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Influence of Hydrological and Meteorological Factors on the Diversity of *Phallus* Species in the Srepok River Basin, Vietnam

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Abstract

Moisture-dependent environments of the tropical river basins influence macrofungal fruit body production at the canopy level, on decomposing substrates, and through the availability of water and climate. The *Phallus* morphotypes documented at Chu Yang Sin National Park in the upper Srepok River Basin, Viet Nam, were analysed with regard to their regional occurrence and environmental data. For 12 main field specimens, sample code was recorded, coordinates, habitat description, morphotype and visible morphological traits and developmental stage. Only exploratory distribution mapping was done for 18 secondary georeferenced records found on GBIF/iNaturalist for a total of 30 occurrence records. Primary specimens included egg and semi-mature and mature stages, which occurred primarily in the moist forest floor, shaded slope, thick litter, humus rich soil, rotting wood and decomposing organic matter. Rainfall, vegetation condition, thermal environment and soil-water availability were given landscape-scale context by open environmental datasets, such as CHIRPS data for rainfall, MODIS land surface temperature, MODIS NDVI/EVI, and SMAP soil moisture, and ERA5-Land variables. Due to the lack of molecular identification and measurements of microclimate at the plot level, the results are considered as tentative associations to the field environment rather than evidence of cause and effect. The framework is useful in planning for future monitoring of fungal biodiversity in the tropical river-basin ecosystems.

Keywords: *Phallus* Morphotypes, Srepok River Basin, Chu Yang Sin National Park, Macrofungal Occurrence, Environmental Datasets.

1. Introduction

The tropical river basins have complex gradients of ecosystems with short range spatial variations in rainfall, vegetation structure, soil moisture and temperature, and hydrological processes. The visible fruiting bodies of macrofungi frequently only occur when moisture, substrate and microclimates are favorable, and this is of special importance for these. Saprotrophic fungi are highly reliant on decomposing litter, rotting wood, organic rich microhabitats in shaded soil in humid forested landscapes. In many tropical areas, however, knowledge of fungi is relatively low in comparison to plants and animals due in part to the seasonal, short-lived, and challenging nature of fruiting bodies to identify without careful morphological and molecular work. Vietnamese macro-fungi have received a lot of attention in recent years focusing on the importance of field collection, ex situ conservation,

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DNA barcoding and enzymatic characterisation for enhancing the knowledge of the diversity of fungi in Vietnam (Psurtseva, Kiyashko, Senik, & Pham, 2025).

The genus *Phallus* is characterized by its rapid fruiting-body development, its pseudo-stipe which is hollow, by a volva and by a pileus with an indusium of gleba. The genus *Phallus* is a distinctive group of stinkhorn fungi recognized by the rapid development of the fruiting body, by the presence of a pseudo-stipe which is hollow, with a volva and a pileus covered with gleba and, in some taxa, a conspicuous indusium in the form of a net. These belong to a group that usually are found in wet soils, rotting vegetation, wood litter and under trees. They are closely associated with the quality of their substrate and the structure of their forest microhabitat due to the insects they attract with their fetid gleba to help disperse the spores. The presence of *Phallus* in Vietnam is of taxonomic importance as new and regionally new records are reported on, indicating that the genus is not well known in Vietnam. Based on the description of *Phallus* coronatus from Vietnam, it is important to further document *Phallus* diversity through careful fieldwork and taxonomic verification (Rebriev, Pham, & Alexandrova, 2014).

The Srepok River Basin in the upper part of the river in Vietnam is a good ecological environment to study the occurrence of *Phallus*, as it covers tropical monsoon seasonality, forested uplands and agricultural mosaics and changing hydrological regime. The basin is situated within the Central Highlands, which has high environmental heterogeneity within the basin and could affect the emergence of fungi based on the levels of wet season rainfall, dry season water stress, canopy structure and soil-water retention. Within this larger basin system, the Chu Yang Sin National Park includes humid forest habitats, shaded slopes, leaf litter and decomposing organic material which can support the saprotrophic macrofungi. Meanwhile, land-use change, hydropower development and climate related changes in hydrology affect the Srepok Basin, potentially resulting in changes in streamflow, habitat stability and soil moisture. The hydrological study conducted in the Srepok River Basin in the past has revealed that the climate and land-use changes can affect the water dynamics of the basin and this landscape is important for biodiversity studies that rely on moisture-sensitive organisms (Nhi, Khoi, Trang, Van Ty, & Fang, 2022).

Fungus occurrence is especially sensitive to moisture availability because it is not necessarily due to rain. Prior to fungi uptake, rainfall needs to be stored in soil, litter or woody material. The interaction between temperature and water availability also involves the effects on evapotranspiration, drying of surfaces, physiological stress. So, the study of *Phallus* occurrence should take into account the rainfall input and soil-water availability as well as vegetation condition and thermal environment, not individually. Expanding ecological data indicates that warming may have strong interactions with soil moisture and that soil moisture should be considered as an interacting environmental parameter (Reich et al., 2018)

The study aims to examine the presence, their morphology and their environment of *Phallus* morphotypes found in Chu Yang Sin National Park, Srepok upper river basin. Exploratory distribution mapping is supplemented with primary field records and secondary data with georeferences. The recorded occurrences are placed in the broader landscape using open datasets from the environment, such as rainfall, vegetation indices, land-surface temperature, and soil moisture and reanalysis-based hydrological variables. Due to the lack of molecular data, the species level confirmation is not possible and the specimens are treated conservatively as *Phallus* sp. or *Phallus* morphotypes. The research will focus on enhancing the biological reporting, deepen understanding of spatial interpretation and create a replicable model to connect fungal field observations to hydrological and meteorological gradients in a tropical river-basin landscape. The major objectives of this study are:

1. To document the occurrence, morphology and developmental stages of *Phallus* morphotypes recorded from Chu Yang Sin National Park, upper Srepok River Basin.
2. To map primary and secondary *Phallus* occurrence records for exploratory distribution analysis in Viet Nam.
3. To examine the environmental context of *Phallus* occurrence using rainfall, temperature, vegetation, soil-moisture and hydrological variables.

2. Methodology

2.1 Study area

This study was carried out in the upper Srepok River Basin, Vietnam, mainly in Chu Yang Sin National Park, Dak Lak Province. The upper Srepok Basin is the Central Highlands region, featuring tropical monsoon seasonality, basaltic uplands, forested slopes, agricultural landscapes and intense wet–dry seasonal contrast. Environmental gradients are suitable for the study of moisture sensitive saprotrophic macro-fungi like *Phallus*, under these conditions. The study area was chosen due to its diversity of vegetation, microhabitats of humid forest, seasonal rainfall patterns, and hydrological link with other parts of the Srepok River system.

2.2 Primary field specimen records

Primary biological data consisted of 12 *Phallus* specimen records obtained from the author's field survey in Chu Yang Sin National Park. Each record included sample code, coordinates where available, habitat description, morphotype, visible morphological characters and developmental stage, based on the author's primary field survey in Chu Yang Sin National Park. The specimens represented different developmental stages, including immature egg forms, emerging forms, semi-mature fruiting bodies and mature indusiate forms. Field habitats included moist forest floor, thick litter, shaded slopes, humus-rich soil, rotting wood, decaying organic debris, rotting roots and damp forest-floor substrates. Because molecular confirmation was not available, specimens were conservatively treated as *Phallus* sp. or *Phallus* morphotypes rather than confirmed species-level identifications.

2.3 Secondary occurrence records

Secondary occurrence data were compiled from publicly available biodiversity platforms, including GBIF and iNaturalist. A total of 18 georeferenced *Phallus* occurrence records from Viet Nam were retrieved and screened as supplementary distribution data. Records were retained only when they included geographic coordinates and sufficient photographic or taxonomic information to support genus-level identification. Entries with unclear locality information, obvious coordinate errors, duplicate records or uncertain generic assignment were excluded. Because these records were not collected directly by the author and were not supported by molecular verification, they were treated conservatively as secondary *Phallus* occurrence records rather than confirmed species-level records. These data were used only for regional distribution mapping and exploratory environmental characterization, and were not treated as primary field specimens or independent taxonomic confirmations.

2.4 Coordinate verification and standardization

Spatial analysis was preceded by the checking of original field coordinates. Coordinate data in degree–minute–second format was checked for uniformity in formatting and translated to decimal degree format for GIS mapping and extraction of environmental data in rasters. If the second was not standard (60 or higher), then the coordinate values were flagged for checking against the original GPS or field log. If in the original record there were grouped field records with the same value for the locality, the same value was only retained as a grouped-location value. Secondary GBIF/iNaturalist records were already available in decimal degrees and were harmonized with the coordinate system used for the primary field records ("GBIF," 2026). No spatial measures were taken as microhabitats and all coordinates were considered to be exploratory spatial records.

2.5 Environmental datasets

Hydrological, meteorological, and vegetation conditions were described using open datasets from satellites and reanalysis data, for the occurrence records of *Phallus*. Daily precipitation was used as a proxy for rainfall input, where it came from CHIRPS. The land surface temperature (LST) was represented by MODIS MOD21A1D land surface temperature data. The vegetation greenness and productivity were represented by MODIS MOD13Q1 NDVI and EVI. Soil-water availability was calculated using SMAP soil moisture products, which were considered to represent surface and root-

zone soil-water availability. The reanalysis data used were ERA5-Land variables, which covered a much wider range of atmospheric and land-surface hydrological variables, such as air temperature, dewpoint, soil temperature, volumetric soil water, runoff, evapotranspiration, wind and radiation.

2.6 Environmental data extraction

Occurrence co-ordinates were verified and subsequently entered in to a GIS based workflow. Raster values for environment were extracted at each occurrence site, based on the spatial resolution of each raster. Monthly and seasonal totals of rainfall were prepared using monthly, seasonal and pre-collection windows as collection dates were available. At site level the following land surface temperature and vegetation indices along with soil moisture, runoff, evapotranspiration and atmospheric variables were summarized. A site level environmental table was created by extracting variables and associated with occurrence type, sample code, morphotype, developmental stage and description of habitat. In the case of secondary records, environmental extraction was used only in the analysis of exploratory scale, on the regional level.

2.7 Distribution mapping

The combined occurrence data was used to make a distribution map. Both field-collected specimens collected in Primary Chu Yang Sin and secondary occurrence records from GBIF/iNaturalist were shown with different symbols to minimize misconception of field collected specimens versus those from external occurrence records. A regional map was utilized to depict the regional distribution of *Phallus* records in Viet Nam and a focused map was utilized to depict the primary records from Chu Yang Sin National Park and the upper portion of the Srepok study area. Records had uncertain coordinates were identified for further spatial interpretation.

2.8 Exploratory analysis

This analysis took an exploratory approach and not a predictive approach due to the small number of primary field specimens collected. Environmental variables at occurring points were summarized using descriptive statistics. The Primary Field Records were analysed in terms of habitat description, developmental stage and morphotype. For those environmental values that were extracted, simple correlation analysis and visualization of the environmental gradient were used to investigate the relationships between occurrence of *Phallus* and rainfall, land-surface temperature, vegetation indices, soil moisture, runoff and evapotranspiration. These associations did not lead to the making of any causal inference.

2.9 Data quality and limitations

The study was a combination of primary field data and secondary, open access occurrence records. Morphological and habitat interpretation was primarily based on primary records, and secondarily used to support regional distribution mapping. Species level confirmation was limited the lack of molecular identification. It was determined that there were several field coordinates that needed to be verified prior to using them in GIS. Moreover, satellite and reanalysis products were used as a proxy for landscape-scale (environmental) conditions. They were unable to adequately represent fine-scale fungal microhabitats, including canopy shade, plot-level soil moisture, litter quality and depth. Future research should involve a greater number of field samples and direct measurements of microclimate and substrates should be made along with identification by DNA.

3. Results

3.1 Field occurrence and morphology of *Phallus* specimens

A total of 12 primary *Phallus* specimen records were documented from Chu Yang Sin National Park in the upper Srepok River Basin. The records represented different developmental stages, including immature egg forms, semi-mature fruiting bodies and fully mature forms. The specimens were mainly associated with moist forest floors, shaded slopes, thick litter, humus-rich substrates, rotting wood and decomposing organic matter. Several mature records showed characters typical of *Phallus*, including a hollow spongy pseudostipe, distinct volva, conical to bell-shaped pileus and olive-brown

gleba. Because molecular confirmation was unavailable, the records were treated conservatively as *Phallus* sp. or *Phallus* morphotypes.

Table 1. Field morphological description, habitat characteristics and developmental stages of *Phallus* specimens collected from Chu Yang Sin National Park, upper Srepok River Basin, Viet Nam

Sample code	Coordinates X	Coordinates Y	Habitat description	Morphotype	Morphological characteristics	Developmental stage
CYS.08.24.M04	108°34′29″	12°48′36″	Moist forest floor, thick litter, medium forest canopy (~70%), wet slopes with leaf litter, partially shady forest edges	*Phallus* sp. (with indusium)	Cylindrical stipe, olive-brown; pileus orange-brown; volva white	Mature stage; typical *P. indusiatus* complex
CYS.08.24.M05	108°34′29″	12°48′36″	Moist forest floor, thick litter, medium forest canopy (~70%), wet slopes with leaf litter, partially shady forest edges	*Phallus* sp. (with indusium)	Stipe cylindrical, white-pinkish; pileus olive-brown; volva intact	Mature stage
CYS.08.24.M06	108°34′29″	12°48′36″	Moist forest floor, thick litter, medium forest canopy	*Phallus* sp.	Early “egg” stage	Early immature stage

			(~70%), wet slopes with leaf litter, partially shady forest edges			
CYS.08.24.M07	108°34′29″	12°48′36″	Moist forest floor, thick litter, medium forest canopy (~70%), wet slopes with leaf litter, partially shady forest edges	*Phallus* sp.	Hollow stipe, brownish-orange; pileus oval; ~5 cm tall; thin, fragile peridium	Fully mature stage; emits fetid odor typical of *Phallus*
CYS.08.24.M08	108°34′29″	12°48′36″	Moist forest floor, thick litter, medium forest canopy (~70%), wet slopes with leaf litter, partially shady forest edges	*Phallus* sp.	Indusium faintly visible; pileus brown; gleba partially degraded	Mature stage; gleba partially decayed
CYS.08.24.M16	108°34′29″	12°48′36″	Moist forest slope, organic cover and semi-decay cover; canopy	*Phallus* sp. (without indusium)	Stipe 8–10 cm, white-pinkish; pileus brownish; volva brown; surface smooth, no	Semi-mature stage

			cover 60–70%		indusium visible	
CYS.08.24.M17	108°34′12″	12°46′14″	Lower slope near grass edge, moist soil with decaying organic debris	*Phallus* sp. (egg stage)	Spherical fruiting body 3.0–3.5 cm, white with faint pink; smooth surface; firm texture	Immature "egg" stage
CYS.08.24.M18	108°34′04″	12°48′06″	Moist humus layer on rotting wood; shady valley bottom (~70% canopy cover)	*Phallus* sp. (egg stage, twin form)	Two "egg" forms together, 2.8–3.2 cm, pinkish-white; enclosed in fibrous layer; firm inside	Immature "egg" stage
CYS.08.24.M34	108°34′15″	12°48′04″	Shady forest edge; soil mixed with rotting tree roots and organic matter near the base of a tree	Unidentified *Phallus* morphotype	Bell-shaped pileus, 4.5–5.0 cm, with small pores; stipe 7–9 cm, white; pileus dry; firm structure	Mature stage
CYS.08.24.M45	108°30′39″	12°43′40″	Open forest edge, sandy loam with rotten grass roots, moderate light	Unidentified *Phallus* morphotype	Cylindrical stipe, 6–9 cm, hollow, light brown; pileus conical, dark brown, smooth; volva white-pinkish	Late mature stage
CYS.08.24.M48	108°46′44″	12°48′40″	Damp forest floor, rotting leaves	Morphologically resembling *P. indusiatus*	Bell-shaped pileus, olive-brown gleba; indusium	Fully mature stage

			mixed with grass stems		orange-pink, 4–6 cm; stipe white-pinkish; volva white-pink	
CYS.08.24.M56	108°25′57″	12°43′35″	Damp forest floor, rotting leaves mixed with grass stems	Morphologically resembling *P. indusiatus*	Stipe short, brownish; volva white-pink; indusium partly visible; stipe 1.5–2.5 cm thick, white-pinkish	Semi-mature stage

Note. Coordinates are presented as recorded or inferred from the grouped field table. Specimens are conservatively treated as *Phallus* sp. or *Phallus* morphotypes because molecular confirmation was not available.

3.2 Habitat characteristics of primary field records

The primary records showed a repeated association with humid, shaded and organic-rich microhabitats. Samples M04–M08 were associated with moist forest floor, thick litter, medium canopy cover and wet slopes with leaf litter. Sample M16 occurred on a moist forest slope with organic and semi-decayed cover. Egg-stage records M17 and M18 were found in moist soil with decaying debris and humus on rotting wood. Other mature specimens were associated with rotting tree roots, sandy loam, damp forest floor, decomposing leaves and grass stems. These observations indicate that moisture retention, shade and organic substrates were important field characteristics of recorded *Phallus* habitats.

Table 3. Summary of habitat features recorded for primary *Phallus* specimens

Habitat feature	Related sample codes	Field observation	Ecological interpretation
Moist forest floor and thick litter	M04–M08	Specimens occurred on wet slopes with leaf litter and partial shade	Indicates importance of litter moisture and shaded forest-floor conditions
Organic and semi-decayed cover	M16	Specimen recorded on moist forest slope with semi-decayed organic cover	Suggests association with decomposing organic substrates
Moist soil with decaying debris	M17	Egg-stage specimen found near lower slope and grass edge	Indicates early development in damp, organic-rich soil
Humus on rotting wood	M18	Twin egg-stage forms recorded on rotting wood in shaded valley bottom	Suggests rotting woody substrates may support immature stages
Rotting roots and tree-base organic matter	M34	Mature specimen recorded near tree base	Indicates possible association with root-zone organic decomposition
Sandy loam with rotten grass roots	M45	Late mature specimen found at open forest edge	Shows occurrence is possible in moderately open but organic-rich substrates

Damp leaves and grass stems	M48, M56	Mature and semi-mature specimens recorded on damp forest floor	Supports importance of decomposing leaf and grass material

Note. Habitat interpretation is based only on the 12 primary field records and should not be extended to the secondary GBIF/iNaturalist records because those records lack detailed field habitat descriptions.

3.3 Spatial distribution of primary and secondary occurrence records

The combined occurrence dataset included 12 primary field records from Chu Yang Sin National Park and 18 secondary georeferenced records from GBIF/iNaturalist, giving 30 occurrence records for exploratory distribution mapping. The distribution map shows that the primary CYS records are concentrated in the upper Srepok/Chu Yang Sin area, while the secondary occurrence records are distributed more broadly across Viet Nam (Figure 2). Red triangles represent primary field specimens, whereas blue circles represent secondary GBIF/iNaturalist records. This distinction is important because the secondary records were used only for regional mapping and were not treated as author-collected field samples.

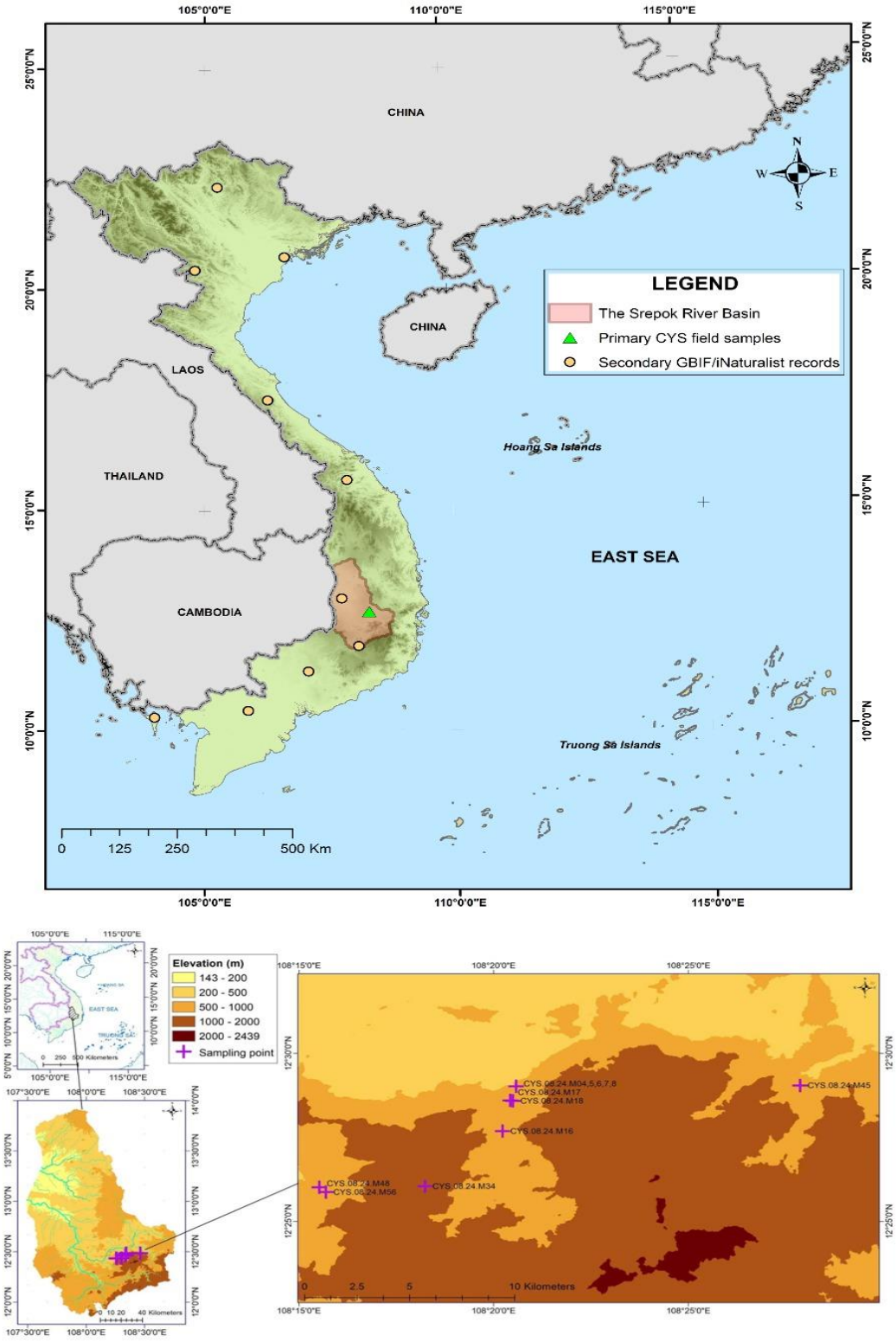


Figure 2. Spatial distribution of *Phallus* occurrence records in Viet Nam and sampling locations in the upper Srepok River Basin. (a) National-scale distribution map showing the Srepok River Basin, primary Chu Yang Sin field sampling location and secondary georeferenced GBIF/iNaturalist records across Viet Nam. (b) Focused elevation-based map of the Chu Yang Sin/upper Srepok study area showing the locations of primary field specimens with sample codes. Primary field records represent author-documented specimens, whereas secondary GBIF/iNaturalist records are used only for exploratory regional distribution mapping and environmental characterization

Table 2. Occurrence records used for exploratory distribution mapping

Record group	Data source	Number of records	Geographic coverage	Main use in study
Primary field specimens	Author field survey	12	Chu Yang Sin National Park, upper Srepok River Basin	Morphology, habitat description, developmental-stage interpretation and local occurrence mapping
Secondary occurrence records	GBIF/iNaturalist	18	Viet Nam	Regional distribution mapping and exploratory environmental characterization
Combined occurrence dataset	Primary field records + secondary occurrence records	30	Chu Yang Sin / upper Srepok and wider Viet Nam	Exploratory distribution mapping and spatial environmental context

Note. Primary records represent author-documented *Phallus* specimens from Chu Yang Sin National Park. Secondary GBIF/iNaturalist records are georeferenced occurrence records and were not treated as author-collected field samples. The combined dataset was used only for exploratory mapping and environmental-context analysis.

3.4 Environmental dataset integration

Occurrence records were correlated to open environmental data of the rainfall, surface temperature, vegetation condition, soil moisture and land-surface hydrology. The precipitation input was represented by CHIRPS rainfall, the surface thermal condition was represented by MODIS land surface temperature and vegetation greenness and productivity was represented by MODIS NDVI/EVI. The variables used for SMAP were surface soil moisture and root-zone soil moisture, and ERA5-Land variables were used for the other aspects of the meteorology and hydrology. This integration was used to set up the environmental variables for site-level comparison of *Phallus* occurrence with rainfall, thermal conditions, vegetation cover, soil-water availability, runoff, evapotranspiration and atmospheric conditions.

3.5 Exploratory environmental interpretation

The field and spatial data indicate that the morpho-type of *Phallus* species recorded was most closely correlated with moist, shaded and litter rich habitats. There were no significant trends in primary records by microhabitat type, except that they tended to be high in forested microhabitats with decomposing organic matter, rotting wood, canopy shade and damp soil conditions. All secondary occurrence records added context to the regional distribution and helped to broaden mapping of *Phallus* occurrence in Viet Nam. These secondary records were not as detailed with habitat data, morphology or information on developmental stage and were therefore used primarily to interpret the ecology of the primary field specimens. The concept of environmental pattern was thus understood as exploratory associations instead of causal or predictive ones.

3.6 Data quality and interpretation limits

However, the results must be interpreted with caution since there were only 12 primary field specimens collected by the authors in Chu Yang Sin National Park. The distribution dataset was extended extended to 30 occurrence records by adding 18 secondary records from secondary GBIF/iNaturalist data, these data were not gathered by the authors and lacked detailed information on morphology, habitat and developmental stage. A few primary field coordinates needed to be validated prior to environmental extraction within GIS due to the non-standard coordinate format used in their recording. It is therefore appropriate that the joined dataset is appropriate for exploratory mapping

and environmental characterization, but not for robust species distribution modelling and causal inference of hydrological and meteorological controls of the occurrence of *Phallus*.

4. Discussion

This study aims to give an exploratory field-environmental interpretation of the occurrence of *Phallus* in the upper Srepok River Basin based on the primary biological data collected in Chu Yang Sin National Park and supplementary data from secondary records in the region. For morphotypes recorded during the first phase of field observations, the results were primarily related to wet, shady and organic rich forest microhabitats. These were: thick litter, wet forest floor, humus-rich soil, decaying wood, decaying grass stems, organic debris and slightly shaded forest borders. Egg forms to semi-mature and mature fruiting bodies as observed in the field, suggest that the local habitat conditions enabled the fruiting bodies to progress through several stages of development. This indicates that moisture retention, canopy protection and decomposition of organic substrates are important ecological characteristics for the emergence and survival of the fruiting bodies of *Phallus* in this tropical upland basin.

The fungal distribution patterns are similar to those reported by previous macrofungal studies that reveal that habitat structure, vegetation composition, moisture, and microenvironmental variation are significant factors affecting the occurrence and diversity of fungi. Macrofungal studies in southern Vietnam have also highlighted the need for in situ documentation of specimens to support the understanding of the diversity of fungi in the region (Lee et al., 2020). The conservative classification of these specimens as morphotypes of *Phallus* sp. is also confirmed by the wider research of the Phallales, which shows the need for molecular phylogenetic data as a tool for reliable species delimitation in the Phallales (Melanda et al., 2021). The relationship between the specimens and overcast forest habitats is in accordance with the evidence for how topography, light availability and forest partitioning can influence macrofungal distribution (Y. Chen et al., 2018). The study of macrofungal diversity with the main environmental factors in forest ecosystems, which is related to the use of environmental variables like temperature, rainfall, vegetation condition and soil moisture, is also supported (Tuo et al., 2022). The high proportion of reoccurrence of specimens in both litter rich and vegetation covered habitats is similar to those reported by Joshi, Adhikari, Aryal, & Shrestha (2022), which showed the variation in macrofungal assemblage due to different vegetation types. Additionally, soil-water availability also has a strong focus on it, aligns with the riparian fungal studies, which indicated soil-water can affect fungal community composition along watershed gradients (Zhou et al., 2022). The perception of moisture retentive habitats as good habitat for fungi was consistent with the findings that natural moisture gradients influence soil fungal communities (X. Chen et al., 2023). The distribution pattern of the combined occurrence dataset is also consistent with previous research that indicated macrofungal diversity and distribution patterns change across primary forest environments and environmental gradients (Han et al., 2023).

It enhances the spatial interpretation of the study and still preserves the authorship of the primary field records from external occurrence records, which are georeferenced. The distribution map indicates that the majority of the records are from the Chu Yang Sin/upper Srepok area while the secondary records are a wider regional context throughout Viet Nam. It is helpful for initial biodiversity assessments as it provides an increased spatial frame to interpret, while not adding to the number of specimens collected. The open environmental datasets also support the ecological interpretation by providing a connection between the occurrence of fungi and the input rainfalls, vegetation greenness, land-surface temperature, soil moisture, runoff and evapotranspiration. This enhances the quality of the study, which is not purely descriptive, but still allows for exploration of the subject.

Results are relevant to fungal biodiversity monitoring of river-basin landscapes in the tropics. The presence of *Phallus* fruiting bodies is also highly sensitive to local moisture and substrate conditions, and is short-lived, meaning that it may be a reflection of fine scale habitat quality not reflected in broad land cover classes. The study indicates that the areas of the upper Srepok landscape which are partially shaded, with a high litter content and high moisture holding capacity may serve as significant habitat for saprotrophic macrofungi. These habitats may be susceptible to fragmentation of forest,

agricultural encroachment, opening the forest canopy, and changes in hydrological patterns. Thus, the field morphology, occurrence mapping and open environmental data sets can offer a useful baseline for climate-sensitive and habitat sensitive fungi in the poorly documented tropics of biodiversity.

The size of the sample was the major constraint as only twelve field specimens were available from the Chu Yang Sin National Park. Secondary GBIF/iNaturalist records increased the extent of the mapping data, but they showed little information of the habitat, morphology, or developmental stage of the data and are not considered to be author-collected. A few of the primary coordinates also needed to be verified before final extraction for GIS, as some were entered in non-standard coordinate format. Microhabitat variables such as litter depth, substrate quality, canopy shade and wood decay stage and plot-level soil moisture are also difficult to quantify from satellite and reanalysis data, and are therefore not fully represented at landscape scales. Future studies should expand on the verified field sampling, incorporate direct microclimatic measurements and expand on the DNA-based identification.

5. Conclusion

Morphotypes of the Recorded *Phallus* species were predominantly linked to moist, shaded and organic-rich forest microhabitats in the upper Srepok River Basin at Chu Yang Sin National Park. The 12 main field specimens recorded a valuable developmental sequence, ranging from immature egg forms through to semi-mature fruiting bodies and mature forms with typical stinkhorn characters like a volva, a pileus covered with gleba, and, in some, an indusium. Species-level identification is provisional, due to a lack of molecular confirmation; the specimens are best viewed as *Phallus* sp. or *Phallus* morphotypes.

Eighteen additional secondary occurrence records from GBIF/iNaturalist were added, giving a spatial context of 30 occurrence records for exploratory distribution mapping in Viet Nam. Occurrence patterns were interpreted within a landscape scale context provided by open environmental data, such as rainfall, land surface temperature, vegetation indices, soil moisture and reanalysis-based hydrological variables. The results indicate that moisture is an important habitat characteristic for *Phallus* emergence, as is canopy shade and decomposing substrates. But sample size was small, environmental measurements were not available at the plot level, and the coordinates were not precise. Future studies need to cover a broader field sample, confirmed GPS locations and direct measurements of microclimate confirmed by DNA identification.

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