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RESEARCH ARTICLE

SPATIAL AND SEASONAL DYNAMICS OF PLANT PATCHES: A STUDY OF BIODIVERSITY AND SOIL VARIABILITY ALONG THE ASMAVATI RIVERFRONT

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ABSTRACT

Patch dynamics play an important role in shaping plant communities by influencing biodiversity, species interactions, and ecological resilience. The stability of patches is highly influenced by environmental disturbances such as seasonal variations, soil composition changes, and human-induced alterations. Thus, the knowledge of structural and functional differences between homogeneous and heterogeneous patches is critical for biodiversity conservation and ecosystem management. This study assesses species composition, biodiversity, and soil properties across homogeneous and heterogeneous patches along the Asmavati Riverfront, Porbandar. It evaluates seasonal variations in species abundance, richness, and connectivity while analysing the influence of environmental factors on patch stability. The key ecological parameters measured were the Perimeter-Area Ratio, Shape Index, and Nearest Neighbour Distance; phytosociological features included Shannon-Weiner Diversity Index and Simpson's Diversity Index. The patch dynamics of a site also related to the soil physicochemical properties like pH, temperature, and water-holding capacity. The results show that heterogeneous patches have higher species richness, ranging from 11 to 15 species. The Shannon-Weiner Index was higher in heterogeneous patches (1.742 to 2.062) than in homogeneous patches (0.624 to 0.673), showing greater ecological stability. Soil pH varied between 7.2 in winter and 9.5 in summer, and water-holding capacity decreased from 40% to 16% in some patches. The ANOVA results showed that the seasonal variations were significant, especially in species abundance ($F = 8.25$, $p < 0.01$) and soil temperature ($F = 56.64$, $p < 1.02 \times 10^{-7}$). These results indicate the ecological benefits of patch heterogeneity in maintaining biodiversity and resilience, emphasizing the need for conservation strategies that prioritize diverse habitat structures to ensure long-term ecosystem sustainability.

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1.INTRODUCTION

1.1General Overview of Ecological Dynamics: Ecological dynamics that mean it is a process of change and interaction which gives shape to ecosystems and plant communities. These dynamics are carried by internal factors like species interactions, competition for resources, reproductive cycles and external influences, including environmental conditions and disturbances, such as the processes described by Tilman (1982), and Pickett & White, 1985. Ecosystems are not stable; they constantly alter in response to change in climate, species behaviour and environmental disturbances (Folke *et al*., 2004). Such changes are significant for sustaining balance and functions in ecosystems and allowing them to persist in the performance of necessary ecosystem services including nutrients cycling, water regulation, and habitat provision (Chapin *et al*., 2002). The different types of vegetative plant patches are two in number, that is Homogeneous Patch and Heterogeneous Patch. In Homogenous patch that where one type of species is present while in heterogeneous patch that where varies type of species are present (Levin, 1992). Plant patches are important in ecological studies because they represent spatial units for analysing plant distribution, diversity, interactions and responses to environmental factors like distribution, diversity, interactions and responses to environmental factors like disturbances like fire, flood, grazing or human activity (Turner, 1989). Plant patches provide microhabitats for a range of species, hence supporting diverse plant, animal and microbial communities. (Forman & Godron, 1986). Plant patches are therefore very important for ecosystem functionality because they enhance resilience, support nutrient cycling, and contribute to food web stability. A plant patch is a relatively small and discrete area. Depending on the type of plant, plant patch have a various type of shape and size. (Forman & Godron, 1986). The high contents of soil nutrients and microbial activity make it able to ameliorate harsh climatic conditions, improve soil moisture conditions, and may also provide shelter against herbivores (Aguiar & Sala, 1999; Schlesinger *et al*., 1990).

1.2 Key components of ecological dynamics: Ecological dynamics consist of several major components that shape the structure and function of plant patches in an ecosystem. Species interactions, which include competition, mutualism, and predation, are major factors in the determination of plant communities. Competition occurs when species compete for limiting resources such as light, water, and nutrients, often resulting in dominance by some species and changes in plant structure (Tilman, 1982; Connell, 1983). On the other hand, mutualistic relationships between plants and pollinators or mycorrhizal fungi enhance growth and biodiversity within plant patches (Bronstein, 1994; Smith & Read, 2008). Resource availability, including sunlight, water, nutrients, and space, significantly impacts plant patch dynamics. Resource-rich zones support a large number of diverse patches while resource-poor areas may host some specialized species that tolerate extreme conditions, resulting in a mosaic of patches across an ecosystem (Schlesinger *et al*., 1990; Loreau *et al*., 2001). Ecological succession then influences the pattern of plant patches through time since pioneer, fast-growing, and light-dependent species dominate disturbed sites while competitive, long-lived species predominate mature ecosystems (Connell & Slatyer, 1977). This process modifies the composition and structure of patches of plants within ecosystems as it heals or matures.

The ecological roles of patches of plants in ecosystems are manifold. They improve habitat diversity because they provide many microhabitats, shelter, and food sources that are integral in supporting the diversity of fauna (Forman & Godron, 1986; Wiens, 1989). Dense shrub patches may be used as bird nests, whereas open grass patches are foraging grounds for herbivores and thus support biodiversity at multiple trophic levels (Fischer *et al*., 2006). Plant patches also play an important role in nutrient cycling by absorbing nutrients from the soil through roots and replenishing it with processes such as leaf litter decomposition and root exudation. This guarantees the presence of key nutrients like nitrogen and phosphorus, which are vital for the sustenance of life (Schlesinger *et al*., 1990). Furthermore, these patches serve as a source of food, shelter, and breeding grounds for many organisms, thereby creating interdependence among species and contributing to the complexity and balance of the ecosystem (Forman & Godron, 1986; Holling, 1992). Finally, plant patches increase the stability and resilience of the ecosystem by promoting biodiversity and ecological interactions. Diverse patches help ecosystems survive better during disturbance, such as droughts or fires, and recover faster and thus maintain ecosystem services such as nutrient cycling, water regulation, and habitat provision. Altogether, these dynamic processes and roles underpin the importance of plant patches in keeping the health, stability, and sustainability of an ecosystem.

1.3 Environmental disturbances and its impact: Natural (fire, flood, drought) as well as anthropogenic (clear-cutting, urbanization, pollution) forms of environmental disturbance disrupt ecosystem functions, causing change in species composition, resource availability, and structure (Pickett & White, 1985; Turner, 2010). Some disturbances alter patch dynamics in a way that opportunist species come to dominate by creating regeneration windows and influencing some critical ecosystem functions such as carbon sequestration and water quality (Chapin *et al*., 2009). In certain specific study areas, the disturbances of agricultural expansion, urbanization, and climate change exacerbate habitat fragmentation, biodiversity loss, and shifts in ecosystem processes (Fahrig, 2003), which affect the resilience of plant communities (Holling, 1973). Understanding the connection of disturbance and ecological resilience can be significant in determining the ecosystem's health (Folke *et al*., 2010). Resilient ecosystems adapt to disturbances and recover functions while maintaining essential ecosystem services (Holling, 1973). Studying plant patches reveals recovery patterns and adaptive mechanisms, informing conservation strategies and enhancing ecosystem sustainability (Seidl *et al*., 2016). Globally, disturbances such as altered fire regimes in grasslands and deforestation in tropical forests disrupt biodiversity and ecological balance (Turner, 2010).

Locally, disturbances driven by human activities and climate shifts influence species composition and ecosystem processes (Chapin *et al*., 2009), emphasizing the need for tailored conservation and restoration efforts to support regional ecological dynamics (Folke *et al*., 2010). From previous studies on ecological dynamics and disturbances, a good understanding of the response of various ecosystems to natural and anthropogenic disruptions has been achieved. It has been extensively documented how fire, invasive species, and habitat fragmentation affect plant communities in various ecosystems. There are still important gaps in the understanding of how local plant patches in the study area respond, especially how they interact with recent environmental changes. There is very little information available concerning the thresholds above which these systems can no longer maintain resilience or how multiple disturbances might cause a cascade effect over plant patches. Filling this gap is, therefore, vital for the full development of knowledge on ecosystem response at both the micro and the macro scales.

This study aims to investigate species composition and biodiversity between homogeneous and heterogeneous plant patches along the Asmavati Riverfront, Porbandar, while analysing the influence of natural environmental disturbances on patch structure, species diversity, and ecological resilience. It wishes to converse on this patch's stability in comparing different seasons together with their rich diversity. The study examines the physicochemical properties of soil like pH, temperature, and water-holding capacity across patches regarding seasonal variation. The study's findings also discuss patch connectivity and fragmentation using spatial metrics and viability of these as factors in ecosystem sustainability.

2. STUDY AREA

Porbandar is situated in the western part of Kathiawar peninsula on the Arabian sea coast. Asmavati riverfront is situated in western part of Porbandar city (Figure 1). Homogeneous and heterogeneous patches are present along the Asmavati Riverfront (Table 1).

3.METHODOLOGY

3.1 Sampling and Data Collection: The site selected was the Asmavati riverfront that covers an area of 200 m². Data were collected in these patches during three seasons. The first collection was Monsoon, followed by winter, and the last one was in Summer.

Table 1. Coordinates of Homogeneous and Heterogeneous Patches

Number of patches	Patch Code	Coordinates
Homogeneous patch 1	HOMO1	69°37'57.15"E, 21°38'32.21"N
Homogeneous patch 2	HOMO2	69°37'58.63"E, 21°38'30.37"N
Homogeneous patch 3	HOMO3	69°37'58.44"E, 21°38'30.29"N
Heterogeneous patch 1	HETERO1	69°38'13.95"E, 21°38'14.02"N
Heterogeneous patch 2	HETERO2	69°38'15.42"E, 21°38'12.98"N
Heterogeneous patch 3	HETERO3	69°38'15.91"E, 21°38'12.57"N

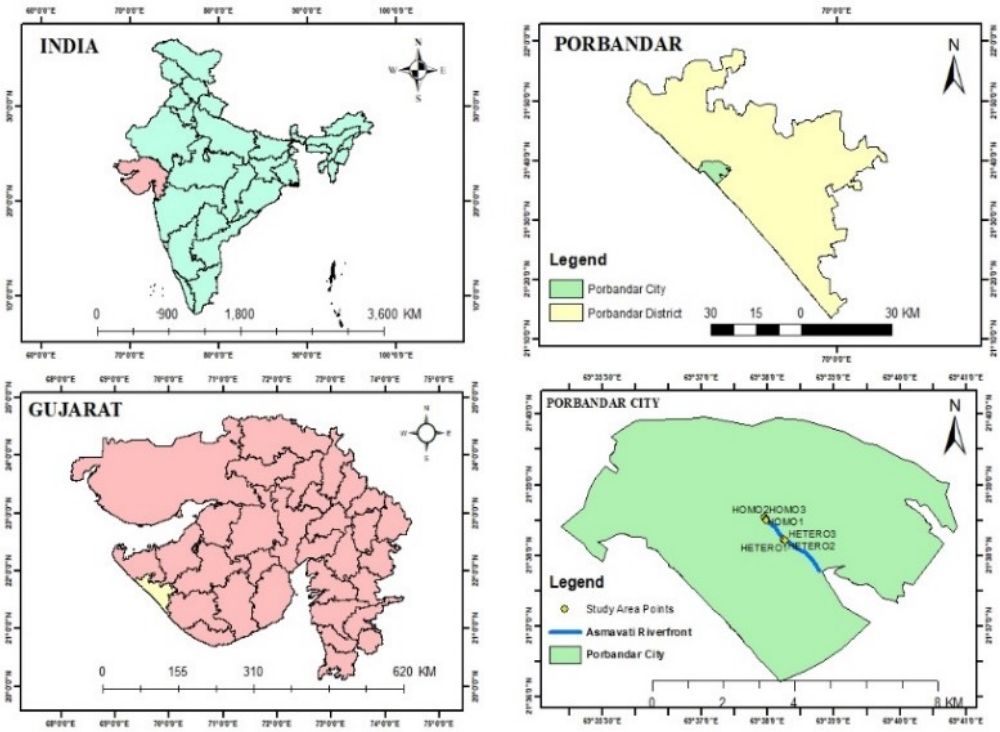


Figure 1. Study Area Map

The two types of patches chosen within this area include three homogenous patches and three heterogeneous patches of which metrics were collected. Each patch had three quadrats that were plotted. Patch size and shape were translated into a perimeter-area ratio, while shape complexity was reduced.

3.1.1 Patch size and shape: Metrics like the Perimeter-Area Ratio (PAR), Shape Index (SI), Nearest Neighbour Distance (NND), Nearest Neighbour Ratio (NNR), and Connectivity Index (CI) are crucial quantitative tools in landscape ecology for evaluating the spatial features and dynamics of habitat patches.

3.1.1.1 Perimeter Area Ratio (PAR): The Perimeter-Area Ratio (PAR) indicates the complexity of a patch's shape, where higher values suggest more irregular or fragmented patches that could be more susceptible to edge effects.

$$\text{PAR} = \frac{Perimeter}{Area}$$

3.1.1.2 Shape Index (SI): The Shape Index (SI) offers a numerical representation of a patch's geometric complexity, aiding in the assessment of whether a patch is compact or elongated, which can affect species movement and habitat suitability.

$$\text{SI} = \frac{0.25 \times Perimeter}{\sqrt{Area}}$$

A shape index value of 1 indicates a perfect circle, while values greater than 1 indicate increasingly irregular shapes.

3.1.2 Patch connectivity: Patch connectivity refers to how patches are connected or linked in the landscape. Connectivity influences species movement, gene flow and ecosystem functioning. Here're the measures:

3.1.2.1 Nearest Neighbour Distance (NND): Nearest Neighbour Distance (NND) measures the shortest distance from the focal patch to its closest neighbouring patch, reflecting the level of isolation or spatial arrangement of patches.

NND = $\frac{1}{n}\sum_{i=1} di$

Where, ***di*** is the distance from the centre of patch i to its nearest neighbouring patch.

3.1.2.2 Nearest Neighbour Ratio (NNR): Nearest Neighbour Ratio (NNR) compares the observed NND to what would be expected in a random distribution, helping to evaluate clustering patterns of patches.

NNR = $\frac{NND(observed)}{NND(expected)}$ [$NND_{expected} = 0.5 \times \frac{\sqrt{A}}{N}$]

Where, A= Total area, N= Number of patches

3.1.2.3 Connectivity Index (CI):

The Connectivity Index (CI) assesses the degree of ecological connectivity between patches, indicating how effectively species can disperse and interact throughout the landscape.

CI = $\frac{Nconnected}{Ntotal}$

Where, $N_{connected}$ =Number of connected patches, N_{total} = Number of patches. A higher CI value indicates greater connectivity between patches. A lower CI value indicates poor connectivity between patches. The low connectivity index suggests isolation of the patches.

3.2 Assessment of edaphic factors: Monitoring environmental variables helps correlate changes in patches with climatic conditions and disturbances. Soil temperature was measured at a depth of 10 to 15 cm using a soil thermometer. The soil thermometer was placed in the hole and left undisturbed for 10 minutes. Then, the temperature was checked on the thermometer. The soil pH was measured using a calibrated digital pH meter after the preparation of soil-water suspension. The Water Holding Capacity (WHC) was evaluated through the process of saturation of 25 gm air-dried soil with water and calculating the moisture retained after drainage. These processes were done for the soil of all patches.

3.3 Phytosociological Analysis: Ecological dynamics and the impacts of environmental disturbances on various plant patches, including homogeneous (similar species composition) and heterogeneous (diverse species composition) patches, were assessed by measuring several ecological parameters.

Here are key parameters, definitions and formulas used in this assessment. The importance of diversity and composition was reflected in changes in species diversity and composition, indicating habitat quality and response to environmental changes.

3.3.1 Frequency: The proportion of sample plots in which a species was found is called Frequency.

Frequency = $\frac{Total\ no.of\ quadrats\ in\ which\ the\ species\ occurs}{Total\ no.of\ quadrats\ sampled}$

3.3.2 Density: The number of individuals that were per unit area is called Density.

D = N / A

Where, N is the total number of individuals of a species, A is the area sampled.

3.3.3 Species Abundance (A): The number of individuals of each species that were found in a given area was called species Abundance.

Abundance = $\frac{Total\ no.of\ individuals\ of\ a\ species\ in\ all\ the\ quadrats}{Total\ no.of\ quadrats\ in\ which\ the\ species\ occured}$

3.3.4 Relative Abundance (RA): The proportion of individuals of a species relative to the total number of individuals of all species is called Relative Abundance.

RA= $\frac{\text{Abundance of a species}}{\text{Total abundance of all species}} \times 100$

3.3.5 Relative Density (RD): The proportion of density of a species that was relative to the total density of all species is called Relative Density.

RD = $\frac{\text{Density of a species}}{\text{Total density of all species}} \times 100$

3.3.6 Relative Frequency (RF): The proportion of frequency of a species relative to the total number of frequencies of all species.

RF = $\frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100$

3.3.7 Importance Value Index (IVI) = Relative frequency + Relative density + Relative abundance

3.4. Biodiversity Indices

3.4.1 Species Richness (S): Species richness (S) is the total number of species in given area.

3.4.2 Species Evenness (E): Species Evenness measures how evenly individuals are distributed among species in a community.

Species Evenness (E)= H'/ ln(S)

Where, H'= Shannon-Weiner Diversity Index, S= Species Richness

3.4.3 Shannon-Weiner Diversity Index (H'): A measure of species diversity in a community that is called Shannon wiener Diversity Index(H').

H'= - $\sum_{i=1}^{s} pi \times ln(pi)$

Where, *pi* is the proportion of individuals of species i

3.4.4 Simpson's Diversity Index (D): A measure of the probability that two individuals randomly selected from a sample would have belonged to the same species.

D = 1 - $\sum_{i=1}^{s} pi_2$

4RESULTS AND DISCUSSION

4.1 Patch metrics and Connectivity: These metrics are crucial for the understanding of patch dynamics because they affect species distribution, ecological interactions, habitat fragmentation, and landscape connectivity. High PAR and SI could mean that the habitat is more fragmented, reducing the quality of the habitat and increasing the edge effects. Low NND and high CI, on the other hand, suggest improved connectivity, which would allow species movement and genetic exchange. These metrics help researchers evaluate habitat resilience, develop conservation strategies, and predict changes in biodiversity due to urbanization or environmental changes.

Table 2. Patch metrics and connectivity

Patch Code	Perimeter (m)	Area (m^2)	PAR	SI	NND	NNR ($NND_{expected}=4.08$)	CI
HOMO1	20	25	0.8	1.13	48.94 m	12.0	0.33
HOMO2	20	25	0.8	1.13			
HOMO3	5	1.5	3.33	1.15			
HETERO1	6.5	1.875	3.47	1.34	48.40 m	11.86	0.66
HETERO2	6.5	1.875	3.47	1.34			
HETERO3	6.5	1.875	3.47	1.34			

The Table 2 outlines various metrics related to patch characteristics, including perimeter, area, perimeter-area ratio (PAR), shape index (SI), nearest neighbour distance (NND), nearest neighbour ratio (NNR), and connectivity index (CI). The patches are divided into two categories: HOMO (homogeneous) and HETERO (heterogeneous), with three patches listed under each type. Perimeter (m) and Area (m^2) indicate the boundary length and total surface area of each patch, respectively. Generally, HOMO patches are larger in area than HETERO patches. The Perimeter-Area Ratio (PAR) measures the complexity of a patch's shape, with higher values indicating more complex shapes. HOMO patches generally have lower PAR values, meaning that they are simpler in shape, whereas HETERO patches have higher PAR values, meaning that they are more complex in shape. Numerical values of the SI represent how complex the shape is. In other words, values closer to 1 denote a more compact and regular shape, like that of a square, and larger values suggest increased irregularity. HETERO patches have more significant SI values than HOMO patches. NND and NNR measure the spatial isolation of patches. A lower NND value means that the patches are close together and may affect ecological interactions. HOMO patches tend to have higher NND values, indicating larger distances apart, whereas HETERO patches seem to be more connected. The Connectivity Index (CI) indicates the connectivity between the patches. The more the patches are connected, the higher the CI would be. A higher CI value of 0.66 for HETERO (heterogeneous patches) shows that it is more ecologically functional and connected, while a low CI value of 0.33 for HOMO (homogeneous patches) indicates fragmentation and possible isolation. It therefore emphasizes the value of diverse land cover and ecological corridors in preserving landscape connectivity for conserving biodiversity. The results show that the size and shape of patches significantly influence the connectivity. More compact, larger patches, like those in the HOMO category, tend to be more isolated, showing higher NND values and lower connectivity. In contrast, smaller and more irregularly shaped patches, like those in the HETERO category, show higher connectivity.

Table 3: Homogeneous Patches with Patch Species

Patch Code	Patch Species	Family	Number of individuals		
			Monsoon	Winter	Summer
HOMO1	*Sphagneticola trilobata* (L.) Pruski	Asteraceae	772	613	596
HOMO2	*Crinum asiaticum* L.	Amaryllidaceae	73	69	66
HOMO3	*Alternanthera brasiliana* (L.) Kuntze	Amaranthaceae	114	103	92

Table 4. Heterogeneous Patches with Patch Species

Patch Code	Patch Species	Family	Number of individuals		
			Monsoon	Winter	Summer
HETERO 1	*Urochloa deflexa* (Schumach.) H.Scholz	Poaceae	233	/	/
	Sonchus oleraceus	Asteraceae	30	/	/
	Chloris barbata Sw.	Poaceae	39	/	/
	Chloris virgata Sw.	Poaceae	28	/	/
	Sonchus arvensis L.	Asteraceae	/	92	66
	Oxalis corniculata L.	Oxalidaceae	/	180	196
	Phyllanthus niruri L.	Phyllanthaceae	/	4	/
	Launaea nudicaulis (L.) Hook.f.	Asteraceae	/	2	4
	Portulaca quadrifida L.	Portulacaceae	/	5	/
	Asphodelus tenuifolius Cav.	Asphodelaceae	/	3	3
	Cynodon dactylon (L.) Pers.	Poaceae	/	59	13
	Cyanthillium cinereum (L.) H.Rob.	Asteraceae	/	54	12
	Portulaca oleracea L.	Portulacaceae	/	12	/
	Sonchus oleraceus L.	Asteraceae	/	/	12
	Euphorbia hypericifolia L.	Euphorbiaceae	/	/	2
HETERO 2	*Corchorus aestuans* L.	Malvaceae	13	/	/
	Cyanthillium cinereum (L.) H.Rob.	Asteraceae	97	66	58
	Cynodon dactylon (L.) Pers.	Poaceae	624	64	32
	Eragrostis viscosa (Retz.) Trin.	Poaceae	21	/	/
	Euphorbia hirta L.	Euphorbiaceae	22	/	/
	Asphodelus tenuifolius Cav.	Asphodelaceae	/	8	/
	Digitaria sanguinalis (L.) Scop.	Poaceae	/	26	6
	Portulaca quadrifida L.	Portulacaceae	/	65	/
	Euphorbia hypericifolia L.	Euphorbiaceae	/	7	6
	Launaea nudicaulis (L.) Hook.f.	Asteraceae	/	8	5
	Sonchus oleraceus L.	Asteraceae	/	/	43
	Sonchus arvensis L.	Asteraceae	/	/	43
	Euphorbia indica Lam.	Euphorbiaceae	/	/	1
HETERO 3	*Euphorbia hypericifolia* L.	Euphorbiaceae	4	13	/
	Launaea nudicaulis (L.) Hook.f.	Asteraceae	12	1	1
	Oxalis corniculata L.	Oxalidaceae	133	/	/
	Phyllanthus niruri L.	Phyllanthaceae	34	4	/
	Phyllanthus urinaria L.	Phyllanthaceae	12	/	2
	Cyanthillium cinereum (L.) H.Rob.	Asteraceae	/	49	37
	Cynodon dactylon (L.) Pers.	Poaceae	/	7	18
	Dinebra retroflexa (Vahl) Panz.	Poaceae	/	/	29
	Urochloa deflexa (Schumach.) H.Scholz	Poaceae	/	/	19
	Portulaca oleracea L.	Portulacaceae	/	/	88
	Urochloa reptans (L.) Stapf	Poaceae	/	/	2

Three families, three genera, and three species were identified in the uniform homogeneous patches (Table 3). *Asteraceae*, represented by *Sphagneticola trilobata*, was the most prevalent family throughout all seasons. *Sphagneticola trilobata* dominated during the monsoon, winter, and summer, due to its vigorous vegetative reproduction and ability to adapt to various environmental conditions. *Crinum asiaticum* and *Alternanthera brasiliana* showed relatively stable populations, suggesting resilience but limited growth compared to *Sphagneticola trilobata*. The monsoon conditions promoted rapid vegetative spread, winter conditions supported moderate growth, and summer survival was aided by deep rooting and drought resistance. A total of 10 families, 15 genera, and 22 species were identified in the diverse heterogeneous patches (Table 4). *Poaceae* emerged as the most dominant family throughout all seasons, thanks to its adaptability and C4 photosynthesis. During the monsoon, *Cynodon dactylon* was the leading species, while *Oxalis corniculata* took the lead in winter and summer. Monsoon species flourish due to the abundance of moisture, winter species thrive in cooler conditions with leftover soil moisture, and summer species have adaptations that help them withstand drought.

Table 5: Allied biodiversity measures for Homogeneous and Heterogeneous Patches

	Patch Code	HOMO1	HOMO2	HOMO3	HETERO1	HETERO2	HETERO3
NOI	**Monsoon**	772	73	114	330	777	195
	Winter	613	69	103	411	244	74
	Summer	596	66	92	308	194	196
Frequency	**Monsoon**	3	3	3	2.98	2.98	2.65
	Winter	3	3	3	5.63	4.97	3.65
	Summer	3	3	3	3.97	4.63	3.97
Density	**Monsoon**	30.88	24.52	23.84	176	414.4	104
	Winter	2.92	2.76	2.64	219.2	130.13	39.47
	Summer	76	68.67	61.33	164.27	103.47	104.53
Abundance	**Monsoon**	257.33	24.33	38	126.17	389.33	166.33
	Winter	204.33	23	34.33	323.66	113.33	28.16
	Summer	198.67	22	30.67	291.33	116.66	165
RF	**Monsoon**	33.33	33.33	33.33	34.61	34.61	30.78
	Winter	33.33	33.33	33.33	39.51	34.88	25.61
	Summer	33.33	33.33	33.33	31.58	36.83	31.58
RD	**Monsoon**	3.22	0.30	7.92	23.35	59.68	14.98
	Winter	3.12	0.35	8.75	56.38	33.47	10.15
	Summer	3.16	0.35	8.13	44.13	27.79	28.08
RA	**Monsoon**	80.50	7.61	11.89	18.50	57.10	24.39
	Winter	78.09	8.79	13.12	69.58	24.36	6.05
	Summer	79.04	8.75	12.20	50.84	20.86	28.80
IVI	**Monsoon**	117.06	41.25	53.15	78.46	151.39	70.15
	Winter	114.55	42.25	55.20	165.47	92.71	41.82
	Summer	115.54	42.44	53.67	126.55	84.99	88.46

4.3 Quantitative Phytosociological Attributes: The key observations and analysis from Table 5 indicate a general decline in individual population size and abundance in homogeneous patches over time. Lighter color shades represent decreases, while darker shades indicate increases. From 772 in Monsoon to 596 in Summer, a significant drop is seen in HOMO1. More population swings are observed in heterogeneous patches, wherein some patches, such as HETERO1, expand, and others, such as HETERO2, decline. In homogeneous patches, the species frequency remains static. In heterogeneous patches, it fluctuates with time, indicating that the environment is alive. Since there are more individuals in homogeneous habitats, the species density of homogeneous patches is always greater than for heterogeneous regions. With time, richness decreases in the homogenous area; for example, HOMO1 decreases significantly from Monsoon, being 257.33, and Summer was just 198.67. This is much richer in the heterogenous patchy area where variation is much greater, showing more dynamic diversity where it could even sustain population in different density variations. Trends have been distinctly delineated between the plots with heterogeneous patches and those with homogeneous patches according to the analysis (Table 5). Relative Frequency (RF), though generally stable at 33.33%, rises to a peak of 39.51% in winter, and drops to 31.58% in Summer for homogeneous patches. Relative Density (RD) essentially explains a downward trend from 3.22 in Monsoon to 3.12 during winter and still holds at the rate of 3.16 in Summer. Relative Abundance has declined from an average count of 257.33 species in Monsoon to as few as 198.67 species in Summer, which indicates lower availability of most species. Even the Importance Value Index declines downward from 117.06 during Monsoon to 115.54 during Summer, which once again indicates stress on the habitat. Population dynamics are more diverse in heterogeneous patches. RF-fluctuating patches fluctuate between the two heterogeneous patches: HETERO1 increased from 34.61% in Monsoon to 36.83% in Summer, and HETERO2 dropped from 30.78% to 31.58%. RD of HETERO1 increased from 23.35 in Monsoon to 44.13 during Summer, while HETERO2 dropped from 56.38 to 27.79. In terms of RA, HETERO1 increased from 59.68 in Monsoon to 57.10 in Summer, and HETERO2 declined from 24.36 to 20.86. II-based computations indicate that HETERO1 increased from 78.46 in Monsoon to 126.55 in Summer, while HETERO2 declined from 70.15 to 88.46. Patches, homogeneous in nature, steadily observe a decrease in abundance of species, heterogeneous patches on the other hand exhibit fluctuations thereby indicating less stress towards their populations. Their fluctuations open broader dynamics showing more responses toward change and, therefore, enhancing resilience in the ecosystem such as better adaptive capability, implying the importance of habitat diversity in fostering ecological integrity. To assess the influence of patch types and seasonal variations on ecological variables, a univariate Analysis of Variance (ANOVA) was conducted, and the F-values for each variable are visualized in the heatmap (Figure 2). The results indicate that patch type significantly affects all measured ecological variables, with particularly high F-values observed for Frequency ($F = 1.96 \times 10^{29}$, $p < 1.3 \times 10^{-144}$), Density ($F = 2.51 \times 10^{29}$, $p < 3.8 \times 10^{-145}$), and IVI ($F = 2.62 \times 10^{29}$, $p < 3.07 \times 10^{-145}$), suggesting substantial variation in vegetation structure across different patches. Seasonal variation also plays a critical role, significantly influencing NOI ($F = 148.0$, $p < 3.73 \times 10^{-8}$), RA ($F = 17.5$, $p < 5.42 \times 10^{-4}$), and Abundance ($F = 8.25$, $p < 7.66 \times 10^{-3}$), highlighting fluctuations in population dynamics and species abundance with changing seasons. Additionally, relative frequency (RF) and relative density (RD) exhibit highly significant effects for both patches and seasons, with p-values below 1.9×10^{-142}, reinforcing the idea that species distribution is influenced by both spatial heterogeneity and temporal shifts. The high statistical significance of these results underscores the heterogeneous nature of plant distribution across patch types and the impact of seasonality on species abundance and community structure. These observed variations may be attributed to differences in microhabitat conditions, resource availability, and phenological adaptations, further emphasizing the dynamic nature of ecological communities.

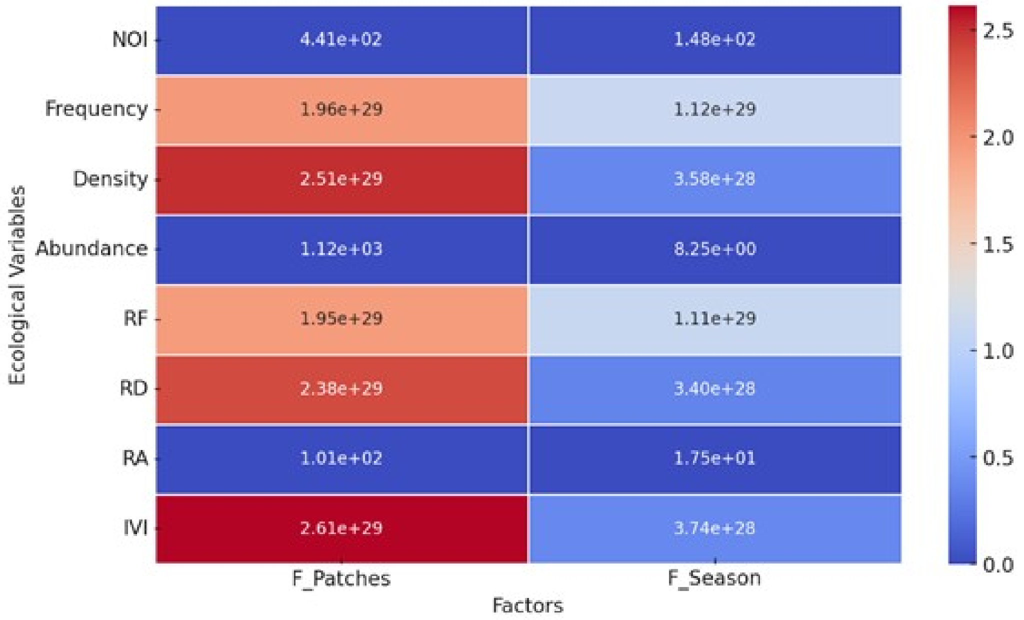
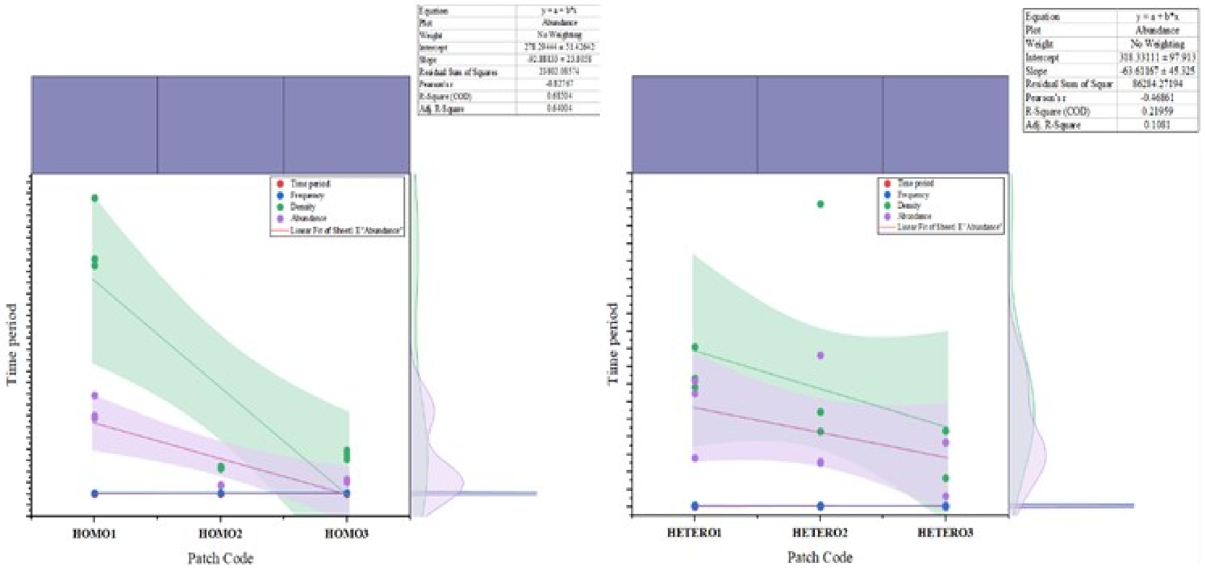


Figure 2. ANOVA matrix: F-values for Patch and Season effects

4.4 Comparative patch stability assessment



Equation	y = a + b*x
Plot	Abundance
Weight	No Weighting
Intercept	278.29444 ± 51.42642
Slope	-82.88833 ± 23.3058
Residual Sum of Squares	23402.00574
Pearson's r	-0.82767
R-Square (COD)	0.68504
Adj. R-Square	0.64004

Equation	y = a + b*x
Plot	Abundance
Weight	No Weighting
Intercept	318.33111 ± 97.913
Slope	-63.61167 ± 45.325
Residual Sum of Squar	86284.27194
Pearson's r	-0.46861
R-Square (COD)	0.21959
Adj. R-Square	0.1081

Figure 3. Population metrics for Homogeneous and Heterogeneous Patches

The linear regression analysis (Figure 3) reveals distinct trends in frequency, density, and abundance across the studied patch codes, with homogeneous patches represented on the left and heterogeneous patches on the right over the observed time period. X-axis specifies different patch types (HOMO1, HOMO2, HOMO3 for homogeneous patches; HETERO1, HETERO2, HETERO3 for heterogeneous patches). Y-axis shows the changing pattern observed with time (Figure 4). For all the abundance, density, and frequency, a color-in point represents each one. The trend lines from the linear regression are provided with the confidence intervals or the shaded areas to depict the trends observed in each parameter. Abundance, of both graphs is represented in purple; a clear negative slope thus depicts a decline across time. Density lies on the green line that continues to decline but at a milder gradient compared to the one of abundance. The frequency, light blue in color, seems relatively stable in both patches. The slope for the homogeneous patches from the left-hand graph is steeper, -29.8953, which indicates that there is significant population decline over time. The higher R^2 value, 0.68504, also suggests possibly a higher correlation between patch types with decreasing abundance. The heterogeneous patches from the right-hand graph shows less steep decline in abundance at -63.6116. Lower R^2 value (0.21959), indicating higher variability and weaker predictive power. The homogeneous patches on one side showed declines in abundance and density with greater rapidity than supports the contention of lower resilience to environmental disturbances. Species here are perhaps further prevented from survival because of monotony in habitat and resource availability. On the other hand, the relatively gentler slope of the heterogeneous patches indicates that survival and stability of species are more favourable. Diversity brings to light the buffer effect of resources and microhabitats on species from environmental fluctuations, thereby improving resilience. With this and relative difference in recovery after disturbance, it is found that, in general, the heterogeneous patches favor long-term survival and stability under changing environments than their homogeneous counterparts.

4.5 Soil physicochemical properties

Table 6. Soil Data of Homogeneous Patches and Heterogeneous Patches

Number of patches	Season	HOMO1	HOMO2	HOMO3	HETERO1	HETERO2	HETERO3
Soil pH	Monsoon	7.5	7	7.3	7.3	7	7.3
	Winter	7.2	9	8.1	8.7	8.3	8.2
	Summer	9.5	9	8.7	8	8.5	7.5
Soil Temperature	Monsoon	44°C	39.5°C	37.5°C	35.5°C	35°C	35.25°C
	Winter	29°C	26°C	26°C	24.5°C	23.5°C	24°C
	Summer	26°C	23°C	24°C	21°C	20.5°C	22°C
Water Holding Capacity %	Monsoon	40%	41%	56%	34%	34%	34%
	Winter	38%	40%	36%	40%	24%	30%
	Summer	48%	28%	24%	32%	14%	16%

The Table 6 represents water-holding capacity (WHC%), pH, and soil temperature in different heterogeneous (HETERO1, HETERO2, HETERO3) and homogeneous (HOMO1, HOMO2, HOMO3) patches from Monsoon to Summer. Light colour shade is showing drop while dark colour shade is showing enhancement in value. The trends show seasonal differences, which are probably caused by environmental elements as biological activity, moisture availability, and temperature swings. There are observed seasonal changes in soil characteristics from Monsoon to Summer including pH rise, declining soil temperature, and overall declining WHC. More pronounced differences are observed within homogeneous patches particularly for pH and WHC. This may be because uniform cover of vegetation controls moisture retention as well as cycling of nutrients. These patches are more uniform in their pH trend but show a more significant drop in WHC, possibly due to variations in plant cover and soil composition which would affect the moisture retention.

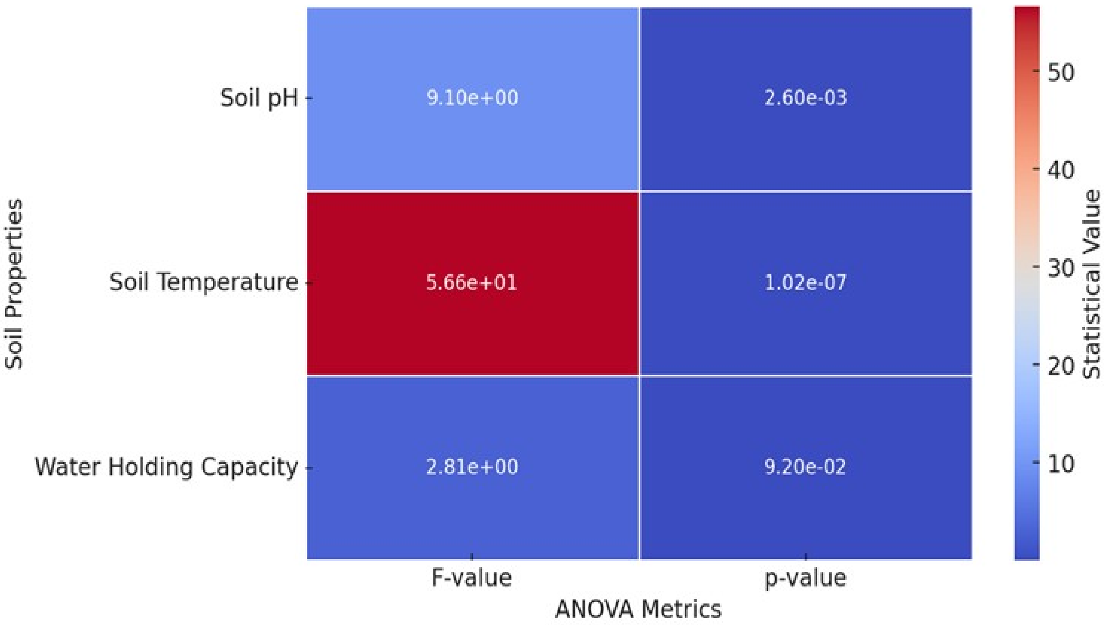


Figure 4. ANOVA matric: Effect of Season and Patch Type on soil properties

The results of the two-way ANOVA indicate significant effects of season and patch type on soil properties (Figure 4). Soil pH exhibited a statistically significant variation across seasons and patch types ($F = 9.10$, $p = 0.0026$), suggesting that both spatial and temporal factors influence soil acidity and alkalinity. Soil temperature showed the most pronounced variation ($F = 56.64$, $p < 1.02 \times 10^{-7}$), highlighting the substantial impact of seasonal fluctuations on thermal properties of the soil. In contrast, water holding capacity did not show a significant effect ($F = 2.81$, $p = 0.092$), indicating that seasonal and patch variations may not strongly govern soil moisture retention. These findings underscore the role of environmental heterogeneity in shaping soil properties across different patches and seasons.

4.6 Diversity Indices: The number of individuals decreases over the months in homogeneous patches while it increases in heterogeneous patches as shown in above table through darker to lighter colour shades (Table 7). Whereas heterogeneous patches host more species and exhibit a slow increase in species diversity (11 to 15), homogenous patches exhibit steady species richness (3).

Table 7. Diversity measures for Homogeneous and Heterogeneous Patches

Patch type	Season	Homogeneous patches	Heterogeneous patches
NOI	Monsoon	959	1302
	Winter	785	729
	Summer	754	698
Species Richness (S)	Monsoon	3	14
	Winter	3	11
	Summer	3	15
Species Evenness (E)	Monsoon	0.568	0.66
	Winter	0.613	0.809
	Summer	0.597	0.761
Shannon-Weiner Diversity Index (H')	Monsoon	0.624	1.742
	Winter	0.673	1.939
	Summer	0.656	2.062
Simpson's Diversity Index (D)	Monsoon	0.668	0.281
	Winter	0.635	0.175
	Summer	0.647	0.16

In heterogeneous patches, the Shannon-Wiener variety Index is much higher, 1.742 to 2.062, showing higher overall variety both in species richness and evenness. The Simpson's Diversity Index is lower (0.281 to 0.16), which shows that species are widely dispersed, and no single species is highly dominant there. The species evenness of heterogeneous patches is better than that of homogeneous patches (0.761), which means no single species is highly dominant there. Heterogeneous patches often have superior species richness, evenness, and variety when compared to homogeneous patches. Therefore, ecological stability is stronger in heterogeneous patches that support a more varied and balanced environment. With a decrease in individual numbers and reduced diversity, homogeneous patches appear to be more vulnerable to changes in the environment. With constant populations and species evenness during three months, heterogeneous patches portray better ecological balance and greater biodiversity. These patches support more species and are longer-lasting. In contrast, homogenous areas have lower biodiversity with greater population decline for individual species and loss of differentness over time. These patches may need more conservation efforts because they are more sensitive to environmental change to maintain their ecological functions. Using heterogeneous patches as conservation priority areas may enhance biodiversity conservation and ecological integrity in the long term. Their ecological utility could also be furthered by methods to reduce fragmentation and increase variety in homogenous sections.

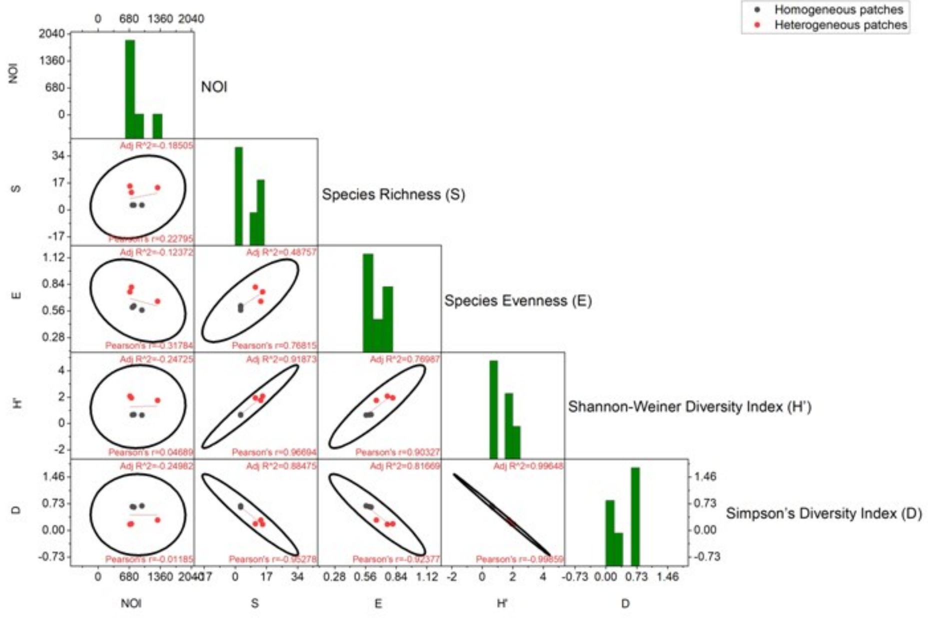


Figure 5. Correlation Matrix of Diversity indices

The correlation matrix gives a good illustration of the associations between ecological variables, such as Number of Individuals (NOI), Species Richness (S), Species Evenness (E), Shannon-Weiner Diversity Index (H'), and Simpson's Diversity Index (D) between homogeneous and heterogeneous patches (Figure 5). Histograms along the diagonal indicate that NOI has the greatest variability, and other indices show relatively tighter distributions. Scatterplots clearly distinguish

between homogeneous (black points) and heterogeneous (red points) patches, with heterogeneous patches showing tighter clustering, which is indicative of more consistent ecological patterns than homogeneous ones. Strong positive correlations are observed between Species Richness (S) and Shannon-Weiner Diversity Index (H') (r = 0.96694), as well as Species Evenness (E) and H' (r = 0.90327), highlighting the pivotal role of richness and evenness in determining overall diversity. Conversely, Simpson's Diversity Index (D) shows a nearly perfect negative correlation with H' (r = -0.99859), reflecting its sensitivity to dominant species compared to Shannon-Weiner's more even representation. Adjusted R^2 values further validate these relationships, with high values for S and H' ($R^2 = 0.91873$) and E and H' ($R^2 = 0.76987$), while weaker relationships are evident between NOI and H' ($R^2 = 0.04689$). The ellipses encircling the data points confirm these trends, where narrow ellipses for pairs like S and H' suggest strong correlations, while wider ellipses, such as for NOI and S, indicate weaker linear relationships.

Overall, the analysis underscores the ecological stability of heterogeneous patches, which support higher and more consistent diversity indices. In contrast, homogeneous patches exhibit greater variability in ecological metrics. This finding emphasizes the critical role of species richness and evenness in shaping biodiversity and reinforces the importance of heterogeneity in maintaining ecological stability and diversity.

5.CONCLUSION

The results of this study show the importance of heterogeneity in maintaining ecological stability and resilience in patches along the Asmavati Riverfront. Patches of different types exhibited greater species richness, diversity, and adaptability compared to the homogeneous patches that gradually declined with a steady species abundance over time. For example, heterogeneous patches supported up to 15 species with Shannon-Weiner diversity indices increasing from 1.742 to 2.062, whereas the homogeneous patches could only support three species, with corresponding diversity indices remaining below 0.7. These results show that not only do heterogeneous patches provide a more favourable environment for species survival but also allow for better ecological responses to environmental disturbances. Seasonal variations in soil properties, for example, an increase in pH from 7.2 to 9.5 and a decline in water-holding capacity from 40% to 16%, further elaborate the dynamic interaction between abiotic factors and plant community structure. However, there are some limitations of the study that should be addressed in future research. The spatial scope was limited to a relatively small area of 200 m^2, which may not fully capture the broader ecological dynamics of the region. In addition, the study focused primarily on three seasonal cycles, which might overlook longer-term ecological trends and responses to environmental disturbances. Anthropogenic influences, such as land use changes and pollution, were not explicitly incorporated into the analysis, leaving gaps in understanding the full spectrum of factors affecting patch dynamics. Future research should expand the study area and include long-term monitoring to capture multi-year ecological trends. Integrating additional environmental variables, such as nutrient cycling, microbial diversity, and human-induced disturbances, would provide a more comprehensive understanding of the factors shaping patch dynamics. Such efforts would further enhance conservation efforts through better conservation strategies that include maintaining heterogeneous patch structures for increasing biodiversity, resilience, and sustainability of ecosystems under environmental change.

Conflict of Interest: The authors declare no conflict of interest regarding the publication of this manuscript.

Author Contributions: BT conducted the fieldwork, collected data, and performed the initial analysis. RGD and KNO contributed to data interpretation, designed the study framework, and assisted in drafting the manuscript. AV supported the statistical analysis and contributed to refining the methodology and results sections. BAJ provided supervision, guided the ecological interpretation, and reviewed the manuscript for intellectual content. All authors read and approved the final version of the manuscript.

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Use of AI: AI tools were used only to refine the language, correct grammar, and clarify the manuscript, whereas AI was not employed for data analysis, interpretation of results, or drafting any scientific content.

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