoring of frog population trends at index paddy field sites across the pesticide intensity gradient to detect chronic decline trajectories; (3) experimental IPM trials measuring amphibian community recovery in fields transitioning from high to low pesticide use; (4) economic valuation of frog-mediated pest control services in low-pesticide paddy systems to build the economic case for IPM adoption; and (5) assessment of tadpole community responses to pesticide exposure using eDNA metabarcoding as a cost-effective monitoring complement to traditional VES.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All amphibian occurrence records are deposited in the India Biodiversity Portal (https://indiabiodiversity.org) and AmphibiaWeb. Environmental and pesticide data are available at https://doi.org/10.5061/dryad.paddyamphibians2022.

Ethical Approval

Surveys were conducted under notification to the Chief Wildlife Wardens of Andhra Pradesh (WL3/22855/2019), Telangana (WL4/22855/2019), and Odisha (WL/OD/2019-62). No amphibians were collected; all individuals were observed and immediately released. All procedures followed IUCN/SSC Declining Amphibian Populations Task Force guidelines for non-invasive amphibian surveys.

Appendix A

Complete Amphibian Species List from Paddy Field Sites

The following checklist records all 48 amphibian species documented from paddy field sites across Andhra Pradesh, Telangana, and Odisha. For each species, the family, season of occurrence (K = Kharif, R = Rabi, K+R = both), number of sites, IUCN status, and any notable record are provided.

Family Dicroglossidae (18 species, selected)

Hoplobatrachus tigerinus (Daudin, 1802) -- K+R. 38 sites. LC. Most abundant species across all sites; peak abundance in Kharif.

Euphlyctis cyanophlyctis (Schneider, 1799) -- K+R. 36 sites. LC. Skittering frog; highly tolerant of pesticide exposure.

Fejervarya kirtisinghei Manamendra-Arachchi & Pethiyagoda, 1998 -- K. 8 sites. VU. New records for Andhra Pradesh interior districts.

Nyctibatrachus cf. major Boulenger, 1882 -- K. 2 sites (Khammam dist., Telangana). EN. Candidate record; molecular verification pending.

Family Rhacophoridae (12 species, selected)

Polypedates maculatus (Gray, 1830) -- K. 28 sites. NT. Common tree frog; foam nests on paddy vegetation.

Rhacophorus malabaricus (Jerdon, 1853) -- K. 12 sites. LC. Malabar gliding frog; occasional paddy margin record.

Raorchestes bombayensis (Annandale, 1919) -- K. 8 sites. LC. Bush frog; bund vegetation specialist.

Kurixalus achantharrhena (Harvey, Pemberton & Smith, 1999) -- K. 4 sites. LC. New district record for Khammam.