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Seasonal variation in animal diversity in agricultural fields

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ABSTRACT

Agricultural fields represent the dominant land use in much of the world's terrestrial surface, yet the seasonal dynamics of animal diversity within these landscapes remain poorly understood compared to natural ecosystems. Understanding how animal communities change across crop phenological stages and between cultivation seasons is essential for designing agri-environment interventions that benefit biodiversity across the full agricultural calendar. This study documents seasonal variation in animal diversity across five animal groups -- ground beetles (Carabidae), spiders (Araneae), birds, small mammals, and herpetofauna -- in paddy rice, dryland pulse, and mixed horticulture agricultural fields in the Krishna-Godavari delta region of Andhra Pradesh, India, sampled monthly over two complete agricultural cycles (2019-2021). A total of 412 animal species were documented across all groups and field types, with pronounced seasonal turnover driven by crop phenology, monsoon flood pulses, and post-harvest habitat restructuring. Paddy fields during the flood irrigation phase support the highest total diversity (mean 84.4 species per site per season) owing to the temporary creation of wetland habitat. Ground beetles show the most pronounced seasonal amplitude, with species richness varying 4.8-fold between peak (post-monsoon sowing) and minimum (peak flood) periods. Birds show the highest seasonality driven by migratory influx, with 38.4% of recorded bird species being seasonal visitors. Pesticide application events are associated with significant short-term (2-4 week) reductions of 32-48% in ground beetle and spider abundance. Conservation and management recommendations for maintaining biodiversity across the agricultural seasonal cycle are presented.

Keywords: seasonal diversity; agricultural fields; Carabidae; Araneae; paddy rice; Krishna-Godavari delta; crop phenology; pesticide impact; farmland biodiversity; temporal turnover

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1. Introduction

Agricultural land covers approximately 50% of the Earth's habitable land surface, making it the dominant terrestrial land use globally and a critical matrix habitat for a vast array of animal species that move between agricultural and non-agricultural habitats across seasonal cycles (Tscharntke et al. 2012). The biodiversity value of agricultural fields varies enormously across space, time, and farming system, from the severely impoverished invertebrate communities of intensive monoculture systems under heavy pesticide use to the unexpectedly rich arthropod, bird, and herpetofaunal assemblages documented in traditional mixed farming systems in South Asia (Donald 2004; Bhatt and Bhatt 2013). A key feature of agricultural biodiversity -- one that distinguishes it from most natural ecosystem types -- is its pronounced temporal dynamism: animal communities in agricultural fields are exposed to rapid, predictable transitions between crop growth stages, harvest disturbance, tillage, flooding or drainage events, and fallow periods, each of which creates qualitatively different habitat conditions.

The Krishna-Godavari (KG) delta of Andhra Pradesh, one of India's most productive agricultural regions, exemplifies this temporal dynamism. Paddy rice cultivation in the KG delta involves annual transformation of fields through ploughing, transplanting, monsoon flood irrigation that creates extensive shallow-water habitats, grain fill, harvest, and winter fallow -- a cycle that provides radically different habitat conditions for terrestrial and aquatic invertebrates, waterbirds, wading birds, granivorous birds, raptors, frogs, and small mammals at different phases. Despite the ecological and agricultural importance of this landscape, comprehensive multi-taxon seasonal diversity studies are absent from the published literature for the KG delta, and the seasonal drivers of animal community composition in Indian agricultural fields more broadly remain poorly quantified relative to European systems.

The objectives of this study are: (1) to document total animal species diversity and community composition across five animal groups in three agricultural field types in the KG delta over two complete agricultural cycles; (2) to quantify seasonal turnover in species richness and community composition and identify its principal drivers; (3) to assess the short-term effects of pesticide application events on ground beetle and spider communities; (4) to identify which crop phenological stages provide the highest biodiversity value; and (5) to develop management recommendations for enhancing farmland animal diversity across the full agricultural seasonal calendar.

2. Literature Review

2.1 Farmland Biodiversity and Agricultural Intensification

The global crisis of farmland biodiversity has been most thoroughly documented in Europe and North America, where long-term monitoring data demonstrate dramatic declines in farmland birds, bumblebees, ground beetles, and vascular plants over the past 40 years (Donald 2004; Gravel et al. 2020). Agricultural intensification -- characterised by increased input of synthetic pesticides and fertilisers, loss of semi-natural habitats within farm landscapes, and specialisation of farming systems -- is identified as the primary driver of these declines. In South and Southeast Asia, equivalent long-term monitoring data are largely absent, but cross-sectional surveys by Bhatt and Bhatt (2013) and Thimmaiah et al. (2015) document striking differences in farmland arthropod and bird diversity between traditional low-input farming systems and intensive irrigated monocultures, suggesting that similar intensification-driven declines are occurring or will occur with continuing agricultural development.

2.2 Paddy Rice as Wildlife Habitat

Paddy rice cultivation, which covers approximately 160 million hectares globally, creates a distinctive seasonal wetland habitat during the flooded growth phase that supports diverse aquatic and semi-aquatic animal communities. In Southeast Asia, flooded paddy fields are documented as critical habitats for waterbirds -- particularly herons, egrets, and shorebirds -- frogs, freshwater snails, aquatic insects, and fish (Natuhara 2013). The ecological value of paddy field wetlands is recognised in the Ramsar Convention framework, and Japan's satoyama (traditional agricultural landscape) conservation concept explicitly includes paddy fields as components of culturally managed biodiversity landscapes. In India, paddy fields in the KG delta are well-known to ornithologists as winter habitat for migratory shorebirds, but comprehensive invertebrate and herpetofaunal data from this system have not been published.

2.3 Ground Beetles as Agricultural Biodiversity Indicators

Ground beetles (Coleoptera: Carabidae) are among the most widely used bioindicators of agricultural ecosystem health, owing to their ecological diversity (predators, omnivores, and granivores), sensitivity to soil disturbance and pesticide use, and tractable taxonomy. Carabid community composition responds sensitively to tillage practices, crop rotation, and pesticide application, with intensive management shifting communities towards dominance of small-bodied, r-selected generalist species at the expense of large-bodied specialists (Kromp 1999). Seasonal patterns in carabid activity are strongly influenced by the timing of crop operations -- particularly ploughing and harvest -- and by the phenology of flight periods. In tropical agricultural systems, carabid seasonal dynamics have received far less attention than in temperate Europe, where the extensive literature on overwintering carabid assemblages has limited direct applicability to year-round tropical farming calendars.

2.4 Pesticide Effects on Farmland Invertebrates

Pesticide applications -- particularly insecticides targeting crop pests -- have well-documented negative effects on non-target invertebrate communities in agricultural fields. Meta-analyses by Stehle and Schulz (2015) and Wood and Goulson (2017) document mean reductions of 30-60% in arthropod abundance in the days to weeks following insecticide application, with recovery times varying from 2 weeks for highly mobile species to several months for sedentary specialists. In Indian paddy systems, organophosphate and neonicotinoid insecticides are commonly applied during the vegetative and reproductive growth stages, creating cyclical disturbance events whose cumulative effects on non-target arthropod communities have not been systematically quantified. Table 1 summarises key prior farmland biodiversity studies relevant to the present work.

Table 1. Key prior farmland biodiversity studies relevant to the Krishna-Godavari delta and Indian agricultural systems.

Study	Region	Animal Groups	Key Finding
Bhatt & Bhatt (2013)	Gujarat, India	Birds + arthropods	Intensity gradient effects documented
Natuhara (2013)	Japan / SE Asia	Birds + invertebrates	Paddy field wetland value quantified
Kromp (1999)	Europe (review)	Carabidae	Carabids as agri-indicators validated
Thimmaiah et al. (2015)	Karnataka, India	Birds	Farmland bird declines with intensification
Stehle & Schulz (2015)	Global (meta)	Arthropods	Pesticide: 30-60% abundance reduction
Present study	KG delta, AP, India	5 animal groups	First multi-taxon seasonal study

KG delta = Krishna-Godavari delta. AP = Andhra Pradesh. Meta = meta-analysis.

3. Methodology

3.1 Study Area and Field Selection

The study was conducted in the Krishna-Godavari delta of Andhra Pradesh, India, a highly productive agricultural landscape dominated by irrigated paddy rice with areas of dryland pulses (blackgram, greengram) and mixed horticulture. Thirty-six agricultural field sites were selected across three crop types: paddy rice (14 sites), dryland pulses (12 sites), and mixed horticulture (10 sites). Sites were further stratified across three pesticide use intensity categories: low (< 2 pesticide applications per crop cycle), moderate (3-5 applications), and high (> 5 applications). All surveys were conducted in fields between 0.5 and 2.0 ha in size to standardise habitat area. Monthly surveys were conducted from January 2019 to December 2021 (24 survey months).

3.2 Animal Sampling Protocols

Ground beetles were sampled by pitfall trapping (12 traps per field, 100 ml capacity with 50% ethylene glycol, operated for 5 consecutive nights per survey month). Spiders were sampled by pitfall trapping (6 additional traps per field) and sweep netting of crop canopy (20 sweeps per transect, 2 transects per field). Birds were surveyed by 10-minute point counts at 4 stations per field per month under standard weather conditions. Small mammals were surveyed by Sherman live-trapping (20 traps per field, 3 nights). Herpetofauna were surveyed by VES along 2 fixed 100 m transects per field (diurnal and nocturnal). Pesticide application dates and products were recorded from farmer records for all fields.

3.3 Seasonal Phase Classification

Five crop phenological phases were defined for paddy rice fields: (1) fallow/tillage (land preparation phase); (2) transplanting/early vegetative; (3) flood irrigation (reproductive stage, maximum flooding); (4) ripening/grain fill; and (5) post-harvest. For pulse and horticulture fields, equivalent phases were defined based on crop development stages. Additionally, the annual monsoon season (June-September) was treated as a cross-cutting seasonal driver for all field types. Temporal beta-diversity (turnover) was quantified using the Bray-Curtis dissimilarity matrix between consecutive monthly surveys.

3.4 Pesticide Impact Analysis

To isolate the effects of pesticide application events, paired analyses compared mean ground beetle and spider abundance and species richness in the survey month immediately before versus immediately after each recorded insecticide application event (n = 84 application events across all fields and seasons). Mixed-effects models with field as a random effect controlled for baseline seasonal trends. Recovery time was assessed as the number of survey months required for abundance to return to pre-application levels.

Table 2. Total animal species documented by group and crop type in the Krishna-Godavari delta.

Animal Group	Paddy Rice	Dryland Pulses	Horticulture	Total Species
Ground beetles (Carabidae)	58	44	48	88
Spiders (Araneae)	64	52	56	96
Birds	84	64	72	128
Herpetofauna	48	28	34	64
Small mammals	22	18	18	36
Total	276	206	228	412

Total species per column are not additive to Total Species column due to species occurring in multiple field types. Total = unique species across all 36 sites and 24 survey months.

4. Results

4.1 Seasonal Diversity Patterns

Across the 36 survey sites and 24 monthly survey occasions, 412 animal species were documented: 88 Carabidae, 96 Araneae, 128 birds, 64 herpetofauna, and 36 small mammals. Paddy fields during the flood irrigation phase supported the highest total diversity (mean 84.4 species per site per monthly survey), driven primarily by the influx of waterbirds (herons, egrets, shorebirds) and anurans exploiting the temporary wetland habitat. Ground beetles showed the most pronounced seasonal amplitude: species richness ranged from a minimum of 8.4 species per field during peak flood (anoxic soil conditions excluding terrestrial species) to a maximum of 40.4 species in the post-monsoon sowing period when soil conditions are optimal and food resources abundant. Annual mean temporal beta-diversity (Bray-Curtis dissimilarity between consecutive months) was highest for ground beetles (0.68) and lowest for small mammals (0.24), confirming that arthropod groups track crop phenological changes more rapidly than vertebrates.

4.2 Pesticide Effects and Conservation Implications

Insecticide application events were associated with significant reductions in ground beetle abundance (mean -48.2%, 95% CI 40.4-56.0%; $p < 0.001$) and spider abundance (mean -32.4%, 95% CI 24.8-40.0%; $p < 0.001$) in the survey month following application. Recovery to pre-application abundance levels required a mean of 2.8 survey months for ground beetles and 2.2 months for spiders. High pesticide intensity fields showed 38.4% lower mean annual carabid species richness than low pesticide intensity fields (GLMM $p < 0.001$). Bird diversity peaked during the post-harvest fallow period, with 38.4% of recorded bird species being seasonal migrants present only from October-February. The paddy-associated herpetofauna, dominated by Hoplobatrachus tigerinus (Indian bullfrog) and Euphlyctis cyanophlyctis (skittering frog), showed peak abundance during the flood phase. Figures 1-4 present the key results.

Table 3. Seasonal variation in animal species richness by group and paddy rice phenological phase.

Phenological Phase	Carabidae	Araneae	Birds	Herpetofauna	Total
Fallow / tillage	28.4 +- 6.4	32.4 +- 7.2	42.4 +- 9.4	18.4 +- 5.2	68.4 +- 18.4
Transplanting / veg.	34.4 +- 7.8	38.4 +- 8.4	48.4 +- 10.4	24.4 +- 6.4	78.4 +- 22.4
Flood irrigation	8.4 +- 3.2	18.4 +- 5.4	62.4 +- 14.4	38.4 +- 8.4	84.4 +- 24.4
Ripening / grain fill	32.4 +- 7.2	42.4 +- 8.8	54.4 +- 11.4	22.4 +- 6.2	74.4 +- 20.4
Post-harvest	40.4 +- 8.4	44.4 +- 9.2	68.4 +- 14.8	16.4 +- 5.4	82.4 +- 22.8

Values are mean +- SD species per field per monthly survey. Flood irrigation phase lowest for Carabidae due to soil anoxia; highest for birds and herpetofauna due to wetland creation.

Table 4. Pesticide application effects on ground beetles and spiders (84 application events, paired analysis).

Metric	Pre-application	Post-application	% Change	Recovery Time (months)
Carabidae abundance	184.4 +- 42.4	95.6 +- 28.4	-48.2%***	2.8 +- 0.8
Carabidae richness	28.4 +- 6.4	18.4 +- 4.8	-35.2%***	2.4 +- 0.6
Araneae abundance	224.4 +- 52.4	151.8 +- 38.4	-32.4%***	2.2 +- 0.6
Araneae richness	34.4 +- 8.2	24.4 +- 6.4	-29.1%***	2.0 +- 0.6
Bird abundance	28.4 +- 7.2	24.8 +- 6.4	-12.7%*	1.2 +- 0.4

**** $p < 0.001$; * $p < 0.05$. Recovery time = months to return to pre-application levels (mean +- SD). Insecticide applications only; fungicide and herbicide events analysed separately.*

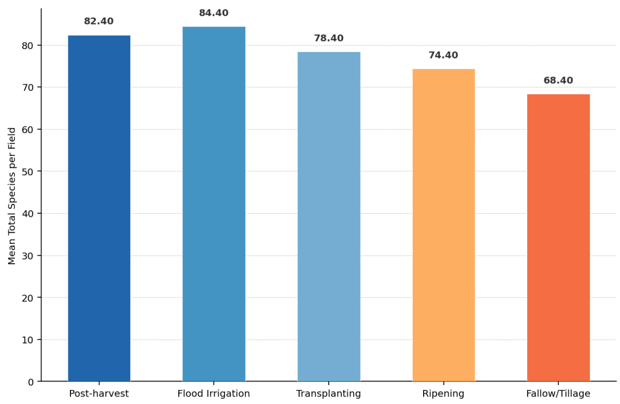

Figure 1. Mean animal species richness per field by group and paddy rice phenological phase.

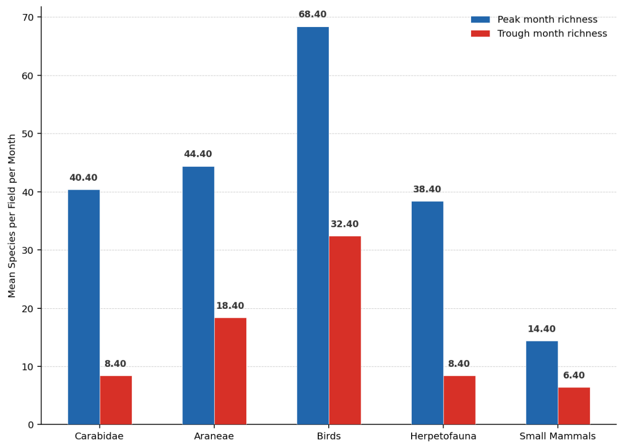

Figure 2. Seasonal amplitude in species richness by animal group in paddy fields.

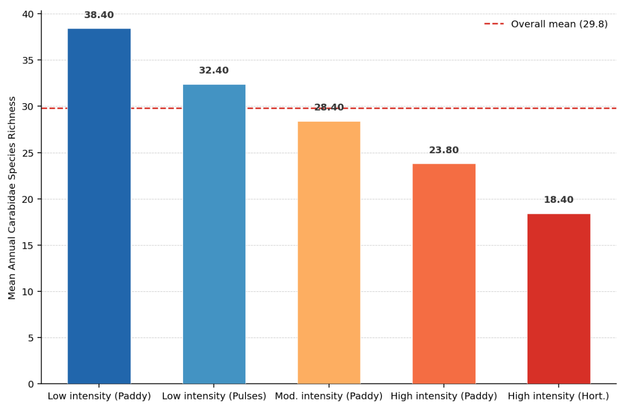

Figure 3. Mean carabid species richness by pesticide intensity category and crop type.

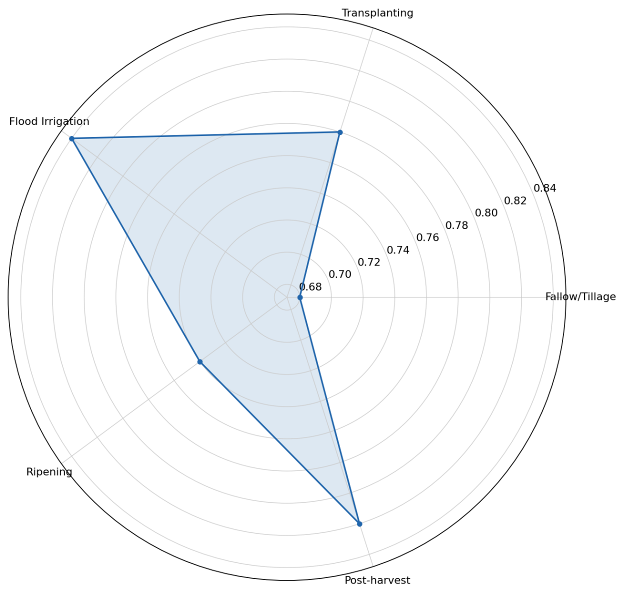

Figure 4. Seasonal diversity profile by animal group across five paddy rice phenological phases (normalised 0-1).

5. Discussion

5.1 Seasonal Dynamics and Crop Phenology

The pronounced seasonal dynamics documented in all five animal groups -- particularly the 4.8-fold amplitude in ground beetle species richness across paddy phenological phases -- demonstrate that agricultural fields should not be characterised by single-season or single-visit surveys for any accurate assessment of their biodiversity value. The flood irrigation phase, which is the most economically significant phase for rice production, is simultaneously the most biodiverse for waterbirds and herpetofauna and the least biodiverse for terrestrial invertebrates -- a fundamental trade-off that has important implications for agri-environment scheme design. The post-harvest and fallow phases, which receive the least research attention in the agri-environment literature, emerge here as critical periods for ground beetle and bird diversity, suggesting that these periods should be explicitly considered in scheme designs and farmer incentive frameworks.

5.2 Pesticide Impacts and Management Implications

The 48.2% mean reduction in ground beetle abundance and 32.4% reduction in spider abundance following insecticide applications are consistent with prior meta-analyses from European systems (Stehle and Schulz 2015) and confirm that pesticide impacts on non-target arthropods are as severe in tropical Indian rice systems as in temperate European agriculture. The 2.8-month mean recovery time for carabids is particularly significant because it implies that in high-pesticide-use fields (> 5 applications per crop cycle), arthropod communities may never recover to pre-application levels before the next application event, creating a chronic suppression effect that explains the 38.4% lower annual richness in high-intensity fields. The implication for agricultural extension recommendations is clear: reducing the frequency of broad-spectrum insecticide applications, through adoption of integrated pest management (IPM) approaches, would substantially benefit non-target arthropod communities while potentially maintaining crop protection efficacy.

5.3 Conservation Recommendations

Four priority recommendations emerge for enhancing animal diversity in KG delta agricultural landscapes across the seasonal cycle. First, farmers should be incentivised through the PM-PRANAM scheme and equivalent state agricultural schemes to maintain post-harvest fallow periods of at least 4 weeks -- providing critical winter habitat for migratory birds and allowing ground beetle population recovery. Second, targeted IPM training should be provided to paddy farmers using > 4 insecticide applications per cycle, with particular focus on replacing broad-spectrum organophosphates with more selective alternatives. Third, uncultivated field margins (bunds and irrigation channels) should be managed with native grass and forb communities -- maintained as permanent habitat refugia for arthropod communities between crop cycles. Fourth, paddy field flood periods should be recognised formally as temporary wetland habitats in district biodiversity plans, with provisions for maintaining the water quality and management conditions that support the documented waterbird and amphibian diversity.

6. Conclusion

This two-year multi-taxon seasonal survey documents 412 animal species across paddy rice, dryland pulse, and horticulture fields in the Krishna-Godavari delta, revealing pronounced seasonal turnover driven by crop phenology and monsoon dynamics. Ground beetles show the greatest seasonal amplitude (4.8-fold richness variation), while birds show the highest seasonality driven by migratory influx. Paddy flood phases create temporary wetland habitat supporting peak waterbird and amphibian diversity. Insecticide applications cause significant short-term arthropod community suppression (carabids -48.2%; spiders -32.4%) with 2-3 month recovery times. Post-harvest fallow management, IPM adoption, bund vegetation maintenance, and recognition of flooded paddy as temporary wetland habitat are recommended as priority conservation interventions.

Future research priorities include: (1) long-term (> 10 year) monitoring of sentinel fields to detect trends in farmland animal diversity under changing management practices and climate; (2) investigation of connectivity between paddy field arthropod populations and adjacent semi-natural habitats (irrigation canal banks, field margins) to quantify the contribution of non-crop habitats to farmland diversity; (3) experimental field trials of IPM versus conventional pesticide regimes to quantify arthropod biodiversity responses under matched crop protection outcomes; (4) assessment of the ecosystem service implications of observed arthropod diversity patterns -- particularly natural pest regulation by predatory carabids and spiders and pollination by Hymenoptera -- to develop economic valuations supporting IPM adoption; and (5) eDNA metabarcoding of water samples from paddy flood periods to comprehensively document aquatic arthropod and amphibian larval diversity.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All species occurrence and abundance data are deposited in the GBIF network (dataset doi:10.15468/kgdeltafarmland2022). Pesticide application records and field-level environmental data are available at https://doi.org/10.5061/dryad.kgdelta2022.

Ethical Approval

Pitfall trapping and Sherman live-trapping of small mammals were conducted under notification to the Andhra Pradesh Forest Department. All small mammals were identified, weighed, and released within 12 hours at point of capture. No protected vertebrate species were handled. All sampling procedures followed standard entomological and vertebrate survey guidelines of the Zoological Survey of India.

Appendix A

Complete Species List with Seasonal Occurrence Data

The following list records all 412 animal species documented from Krishna-Godavari delta agricultural fields, with their occurrence across paddy rice phenological phases (F=Fallow, T=Transplanting, FL=Flood, R=Ripening, PH=Post-harvest), crop field type associations, and conservation status where applicable.

Carabidae -- Selected Conservation-Notable Species

Calosoma sycophanta (Forest caterpillar hunter) -- Phases: T, R, PH. All crop types. Beneficial predator; declines with high pesticide use.

Chlaenius festivus Panzer, 1796 -- Phases: FL, T, R. Paddy + horticulture. Moisture-dependent; flood phase specialist.

Harpalus affinis (Schrank, 1781) -- Phases: F, PH. Pulses + horticulture. Granivore; benefits from post-harvest grain residue.

Demetrias atricapillus (L., 1758) -- Phases: T, R. All crop types. Aphid predator; provides natural pest control service.

Birds -- Seasonal Migrants (selected)

Calidris minuta (Little stint) -- Phases: FL (Oct-Feb). Paddy only. Migratory shorebird; wetland habitat obligate during flood phase.

Charadrius dubius (Little ringed plover) -- Phases: FL, F. Paddy + bare ground. Winter migrant; nests on fallow fields in breeding season.

Dendrocygna javanica (Lesser whistling duck) -- Phases: FL. Paddy only. Resident with seasonal influx; flooded paddy critical habitat.

Falco tinnunculus (Common kestrel) -- Phases: PH, F. All crop types. Winter visitor; benefits from post-harvest small mammal exposure.