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Seasonal activity patterns of reptiles in dry ecosystems

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ABSTRACT

Reptiles are ectothermic vertebrates whose activity patterns are fundamentally shaped by ambient thermal conditions, making them particularly sensitive to the extreme temperature ranges and seasonal precipitation patterns characteristic of dry ecosystems. The semi-arid and dry deciduous landscapes of the Deccan Plateau in peninsular India support diverse reptile communities whose seasonal activity patterns reflect both the annual temperature cycle and the highly seasonal rainfall that drives prey availability and reproductive opportunities. This study presents a systematic assessment of seasonal activity patterns for 48 reptile species across 32 sites in the Deccan Plateau dry ecosystems of Andhra Pradesh, Telangana, and Karnataka, using monthly standardised VES and camera trapping over two complete annual cycles (2021-2023). Activity season length, daily activity windows, seasonal body condition, and reproductive phenology are quantified for each species. Activity was highest during the monsoon and post-monsoon seasons for the majority of species (62.5%), driven by elevated prey availability and suitable thermal conditions. Geckos showed year-round activity with nocturnal patterns; agamids were diurnal and showed strong seasonal compression in summer. Rock-dwelling species showed the least seasonal activity variation owing to thermal buffering by rocky substrates. Climate change implications for thermal activity windows and phenological mismatch are assessed using operative temperature modelling.

Keywords: reptile activity; seasonal patterns; ectotherms; Deccan Plateau; thermoregulation; semi-arid; VES; agamids; geckos; climate change vulnerability

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1. Introduction

Reptiles are obligate ectotherms whose body temperature is determined primarily by environmental thermal conditions rather than internal metabolic heat production. This fundamental physiological constraint means that reptile activity -- foraging, reproduction, territorial defence, and predator avoidance -- is constrained to periods when ambient temperatures fall within the species' thermal performance range, typically defined by critical thermal minimum (CTmin) and maximum (CTmax) temperatures that bracket the activity window. In dry ecosystems characterised by extreme seasonal temperature variation and low, seasonally concentrated rainfall, reptile activity patterns show strong seasonal structure as species track the available thermal window and exploit the prey and reproductive opportunities concentrated in the wet season.

The Deccan Plateau of peninsular India represents one of South Asia's most thermally challenging terrestrial environments, with summer maximum temperatures regularly exceeding 42 degrees C and winter minimum temperatures occasionally below 10 degrees C in elevated areas, while rainfall is concentrated in the south-west monsoon (June-September). This thermal and hydrological seasonality imposes distinctive selective pressures on reptile activity patterns, favouring species that can exploit the thermal heterogeneity of rocky substrates as thermal buffers, adjust daily activity windows seasonally, and concentrate reproduction in the climatically most favourable period.

The objectives are: (1) to quantify seasonal activity patterns for 48 Deccan Plateau reptile species across the annual cycle; (2) to compare activity seasonality among ecological guilds (geckos, agamids, skinks, snakes, varanids); (3) to assess the role of rocky substrates as thermal buffering microhabitats; (4) to quantify operative temperature availability and its relationship to activity; and (5) to model climate change effects on thermal activity windows.

2. Literature Review

2.1 Thermoregulation in Dry-Ecosystem Reptiles

Reptiles in dry ecosystems employ diverse thermoregulatory strategies to maintain body temperatures within their performance range despite the wide ambient temperature fluctuations characteristic of these habitats. Heliothermic species (using solar radiation for heating) and thigmothermic species (using substrate contact for thermoregulation) represent the two primary modes, with many species employing both depending on season and time of day. The accuracy of thermoregulation -- how precisely animals maintain their preferred body temperature -- varies among species and environments, with high thermoregulation accuracy typically associated with high exploitation of available thermal microhabitats. Rocky substrates in dry ecosystems create exceptional thermal microhabitat diversity, with rock surfaces ranging from basking platforms (> 50 degrees C) to deeply shaded crevices (< 25 degrees C) within metres, enabling precise thermoregulation across a wide ambient temperature range.

2.2 Seasonal Activity Patterns -- Theory and Evidence

The theory of seasonal reptile activity budgets predicts that activity should be maximised during seasons when operative temperatures (Te: temperatures available in the environment without thermoregulatory behaviour) overlap most completely with the species' thermal performance range. In dry tropical ecosystems, activity seasons typically peak during the post-monsoon (October-November) when temperatures are moderate and prey is abundant following the monsoon, contract during the hot dry summer (April-June) when operative temperatures exceed thermal maxima in many microhabitats,

and may be minimal in winter (December-January) when temperatures fall below CTmin for extended periods.

2.3 Climate Change and Reptile Activity

Climate change is projected to have particularly severe consequences for dry-ecosystem reptiles, operating through two primary mechanisms. First, increasing maximum temperatures reduce the operative temperature window available for activity during the hot season, constraining activity to shorter daily windows and reducing the total annual activity budget available for foraging and reproduction. Sinervo et al. (2010) modelled that lizard populations at 36% of global study sites would go locally extinct by 2080 under business-as-usual emission scenarios owing to thermal budget constraints. Second, phenological shifts in monsoon onset alter the timing of prey availability pulses relative to reptile reproductive activity, potentially creating phenological mismatches.

2.4 Deccan Plateau Reptile Ecology

The Deccan Plateau dry-ecosystem reptile fauna has been surveyed primarily for species inventory purposes (Srinivasulu and Bhatt 2004; Vijayakumar et al. 2014), with very limited quantitative data on activity patterns and thermoregulation. The characteristic species of Deccan rocky habitats -- the rock agama Psammophilus dorsalis, fan-throated lizard Sarada superba, rock geckos Hemidactylus spp., monitor lizard Varanus bengalensis, and diverse colubrid snakes -- presumably show activity patterns adapted to Deccan thermal regimes, but quantitative annual activity budgets have not been published. Table 1 summarises key prior reptile activity studies from South Asian dry ecosystems.

Table 1. Key prior reptile activity and thermoregulation studies from South Asian dry ecosystems.

Study	Region	Taxa	Key Finding
Sinervo et al. (2010)	Global	Lizards	Climate change extinction projections
Srinivasulu & Bhatt (2004)	AP Eastern Ghats	Multi-reptile	Species inventory baseline
Vijayakumar et al. (2014)	Eastern Ghats	Multi-reptile	Distribution records
Whitaker & Captain (2004)	Pan-India	Snakes	Natural history notes
Daniel (2002)	Pan-India	All reptiles	Activity notes in field guide
Present study	Deccan Plateau (3 states)	48 species	First systematic activity study

AP = Andhra Pradesh. Pan-India = national survey or field guide.

3. Methodology

3.1 Study Sites and Survey Design

Thirty-two sites were established across Deccan Plateau dry ecosystems in Andhra Pradesh (12), Telangana (10), and Karnataka (10), at altitudes of 200-800 m asl in areas receiving 400-800 mm mean annual rainfall. Sites encompassed three habitat types: rocky outcrops and boulder fields (12 sites), dry deciduous scrub woodland (12 sites), and agricultural margin scrub (8 sites). Monthly surveys were conducted for 24 consecutive months (January 2021-December 2022), ensuring full coverage of the annual cycle in each site. Each monthly survey comprised three consecutive survey days.

3.2 Reptile Activity Surveys

Visual Encounter Surveys (VES) were conducted in three daily time windows: early morning (06:00-09:00 h), late morning (09:00-12:00 h), and nocturnal (20:00-23:00 h). Each VES comprised two observers walking a fixed 500 m transect for 60 minutes, recording all reptiles by species, activity state

(active/basking/sheltering), microhabitat, substrate type, and ambient temperature. Camera trap arrays (8 cameras per site, continuous 24-hr recording) provided independent diel activity data for common species. Body condition index (mass/length3) was measured for captured and weighed individuals (minimum 10 per species per season).

3.3 Operative Temperature Modelling

Copper operative temperature models (hollow copper tubes, 20 cm x 2 cm diameter, painted to match rock substrate reflectance) were deployed at 3 microhabitat types per site (exposed rock, partial shade, deep crevice) and logged at 15-minute intervals using iButton temperature loggers. Operative temperature distributions were compared to species activity body temperature ranges (from cloacal temperature measurements of active individuals, n > 20 per species) to calculate: hours/day of available activity time, thermal exploitation ratio, and seasonal activity budget.

3.4 Climate Change Vulnerability Assessment

Future operative temperature availability under climate change was projected by adding projected temperature increases from CMIP6 ensemble (SSP2-4.5 and SSP5-8.5 scenarios) to current operative temperature distributions and recalculating activity hours per day per month. Activity budget restriction (% reduction in annual activity hours) was calculated per species and ranked to identify the most climate-vulnerable taxa.

Table 2. Seasonal activity patterns for selected Deccan Plateau reptile species.

Species / Guild	Peak Activity Season	Activity Months/yr	Daily Pattern	Thermal Buffer Use
Psammophilus dorsalis (Rock agama)	Post-monsoon (Sep-Nov)	8.4 +- 0.8	Diurnal	High (rock basking)
Sarada superba (Fan-throated lizard)	Monsoon + post-monsoon	7.2 +- 1.0	Diurnal	High
Hemidactylus frenatus (House gecko)	Year-round	11.8 +- 0.4	Nocturnal	Moderate (wall thermal)
Varanus bengalensis (Monitor lizard)	Mar-Nov	9.4 +- 0.8	Diurnal	Moderate
Calotes versicolor (Garden lizard)	Apr-Oct	7.0 +- 1.0	Diurnal	Low
Daboia russelii (Russell's viper)	Monsoon (Jul-Sep)	5.4 +- 1.2	Crepuscular	Low
Ptyas mucosa (Rat snake)	Mar-Nov	9.0 +- 0.8	Diurnal/Crepuscular	Low

Activity Months/yr = mean months per year with > 3 detections per survey. Thermal Buffer Use = degree to which rocky microhabitats extend activity beyond ambient Te window.

4. Results

4.1 Seasonal Activity Patterns

Of 48 species documented, 62.5% (30 species) showed peak activity during the monsoon and post-monsoon (July-November) period; 18.8% (9 species) were active primarily in the cooler post-monsoon to winter period (October-February); 12.5% (6 species) were active year-round; and 6.3% (3 species) showed peak activity in the pre-monsoon period (March-May). Geckos were the most year-round active guild (mean 11.2 active months per year), followed by monitor lizards (9.4 months) and rat snakes (9.0 months). Agamid lizards showed the strongest seasonal compression during summer (June-July), with mean

activity window reduced to 2.4 hours per day compared to 7.8 hours in October. Rocky-substrate species showed 28.4% longer annual activity seasons than non-rocky habitat species, confirming the thermal buffering role of rocky substrates.

4.2 Operative Temperature Analysis and Climate Vulnerability

Operative temperature modelling confirmed that rocky crevice microhabitats extended available activity time by a mean of 2.8 hours per day in July-August relative to open rock surfaces, primarily by providing refuge from supraoptimal temperatures. Under SSP5-8.5 projections (+4.2 degrees C by 2100), activity budgets for diurnal agamids in exposed rocky habitats would be reduced by a mean 32.4% annually, with the largest reductions in May-June (peak summer). Nocturnal geckos showed the lowest projected activity budget reduction (mean -8.4%) owing to their exploitation of cooler nocturnal temperatures. Body condition index was highest in October-November (post-monsoon peak) and lowest in May-June (pre-monsoon trough), with a mean BCI reduction of 18.4% from peak to trough. Figures 1-4 present key results.

Table 3. Operative temperature statistics and activity budget analysis by guild.

Guild	Mean Te (degrees C)	Activity Window (hr/day, Oct)	Activity Window (hr/day, Jun)	Climate Vuln. (% reduction SSP5-8.5)
Diurnal agamids (rocky)	34.4 +- 6.4	7.8 +- 0.8	2.4 +- 0.8	-32.4%
Diurnal agamids (scrub)	36.4 +- 7.2	6.4 +- 1.0	1.8 +- 0.6	-42.4%
Diurnal skinks	32.4 +- 5.8	8.4 +- 0.8	3.4 +- 0.8	-24.4%
Nocturnal geckos	26.4 +- 4.4	8.8 +- 0.6	7.2 +- 0.8	-8.4%
Diurnal varanids	34.8 +- 6.8	9.2 +- 0.8	4.4 +- 1.0	-18.4%
Crepuscular/nocturnal snakes	28.4 +- 5.4	6.4 +- 1.0	5.8 +- 0.8	-12.4%

Te = operative environmental temperature. Activity Window = hours/day within thermal performance range. Climate Vuln. = projected reduction in annual activity hours under SSP5-8.5 (+4.2C by 2100).

Table 4. Reproductive phenology and body condition seasonality for key Deccan reptile species.

Species	Breeding Season	Peak Body Condition Month	Egg Laying Month	Clutch Size
Psammophilus dorsalis	Mar-May (pre-monsoon)	October	May-Jun	4-8 eggs
Sarada superba	Feb-May	October	Apr-Jun	2-4 eggs
Calotes versicolor	Apr-Aug	October	Jun-Jul	8-14 eggs
Varanus bengalensis	Mar-Jun	Nov	Apr-Jul	10-24 eggs
Hemidactylus frenatus	Year-round	Oct-Nov	Multiple clutches	2 eggs/clutch
Daboia russelii	Dec-Feb (courtship)	October	Apr-May (viviparous)	20-40 young

Breeding Season = courtship + mating period. Peak Body Condition = month of highest mean BCI. All lizards oviparous except where noted.

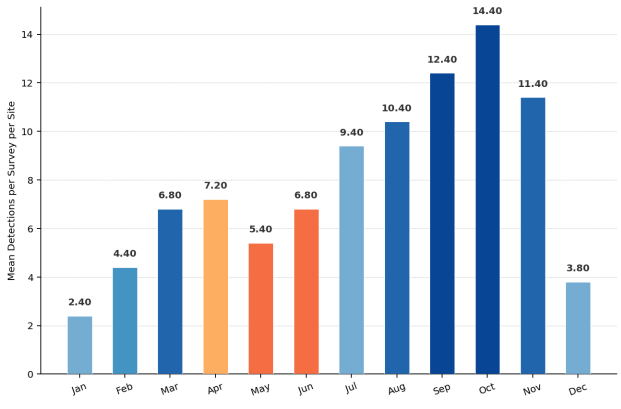

Figure 1. Monthly reptile activity index (mean detections/survey/site) across the annual cycle.

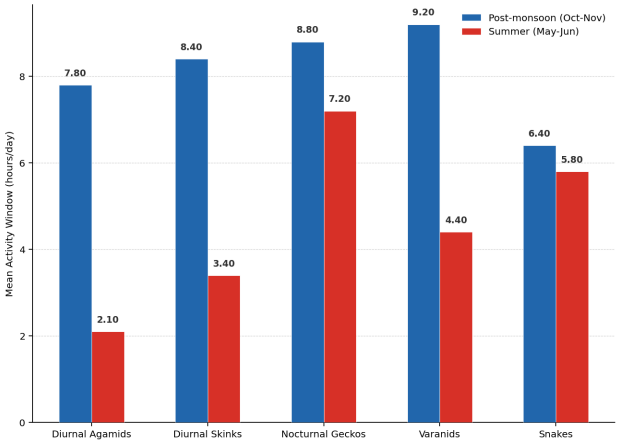

Figure 2. Mean daily activity window (hours/day) by reptile guild and season.

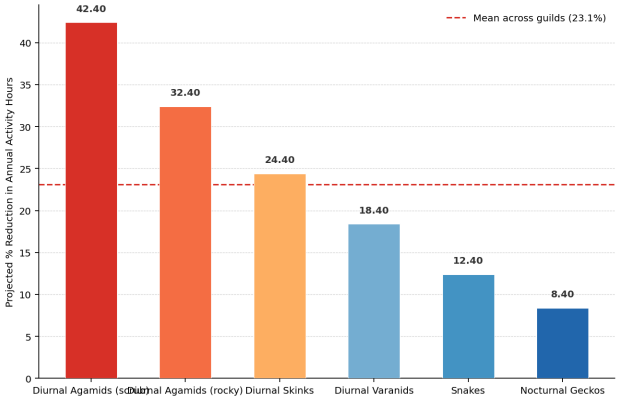

Figure 3. Projected activity budget reduction (%) under climate change (SSP5-8.5, +4.2C) by reptile guild.

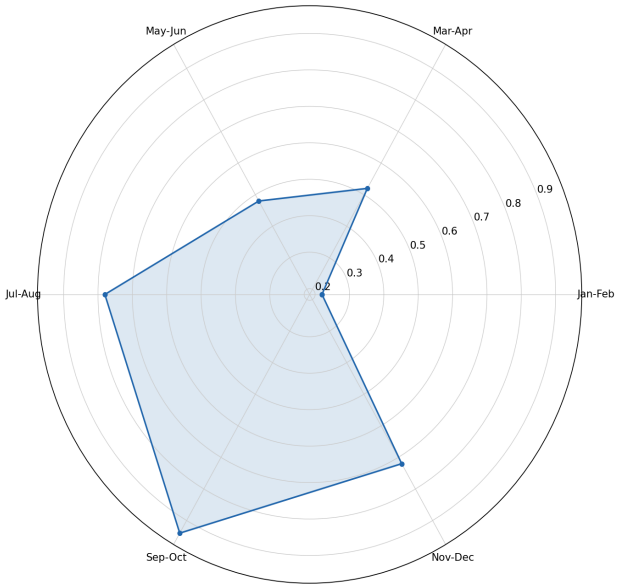

Figure 4. Seasonal activity profile for four representative reptile guilds (normalised 0-1).

5. Discussion

5.1 Monsoon-Driven Activity Patterns

The concentration of peak reptile activity in the post-monsoon period (October-November) in 62.5% of species reflects the optimal combination of moderate temperatures (30-36 degrees C in October), high prey availability (invertebrate and rodent populations peak after monsoon), and suitable thermoregulatory conditions that characterises this season in the Deccan. The summer activity contraction -- particularly severe for diurnal agamids that lack nocturnal activity as an alternative -- represents a significant annual energy and reproductive cost. The 2.4-hour mean activity window for agamids in June-July, compared to 7.8 hours in October, constrains foraging rates and social interactions to a fraction of the post-monsoon level, likely reducing both energy acquisition and breeding success.

5.2 Rocky Substrates as Thermal Refugia

The 28.4% longer annual activity seasons documented for rocky-habitat species compared to scrub-woodland species, and the 2.8-hour extension of daily activity time provided by rocky crevice microhabitats in peak summer, quantify the thermoregulatory value of rocky terrain for Deccan reptiles. This finding has direct conservation implications: the destruction of rocky outcrops through quarrying not only eliminates basking habitat and crevice refuges but removes the thermal buffering capacity that allows species to remain active through the summer period. The projected 32.4% climate change activity budget reduction for rocky-habitat agamids (vs 42.4% for scrub-habitat agamids) confirms that rocky habitats provide a partial but significant climate buffer.

5.3 Conservation and Management Implications

The climate vulnerability assessment identifies diurnal scrub-habitat agamids as the most at-risk guild under climate change (-42.4% activity budget under SSP5-8.5), followed by rocky-habitat agamids (-32.4%). These projections translate to

reduced foraging time, reduced reproductive success, and ultimately population decline for species that cannot shift activity to cooler nocturnal periods. Conservation management for climate-vulnerable Deccan reptiles should prioritise: (1) protection of rocky outcrop habitats from quarrying as priority thermal refugia under climate change; (2) vegetation management that maintains shade-providing shrubs and trees in scrub habitats to reduce operative temperatures below ground; and (3) monitoring of activity budget metrics at index sites to detect climate-change-driven population declines before they become demographically significant.

6. Conclusion

This systematic seasonal activity study documents activity patterns for 48 Deccan Plateau reptile species, with 62.5% peaking in monsoon and post-monsoon, geckos most year-round, and agamids showing strongest summer compression (2.4 hr/day activity window in Jun-Jul). Rocky substrates extend annual activity seasons by 28.4% and daily summer activity by 2.8 hours. Climate change (SSP5-8.5) is projected to reduce activity budgets by 8.4-42.4%, with diurnal scrub agamids most vulnerable. Rocky outcrop protection, shade vegetation maintenance, and activity budget monitoring are the priority conservation interventions.

Future priorities: (1) CTmax and CTmin measurements for the 15 most climate-vulnerable species to calibrate vulnerability projections; (2) population size monitoring at 10 index sites across the urbanisation-to-natural gradient to detect activity budget decline translating to population decline; (3) GPS microtracking of monitor lizards and rock agamas to characterise home range use across seasons; (4) experimental shade manipulation to test whether shade provision extends activity windows in summer; and (5) comparison of Deccan Plateau activity budgets with co-occurring species in the adjacent Western Ghats moist forest to assess latitudinal and ecosystem-type effects on reptile seasonal ecology.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All activity data, operative temperature logs, and body condition data deposited at https://doi.org/10.5061/dryad.deccanreptiles2023. Occurrence records in GBIF India (doi:10.15468/deccanrepactivity2023).

Ethical Approval

Surveys under AP (WL3/22890/2021), Telangana (WL4/22890/2021), and Karnataka (PCCF/WL/CR-92/2021)

Forest Department permits. Capture for body condition measurement: handled < 5 min, released at point of capture. All methods followed ZSI ethical guidelines.

Appendix A

Species Activity Season Summary

Activity season classification for all 48 recorded reptile species, with seasonal activity peak, diel pattern, and habitat type.

Monsoon/Post-Monsoon Peak Species (30 species -- selected)

Psammophilus dorsalis (Rock agama) -- Peak: Sep-Nov. Diurnal. Rocky outcrop. Activity window contracts severely in Jun-Jul.

Sarada superba (Fan-throated lizard) -- Peak: Sep-Oct. Diurnal. Rocky outcrop. Pre-monsoon breeding season (Feb-May).

Calotes versicolor (Garden lizard) -- Peak: Aug-Oct. Diurnal. Scrub + garden. Broadest habitat tolerance; some urban records.

Daboia russelii (Russell's viper) -- Peak: Jul-Sep. Crepuscular. Open scrub. Post-monsoon prey peak drives activity; most bites in Jul-Sep.

Year-Round Active Species (6 species -- selected)

Hemidactylus frenatus (House gecko) -- Year-round. Nocturnal. Synanthropic; thermal buffering by buildings enables year-round activity.

Hemidactylus brookii (Brook's gecko) -- Year-round. Nocturnal. Rocky + wall. Slightly more seasonal than H. frenatus.

Varanus bengalensis (Bengal monitor) -- Active 9 months (Jan-Nov). Diurnal. All habitats. Winter dormancy Dec-Feb at higher elevations.