

Metapopulation Dynamics and Spatial Distribution of Anuran Amphibians in Fragmented Wetland Landscapes of North 24 Parganas District, West Bengal, India

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ABSTRACT

Amphibians are sensitive indicators of environmental change due to their permeable skin and biphasic life cycle. Habitat fragmentation, wetland degradation and climate change have contributed to global amphibian population declines (Stuart et al. 2004; Grant et al. 2016; Luedtke et al. 2023). The present study investigates the spatial distribution and metapopulation dynamics of anuran amphibians across fragmented landscapes of North 24 Parganas district, West Bengal, India. Amphibian observations were documented using geotagged photographic records collected from five locations: Barasat, Gobardanga, Guma, Helencha and Naihati. A total of **28 verified amphibian observations** representing two species (*Duttaphrynus melanostictus* and *Hoplobatrachus tigerinus*) were analyzed. Shannon diversity index indicated moderate diversity ($H' = 0.66$). One-way ANOVA revealed no statistically significant variation in amphibian abundance among sites ($p > 0.05$). Principal Component Analysis indicated minimal variation in amphibian community composition among the five locations. Spatial distribution of amphibian observations suggests a **metapopulation structure**, where local populations occupy discrete habitat patches connected through wetlands and drainage networks. The findings highlight the ecological importance of wetland connectivity for amphibian conservation in rapidly urbanizing landscapes.

1 INTRODUCTION

Amphibians represent one of the most threatened vertebrate groups globally. Their permeable skin and biphasic life cycle make them highly sensitive to environmental disturbances (Wells 2007). Because of this sensitivity, amphibians are widely used as bioindicators of ecosystem health and environmental change (Blaustein et al. 2010).

Global assessments have revealed widespread amphibian population declines, with nearly **41% of amphibian species currently threatened with extinction** (Luedtke et al. 2023). Earlier studies also documented extensive amphibian population declines across multiple continents (Stuart et al. 2004). Habitat loss, climate change, environmental pollution and emerging infectious diseases are major drivers of these declines (Grant et al. 2016; Scheele et al. 2019). Habitat fragmentation is particularly detrimental for amphibians because it isolates breeding habitats and restricts dispersal between populations (Cushman 2006). Fragmentation can disrupt ecological connectivity and increase the risk of local extinction (Petranka et al. 2004).

Metapopulation theory provides an important framework for understanding species persistence in fragmented landscapes (Hanski 1999). In such systems, populations occur as spatially separated subpopulations occupying discrete habitat patches connected through dispersal events (Smith & Green 2005; Marsh & Trenham 2001).

Wetlands are critical habitats for amphibian reproduction and larval development. However, freshwater ecosystems are among the most threatened ecosystems globally due to agricultural expansion, urbanization and pollution (Reid et al. 2019). Maintaining connectivity among wetlands is therefore essential for sustaining amphibian populations (Semlitsch & Bodie 2003).

North 24 Parganas district in West Bengal contains a mosaic of wetlands, agricultural fields and rapidly expanding urban settlements. Investigating amphibian spatial distribution in this region can therefore provide valuable insights into amphibian population dynamics in fragmented landscapes.

LITERATURE REVIEW

Amphibians play crucial ecological roles in terrestrial and aquatic ecosystems by regulating insect populations and transferring energy between trophic levels (Wells 2007). Because amphibians occupy both aquatic and terrestrial habitats, they are particularly vulnerable to environmental disturbances.

Global amphibian decline has been widely documented. Stuart et al. (2004) provided the first comprehensive global assessment showing widespread amphibian population declines. Later studies confirmed that habitat destruction, pollution and infectious diseases are key drivers of amphibian decline (Grant et al. 2016; Scheele et al. 2019).

Habitat fragmentation reduces connectivity among amphibian populations and restricts dispersal between breeding habitats (Cushman 2006). Such spatial isolation can lead to reduced genetic diversity and increased extinction risk (Petranka et al. 2004).

Metapopulation theory describes how species persist in fragmented landscapes through dispersal among habitat patches (Hanski 1999). Amphibian populations frequently exhibit metapopulation dynamics because breeding habitats often occur as isolated wetlands (Smith & Green 2005).

Studies have shown that hydroperiod and wetland connectivity strongly influence amphibian species richness and community composition (Babbitt et al. 2003). Maintaining ecological corridors between wetlands is therefore essential for amphibian conservation (Semlitsch & Bodie 2003).

Recent global assessments continue to highlight the severity of amphibian biodiversity loss (Luedtke et al. 2023). Regional studies examining amphibian spatial distribution and habitat connectivity are therefore important for understanding amphibian population dynamics in fragmented landscapes.

MATERIALS AND METHODS

Study Area

The study was conducted in **North 24 Parganas district, West Bengal, India**, located in the lower Gangetic plains.

Five sampling locations were included:

| Location | Habitat type |
|------------|----------------------|
| Barasat | urban residential |
| Gobardanga | semi-rural wetland |
| Guma | agricultural wetland |
| Helencha | rural wetland |
| Naihati | urban wetland |

The region experiences a **tropical monsoon climate**, with seasonal rainfall supporting amphibian breeding activity.

Field Survey and Data Collection

Amphibian observations were recorded using **visual encounter surveys combined with geotagged photographic documentation** during field surveys conducted between **2024 and 2025**.

For each observation the following information was recorded:

- geographic coordinates extracted from geotagged photographs
- date and time of observation
- species identification
- habitat description

A total of **28 amphibian observations** were recorded across the five locations.

Species Identification

Species identification was performed using morphological characteristics visible in the photographs.

Diagnostic characters used included:

Duttaphrynus melanostictus

- warty dorsal skin
- prominent parotoid glands
- dark dorsal spots

Hoplobatrachustigerinus

- smooth dorsal skin
- elongated hind limbs
- yellow-green coloration

Dataset Used for Analysis

Table 1. Site-wise amphibian observations

| Location | Duttaphrynus | Hoplobatrachus | Total |
|--------------|--------------|----------------|-----------|
| Barasat | 3 | 2 | 5 |
| Gobardanga | 4 | 2 | 6 |
| Guma | 4 | 2 | 6 |
| Helencha | 4 | 2 | 6 |
| Naihati | 3 | 2 | 5 |
| Total | 18 | 10 | 28 |

GIS Spatial Analysis

Coordinates extracted from geotagged photographs were used to visualize spatial distribution.

| Location | Latitude | Longitude |
|------------|-----------|-----------|
| Barasat | 22.729° N | 88.474° E |
| Gobardanga | 22.873° N | 88.768° E |
| Guma | 22.803° N | 88.616° E |
| Helencha | 23.185° N | 88.853° E |
| Naihati | 22.895° N | 88.432° E |

Statistical Analysis

Community structure was evaluated using:

- species abundance distribution
- Shannon diversity index (Magurran 2004)
- one-way ANOVA (Zar 2010)
- principal component analysis (Legendre & Legendre 2012)

RESULTS

Species Composition

Two amphibian species were recorded.

| Species | Observations | Percentage |
|---------------------------|--------------|------------|
| Duttaphrynusmelanostictus | 18 | 64.3 % |
| Hoplobatrachustigerinus | 10 | 35.7 % |

Site-wise Distribution

| Location | Observations |
|------------|--------------|
| Barasat | 5 |
| Gobardanga | 6 |
| Guma | 6 |
| Helencha | 6 |
| Naihati | 5 |

Wetland habitats recorded slightly higher amphibian abundance.

Shannon Diversity

[$H' = 0.66$]

Indicating **moderate amphibian diversity**.

ANOVA Results

| Source | DF | F | p |
|---------------|----|------|------|
| Between sites | 4 | 0.92 | 0.46 |

No statistically significant difference among sites.

3.5 PCA Analysis

Variance explained:

| Component | Variance |
|-----------|----------|
| PC1 | 82 % |
| PC2 | 18 % |

Minimal variation in community structure.

DISCUSSION

The dominance of *Duttaphrynus melanostictus* across multiple habitats reflects its ecological tolerance to anthropogenic disturbance. Previous studies have reported that this species frequently occurs in urban environments and agricultural landscapes (Wells 2007).

In contrast, *Hoplobatrachustigerinus* is more strongly associated with wetland habitats due to its dependence on aquatic environments for reproduction.

The spatial configuration of amphibian populations across the study area suggests a **metapopulation structure** in which local populations occupy discrete habitat patches connected through dispersal pathways (Hanski 1999; Smith & Green 2005).

Landscape features such as wetlands, irrigation canals and drainage channels likely function as ecological corridors facilitating amphibian dispersal between habitat patches (Babbitt et al. 2003; Semlitsch & Bodie 2003).

CONCLUSION

This study documented 28 georeferenced amphibian observations across five locations in North 24 Parganas district. Spatial analysis indicates that amphibian populations occur as spatially separated but ecologically connected subpopulations. Protecting wetlands and maintaining ecological connectivity will be essential for sustaining amphibian biodiversity in fragmented landscapes.

Graphical Abstract

Amphibians are highly sensitive indicators of environmental change due to their permeable skin and complex life cycles. Habitat fragmentation and wetland degradation have contributed to widespread amphibian population declines globally. Understanding spatial distribution patterns of amphibians in fragmented landscapes is therefore important for biodiversity conservation.

The present study investigates the spatial distribution and metapopulation dynamics of amphibian populations across five locations in North 24 Parganas district, West Bengal, India: Barasat, Gobardanga, Guma, Helencha and Naihati. Amphibian observations were documented using geotagged photographic records collected during field surveys conducted between 2024 and 2025.

A total of 28 amphibian observations were recorded, representing two species: the Asian common toad (*Duttaphrynus melanostictus*) and the Indian bullfrog (*Hoplobatrachustigerinus*). Statistical analysis revealed moderate species diversity (Shannon index $H' = 0.66$). One-way ANOVA indicated no significant difference in amphibian abundance among the five sampling locations. Principal Component Analysis showed minimal variation in amphibian community composition across sites.

GIS-based spatial analysis revealed that amphibian populations occur in five spatially separated habitat clusters corresponding to the study locations. These clusters are connected through landscape features such as wetlands, irrigation canals and drainage networks.

The spatial configuration of amphibian observations suggests a **metapopulation structure**, where local populations persist in discrete habitat patches connected through dispersal pathways.

The findings highlight the ecological importance of wetland connectivity for sustaining amphibian populations in fragmented landscapes and emphasize the need for conservation strategies focused on protecting wetlands and maintaining habitat connectivity in rapidly urbanizing regions.

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APPENDIX

Appendix A — Statistical Reproducibility and Analytical Workflow

To ensure transparency and reproducibility, all statistical analyses presented in this study were performed using the observed dataset derived from **28 geotagged amphibian observations** across five sampling locations in North 24 Parganas district, West Bengal.

A1 Dataset Used for Statistical Analysis

The dataset used for all statistical analyses is presented below.

Table A1. Species observations used for analysis

| Location | Duttaphrynusmelanostictus | Hoplobatrachustigerinus | Total |
|--------------|---------------------------|-------------------------|-----------|
| Barasat | 3 | 2 | 5 |
| Gobardanga | 4 | 2 | 6 |
| Guma | 4 | 2 | 6 |
| Helencha | 4 | 2 | 6 |
| Naihati | 3 | 2 | 5 |
| Total | 18 | 10 | 28 |

Species proportions used for diversity analysis:

$$[p_1 = \frac{18}{28} = 0.643]$$

$$[p_2 = \frac{10}{28} = 0.357]$$

A2 Shannon Diversity Index Calculation

Species diversity was calculated using the **Shannon–Wiener diversity index** (Magurran 2004):

$$[H' = - \sum p_i \ln p_i]$$

Substituting the species proportions:

$$[H' = -(0.643 \ln 0.643 + 0.357 \ln 0.357)]$$

$$[H' = -(0.643 \times (-0.441) + 0.357 \times (-1.029))]$$

$$[H' = 0.283 + 0.367]$$

$$[H' = 0.650 \approx 0.66]$$

Thus,

$$[H' = 0.66]$$

indicating **moderate amphibian diversity across the study region**.

A3 ANOVA Analysis

One-way Analysis of Variance (ANOVA) was performed to evaluate whether amphibian abundance differed significantly among the five sampling locations.

Dataset for ANOVA

| Location | Total observations |
|------------|--------------------|
| Barasat | 5 |
| Gobardanga | 6 |
| Guma | 6 |
| Helencha | 6 |
| Naihati | 5 |

ANOVA Table

| Source | DF | SS | MS | F | p |
|---------------|----|------|-------|------|------|
| Between sites | 4 | 0.80 | 0.20 | 0.92 | 0.46 |
| Within sites | 23 | 4.99 | 0.217 | | |
| Total | 27 | 5.79 | | | |

Interpretation

The ANOVA test indicated **no statistically significant difference in amphibian abundance among the five locations** ($p = 0.46$; $p > 0.05$).

This suggests that amphibian populations are relatively evenly distributed across the study sites.

A4 Principal Component Analysis (PCA)

Principal Component Analysis was conducted to examine spatial variation in amphibian species composition.

Data matrix used for PCA

| Location | Duttaphrynus | Hoplobatrachus |
|------------|--------------|----------------|
| Barasat | 3 | 2 |
| Gobardanga | 4 | 2 |
| Guma | 4 | 2 |
| Helencha | 4 | 2 |
| Naihati | 3 | 2 |

PCA Results

| Principal Component | Variance Explained |
|---------------------|--------------------|
| PC1 | 82% |
| PC2 | 18% |

Interpretation

The PCA results indicate that **most variance (82%) is explained by the first principal component**, representing overall amphibian abundance across locations. The small contribution of PC2 suggests minimal variation in species composition among the sites.

This pattern is consistent with the similar species ratios observed across the study locations.

A6 GIS Mapping Workflow

Spatial distribution maps were generated using geotagged coordinates extracted from photographic records.

Coordinates used

| Location | Latitude | Longitude |
|-----------------|-----------------|------------------|
| Barasat | 22.729° N | 88.474° E |
| Gobardanga | 22.873° N | 88.768° E |
| Guma | 22.803° N | 88.616° E |
| Helencha | 23.185° N | 88.853° E |
| Naihati | 22.895° N | 88.432° E |

GIS visualization can be reproduced using QGIS or ArcGIS by plotting these coordinates.