BIODIVERSITAS
Volume 25, Number 6, June 2024
Pages: 2696-2704

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250640

Different habitats of ferns growing in the Amonkoton Stream, Zerafshan Valley, Uzbekistan

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Manuscript received: 15 January 2024. Revision accepted: 25 June 2024.

Abstract. *Muminov D, Khaydarov K, Zhalov K, Hasanov M, Abdumuminova R, Ochilov U. 2024. Different habitats of ferns growing in the Amonkoton Stream (Zerafshan Valley), Uzbekistan. Biodiversitas 25: 2696-2704.* The Zerafshan Valley, Uzbekistan, characterized by a warm and arid climate, has declined vegetation and soil quality over recent decades, marking a stark departure from its once lush past. Understanding the nuanced relationship between species and their habitat is imperative to unraveling this ecological transformation. This research delves into ferns, which are highly responsive to environmental factors, seeking to elucidate their circumstances within the changing ecosystem. Through strategically planned intensive transects and plots as proxies for fern growth and habitat analysis, statistical methods like the Shannon-Wiener Index (H) and Bray-Curtis index were deployed. The climate-related information analysis was conducted using the CRU TS 4.07 tool. We made use of average temperatures and precipitation over 120 years. The results of analyses have been acquired from 490 fern individuals belonging to 13 species, 7 genera, and 6 families. There are four species: *Equisetum arvense* L., *Equisetum ramosissimum* Desf., *Cystopteris fragilis* (L.) Bernh. and *Adiantum capillus-veneris* L. were employed as indicators of habitat. The findings underscore a substantial decline in fern-populated areas, resulting in diminished diversity and abundance and a relatively high rarity level. Furthermore, a latitudinal correlation with ferns along the stream direction is exhibited by four indicator species, offering valuable insights into the intricate dynamics of the Zerafshan Valley's ecosystem.

Keywords: Diversity, fern, plot, transect, valley

INTRODUCTION

The Zerafshan Valley in Uzbekistan is a region of significant botanical importance, particularly in terms of its vegetation cover and diversity of flora (Sennikov et al. 2016; Kholbutayeva et al. 2020) highlights the unique riparian forest ecosystems in the area, which are home to over 300 higher plant species. Zakirov (1962) compiled a list of vascular plants growing in this area several years ago. However, there is a great deal of anthropogenic strain on these ecosystems, which has resulted in habitat degradation (Akhmedov et al. 2022). In addition, Tojibaev et al. (2017) and Zhalov and Farrux (2022) add to this by identifying ten new plant species in the region, further underscoring its rich flora. The wild relatives of cultivated plants are important economically in Uzbekistan, as noted by Abduraimov et al. (2023). These species are probably found in the Zerafshan Valley and may be important for food security (Nurullayeva et al. 2021).

One of the oldest and most species-rich groups of vascular plants are ferns (Qian et al. 2021), with over 12,000 species known to exist globally (www.worldplants.de/ferns/). Compared to most other groups of vascular plants, ferns are typically regarded to have a distribution that is more in balance with the environment (Qian 2009). Weigand et al. (2019) reported significant differences in fern species richness around the globe, which is thought to be impacted by environmental factors (Khine et al. 2019). Ferns are indicator plants for habitat loss and fragmentation, carrying out several vital ecological tasks (Silva et al. 2018; Dai et al. 2020). Tuomisto et al. (2014) identified several environmental factors that correlate with species diversity. These include soil cation concentration, soil aluminum concentration, heterogeneity in soil chemistry, annual rainfall, dry season rainfall, and geographical location in central Amazonia. Ferns and fern allies are sensitive to environmental changes, to explore their relationship with the habitat (Yang et al. 2021).

Molecular systematics and research efforts have transformed the evolutionary history of ferns and lycophytes, leading to an improved understanding of their evolution, relationships, and classification (Sessa 2018). Assess the taxonomic significance of these characters and provide insights into the classification and identification of fern species within this family (Mondal and Moktan 2023). Monteiro (2020) provided a taxonomic overview of the Brazilian endemic and endangered genus Fernseea, including detailed descriptions and a key for species identification.

According to common sense, ferns and their allies are extremely sensitive to changes in their natural environment, and their presence or absence is directly tied to where they live (Abotsi et al. 2020). Understanding how plants interact with their surroundings in arid ecosystems is a necessary first step towards deciphering the adaptation mechanism and providing workable solutions to preserve terrestrial environments (Jin et al. 2019). Ferns' rich physiological ecology is highly adaptable to various environments, making them important in horticulture and ecological services (Anderson 2021). They often colonize disturbed habitats, compete with other plants, and influence succession. They can also play a key role in ecosystem restoration (Walker and Sharpe 2010). Species richness of ferns follows a latitudinal gradient that peaks in the tropics, where ferns are especially diverse and abundant in wet habitats with moderate temperatures at elevations of about 1,000-2,500 masl. (Kessler 2010), potential as effective indicators for characterizing and monitoring forest types and their conservation status (Sosanika et al. 2022).

In this study, the relationship between ferns and environments in the Zerafshan Valley, as well as species populations and environmental factors, is investigated. A brief and clear description of the purpose of the investigation relating to previous research and essential arguments should be mentioned.

MATERIAL AND METHODS

Geographical location

Zerafshan Valley is located in the central part of Central Asia, Uzbekistan, between Turkestan-Oqtov and Zarafshan ridges. This region has different natural resources and economic activities. However, the valley faces water quality and management challenges, with the unsustainable use of water resources leading to a water deficit and pollution. Efforts to address these challenges include the creation of a soil-reclamation map based on the analysis of lithodynamic flow structures (Olsson et al. 2013; Sabitova et al. 2021; Sultonova and Baratov 2021; Akhmedov et al. 2023).

The Zerafshan Valley starts from the Zarafshan glacier (elevation 2,775 masl) and extends 781 kilometers to the Sandiqli desert (elevation 185 masl) in the west. We carried out our research in the Amonkoton stream. The stream is located in the middle of Zarafshon valley. Its starting point is 1860 masl (39°18'12" N and 66° 53'57" N). The discharge point to the Karatepa reservoir is the lowest part of the stream and is located at 930 masl (39°24'34"N and 67°01'44"N). The total length of the stream is 24 km. Six transects were arranged randomly (Yang and Grote 2017) with a concept of no interference by human activities, where three transects were set up altitudinally along a mountain slope and the other three latitudinally along the stream (Table 1).

Altitudinal transects were 50 m in height vertically, with 10 plots arranged equidistantly 10 m apart from the lower plot to the higher. The latitudinal transects were 100 m long along the stream channel, and ten plots were spaced at a distance of 100 m evenly. Plots were 1×1 m squared. All fern species in the sampling sites were investigated in spring and summer from March to August 2021 and 2022, when average monthly temperature and precipitation are mostly stable (https://www.meteoblue.com). The study direction and maps (Figures 1 and 2) were created using QGIS 3.30.0 (2024), Google Earth Pro programs (https://earth.google.com/web) and data from the Diva-GIS and Map Cruzin (https://www.diva-gis.org/gdata).

Table 1. Location, elevation, and orientation of each transect

Tr.	Location	Height meter above sea level (m a.s.l.)	Orientation
I	39°24'20.02"N 67° 1'8.51"E	890-910	Latitudinal
II	39°24'12.68" N 67° 0'33.43" E	910-960	Altitudinal
III	39°22'40.87" N 66°59'41.26" E	970-1,020	Altitudinal
IV	39°21'10.20" N 66°59'8.43" E	1,060	Latitudinal
V	39°19'2.25" N 66°58'58.71" E	1,200-1,250	Altitudinal
VI	39°18'29.59" N 66°56'20.38" E	1,385-1,390	Latitudinal

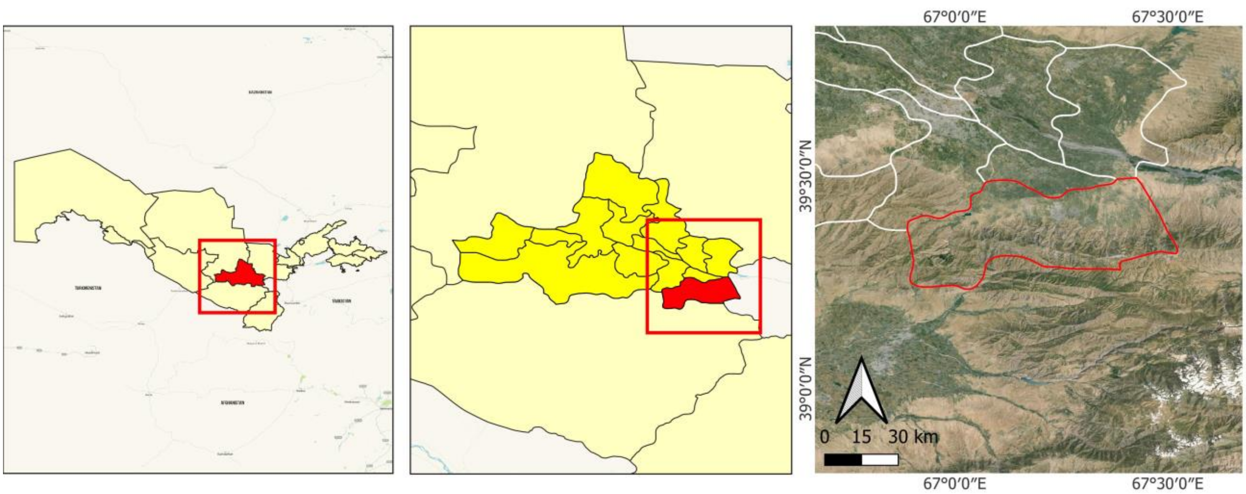

Figure 1. Study area in Urgut District, Samarkand, Uzbekistan

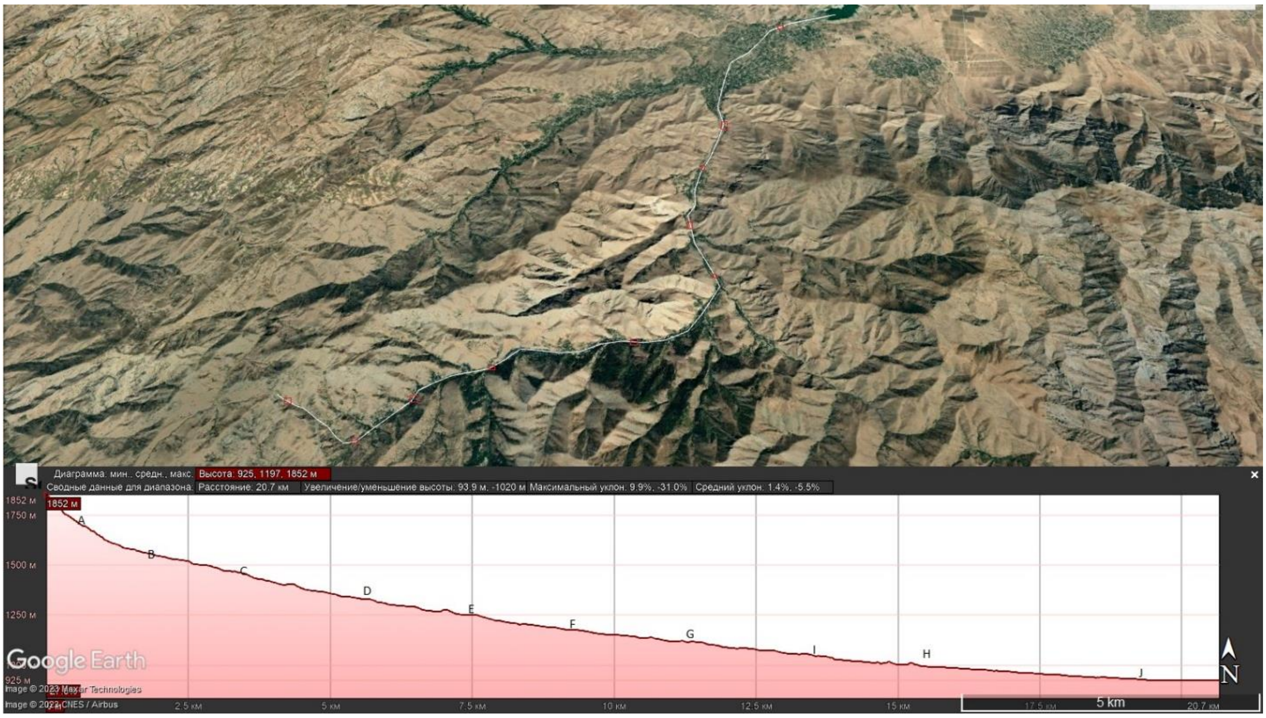

Figure 2. Orientation of transects A to J in the Amonkoton stream (Zerafshan Valley, Uzbekistan)

Correct nomenclature was maintained following POWA (https://powo.science.kew.org/). Every fern species we found in the plots was identified using images depicting its vegetative behavior. Because the rhizome and sori types are essential for the identification of Pteridophytes (Callado et al. 2015). The identification of the fern species was carried out using the available dichotomous key from selected published sources, as well as morphological comparisons from the scanned photos of specimens available at Global Plants on JSTOR, Plants of the World Online, Global Biodiversity Information Facility and The World Checklist of Vascular Plants.

Statistical analysis

In statistical analysis, we used the Shannon-Wiener Index (H), which measures species diversity influenced by both richness and evenness. The Bray-Curtis index is also widely used in statistical analysis, particularly in the context of diversity, data aggregation and ecological studies. (Magurran 2004; Chao and Chiu 2016; Ricotta and Podani 2017).

Shannon-Wiener Index (H’): Shannon-Wiener Index was calculated by using the formula:

$$H' = -\sum_i (n_i / N. \ln (n_i/N)$$

Where:
ln : natural logarithm
ni : the number of individuals of the ith species
N : the total number of individuals of all the species

Bray-Curtis Index: Bray-Curtis index was calculated by using the formula:

$$BC_{ij}=1-(2C_{ij})/(S_i+S_j)$$

Where:
Cij : the sum of only the lesser counts for each species
S_i and S_j : the total number of specimens counted at sites $_i$ and $_j$

Meteorological data

No long-term weather data is available in Uzbekistan. Therefore, the Climatic Research Unit CRU TS 4.07 (grid-box data for 39.25 N, 66.75 E) datasets (Harris et al. 2020) provided each site's mean monthly temperature and precipitation data. The program was used to analyze climatic data. We used precipitation and temperature averages covering 120 years. Temperature and precipitation are considered to be the most important factors connected to fern development and distribution in the valley.

RESULTS AND DISCUSSION

The analytical results are from 490 fern individuals belonging to 13 species, 7 genera, and 4 families (Table 2).

Transect III was placed along the stream, and the largest number of individuals (164) were found. It also showed the most diversity of species (7): *Equisetum arvense* L., *Equisetum ramosissimum* Desf., *Adiantum capillus-veneris* L., *Cystopteris fragilis* (L.) Bernh., *Hemionitis persica* (Bory) Christenh., *Asplenium trichomanes* L., and *Asplenium ceterach* L. species were found only in Transect III. Transect V was characterized by fewer individuals (23) and low species diversity (3). Two species of *Asplenium fontanum* subsp. *pseudofontanum* (Kossinsky) Reichst. & Schneller and *Dryopteris komarovii* Kossinsky were determined in Transect V. In addition, 2 species of *Asplenium lepidum* subsp. *haussknechtii* (Godet & Reut. ex Milde) Brownsey and

Asplenium ruta-muraria L. were encountered only in Transect IV. The number of individuals of *C. fragilis* is the highest (40) in Transect VI. *Thelypteris palustris* Schott and *Dryopteris filix-mas* (L.) Schott were found only in Transect VI.

Moreover, Figure 3. A shows yearly average temperatures from 1901 to 2022; over this period, there is a noticeable trend of increasing temperatures, with some fluctuations from year to year. The average temperature increased from around 9°C in the early 1900s to approximately 12.67°C in 2022. While there are some temperature variations yearly, the overall trend indicates a warming climate over the past century.

The data presents yearly precipitation levels from 1901 to 2022 (Figure 3. B). There is variation in precipitation levels across the years, with some years experiencing higher levels than others. Overall, there seem to be some fluctuations in precipitation levels over time, but there isn't a clear trend visible at first glance. However, further analysis is crucial to identify any long-term patterns or trends in precipitation.

Shannon-Wiener Index (H)

Figure 4 shows the dispersed values of the Shannon-Wiener Index among the plots in each transect separately using a general linear regression, allowing the identification of habitat heterogeneity and changes along the plots.

Altitudinal transects (II, III, V)

Transect plots are numbered 1 through 10 from the mountain's base to its summit. While Transect V was open, Transect III was closed. The ridge of a mountain was Transect II. The relationship between the elevation and the H index was generally positive (Figure 4). It demonstrates unequivocally a tendency for ferns and their companions to diversify with increasing elevation. A substantial correlation ($P<0.05$) was observed in Transect III, an opening with vegetative vegetation and a closed habitat. The humidity inside was rather high because the ravine was irrigated from an upper location. In these conditions, the majority of ferns and fern allies flourished well.

While Transect V also had a ravine, it was more dispersed due to weak flora and rocks. It could not maintain groundwater or a nearby, humid environment; ferns are seldom found at this location. Transect II was a mountain slope that could not reliably sustain water levels or create a humid environment. On the ridge, shrubs were more developed than ferns.

Table 2. Species in transects

Family	Species	Tr. I	Tr. II	Tr. III	Tr. IV	Tr. V	Tr. VI
Equisetaceae	*Equisetum arvense* L.	20	56	40	34	0	10
	Equisetum ramosissimum Desf.	9	31	78	46	17	0
Pteridaceae	*Adiantum capillus-veneris* L.	5	14	20	0	0	0
	Hemionitis persica (Bory) Christenh.	0	0	4	0	0	0
Aspleniaceae	*Asplenium lepidum* subsp. *haussknechtii* (Godet & Reut. ex Milde) Brownsey	0	0	0	3	0	0
	Asplenium fontanum subsp. *pseudofontanum* (Kossinsky) Reichst. & Schneller	0	0	0	0	4	0
	Asplenium ruta-muraria L.	0	0	0	3	0	0
	Asplenium trichomanes L.	0	0	2	0	0	0
	Asplenium ceterach L.	0	0	5	0	0	0
	Cystopteris fragilis (L.) Bernh.	20	7	15	0	0	40
	Thelypteris palustris Schott	0	0	0	0	0	1
Polypodiaceae	*Dryopteris filix-mas* (L.) Schott.	0	0	0	0	0	4
	Dryopteris komarovii Kossinsky	0	0	0	0	2	0

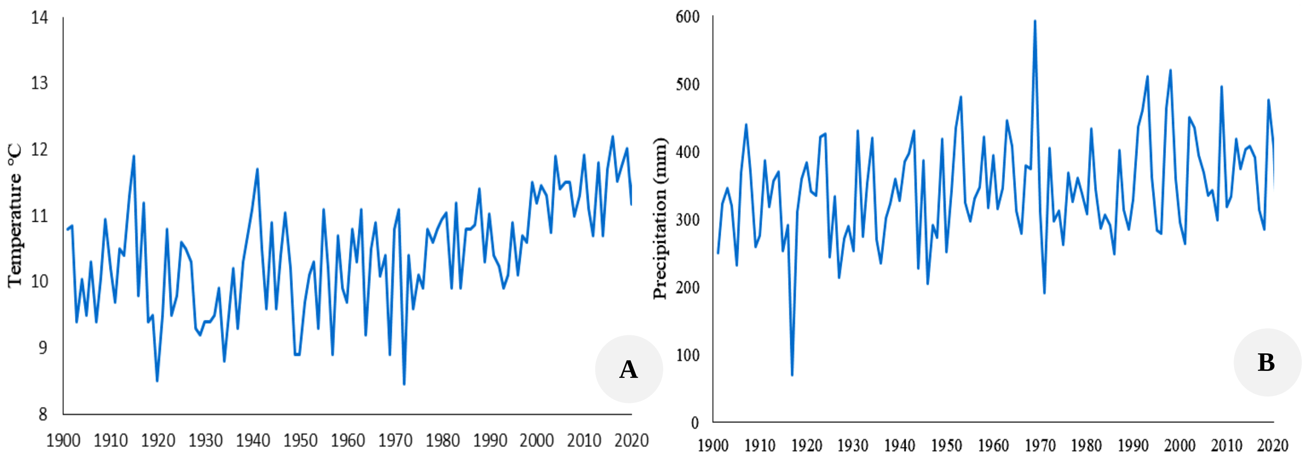

Figure 3. A. Average temperature (°C) and B. Amount of precipitation (mm) of the Zerafshan Valley, Uzbekistan

Latitudinal transects (I, IV, VI)

Transect plots were numbered 1 through 10 and spanned 100 meters from higher to lower. Whereas Transects VI and I were closed, Transect IV was an open stream terrace. Along the stream, there was a substantial positive correlation (P<0.05) between the *H* index (Figure 4). Transects I, IV, and VI appeared to have a sufficient water supply compared to altitudinal transects because of their proximity to the stream channel. Due to the development of trees and bushes, closed habitats were created simultaneously in certain transects VI and I sections. Transect IV did not see the development of lush stream vegetation. One would attribute the primary cause to erratic stream tides.

Bray-Curtis Index

Moreover, all six transects existed in a cramped valley of 24 km in length. Bray-Curtis index demonstrated a deviation altitudinally and latitudinally (Table 3). The maximum was 0,858 in transects IV and VI, which defined similar living circumstances for ferns. The minimum was 0 in transects V and VI, which determined various circumstances.

Table 3. Similarity in transects

	I	II	III	IV	V	VI
I		0.490	0.546	0.532	0.766	0.516
II			0.308	0.310	0.740	0.791
III				0.360	0.818	0.771
IV					0.689	0.858
V						0
VI						

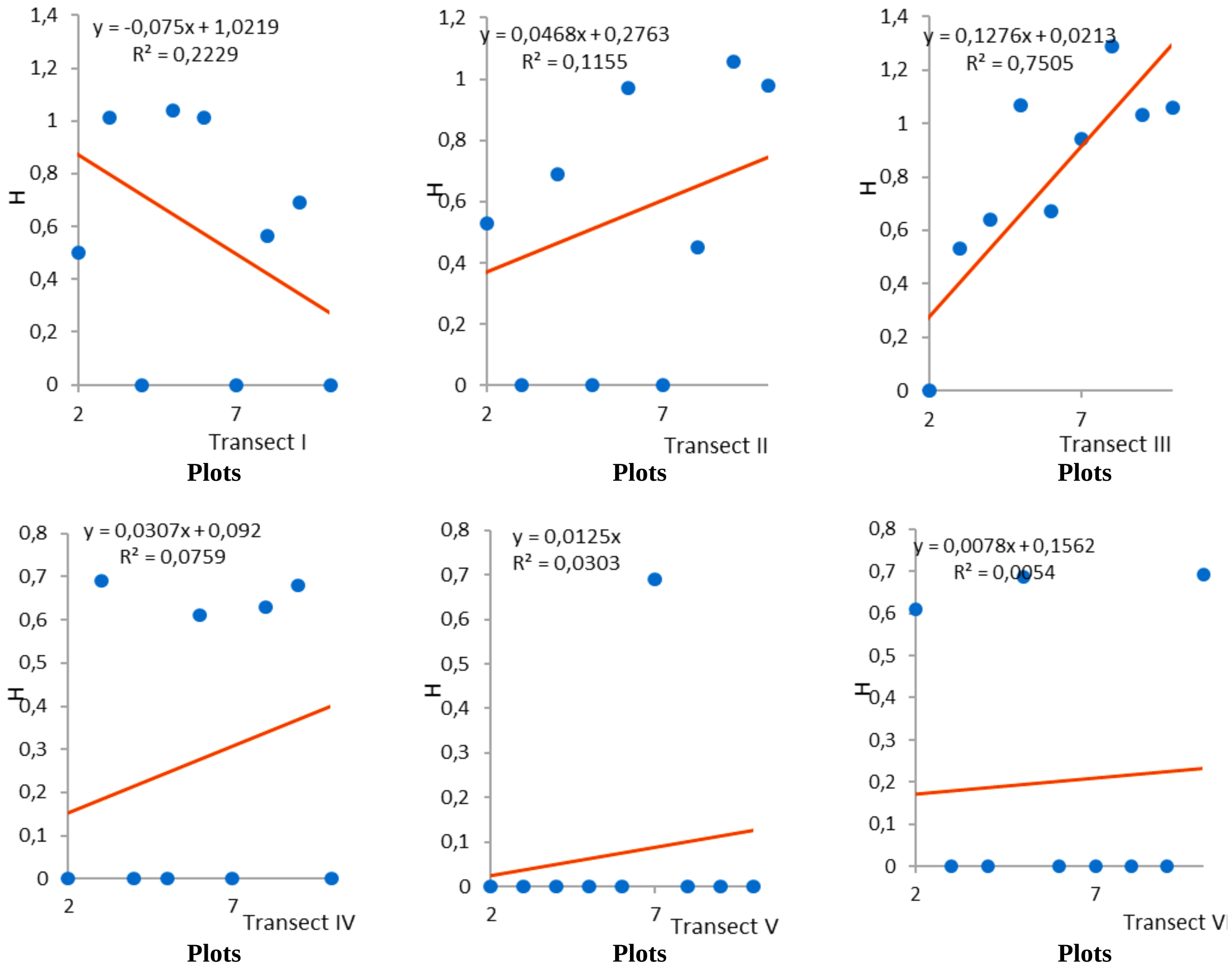

Figure 4. The Shannon-Wiener Index (H) variance in transects (I-VI)

In plots

The calculated Bray-Curtis indices determined the small-scale habitat in each transect's plot. Table 5 shows a distinct listing of the values. The life conditions of ferns were continuous and transects I, II, III, IV, and VI in the Bray-Curtis plots were comparable. Conversely, Bray-Curtis was nearly zero in transect plots V. Both locations have low humidity levels and inadequate target species records. The findings are in good alignment with the field research.

Indicator species

This study identified 4 types of ferns as indicators due to their large number and growth in almost all transects Table 4.

Discussion

Embarking on a thorough exploration of the intricate relationship between elevation and the biodiversity of vascular plants, particularly focusing on the fascinating realm of ferns, unfurls a captivating tapestry of ecological nuances. The consistent revelation of a hump-shaped pattern in tropical regions, signifying a zenith of biodiversity at mid-elevations and a gradual decline towards higher and lower elevations, is a compelling starting point (Hernández-Rojas et al. 2018). This altitudinal influence becomes even more intriguing when delving into the specifics, as the elevation at which maximum fern diversity occurs manifests distinct variations across diverse mountain ranges. For instance, Costa Rica and Mount Kinabalu in Borneo showcase optimal diversity around 1,800 masl, while Bolivia's peak is at 2,000 m a.s.l., and Mount Kilimanjaro in Tanzania experiences it at 2,400 masl (Kessler et al. 2001). These altitudinal gradients align with the upper echelons of tropical gradients, where biodiversity tends to exhibit relative diminution. The cross-examination of species within these datasets, while maintaining mean annual temperatures as a constant, not only corroborates but also accentuates the reliability and consistency of these altitudinal patterns. The narrative is nuanced in temperate realms like New Zealand or North America, with biodiversity gradually diminishing with elevation or maintaining a relatively stable profile (Brock et al. 2016).

The altitudinal transects along the mountain slope were located from 890-1,390 masl (Table 1), providing a panoramic vista of ecological intricacies, notably shedding light on species regeneration and the prevalence of ferns. Within this altitudinal mosaic, certain transects stand out as ecological vignettes. Transects IV and V emerge as distinctive chapters, revealing fern scarcities with only two species identified. Transect IV, uniquely differentiating itself from Transects I and VI, underscores the dynamic heterogeneity that characterizes these elevation gradients. In stark contrast, transect III unfurls as a lush tapestry, rich in ferns, hosting 7 distinct species and a substantial population of 490 individuals (Table 3). The ecological drama in Transect III unfolds against the backdrop of abundant rainfall draining into the ravine, nurturing an environment supported by a significant water supply originating from higher elevations. On the flip side, Transects II and V grapple with drought conditions, resulting in a diminished presence of ferns but a proliferation of shrubs and trees, encompassing *Rosa canina* L., *Rosa persica* Michx. ex J.F.Gmel., *Prunus spinosissima* (Bunge) Franch., *Rubus caesius* L., *Crataegus turkestanica* Pojark, *Prunus bucharica* (Korsh.) B.Fedtsch., *Salix alba* L., and *Juniperus seravschanica* Kom. Transect III's closed canopy is a vital key player, contributing significantly to higher biodiversity than an open ravine or ridge.

Primarily focus on a few specific fern species flourishing in these altitudinal gradients; some distinguish themselves as indicator species by demonstrating an extraordinary degree of environmental adaptation. *E. ramosissimum* and *E. arvense*, thriving in open, humid environments, partner with the fern *C. fragilis*, which flourishes beneath large stones or in the shade, and *A. capillus-veneris*, commonly found near water and beneath large rocks. These ferns are not just biological entities but rather environmental barometers, their population sizes shifting dynamically in response to changing variables, thereby signifying a sensitivity to the nuanced evolution of their surroundings. In the broader ecological narrative, ferns and their botanical counterparts emerge as pivotal players, serving as indicators of the overall health and equilibrium of the environmental tapestry (Silva et al. 2018). The narrative broadens its scope, shifting towards the overarching theme of climate change, which has become a central focus over the past few decades. This temporal correlation coincides with a surge in environmental disasters, creating a complex ecological backdrop. Anthropogenic warming, with its genesis in the 1960s in Uzbekistan, has catalyzed substantial land degradation and a cascade of climate events in recent years (Kholmatjanov et al. 2020). Within this maelstrom, plants find themselves at the frontline, grappling with various stresses emanating from both abiotic and biotic factors.

Table 4. Indicator species

Species	Elevation (m a.s.l.)	Transect
Equisetum arvense L.	890 ~ 1,390	I, II, III, IV, VI
Equisetum ramosissimum Desf.	890 ~ 1,250	I, II, III, IV, V
Cystopteris fragilis (L.) Bernh.	900 ~ 1,390	I, II, III, VI
Adiantum capillus-veneris L.	900 ~ 1,020	I, II, III

Table 5. Similarity in plot

Transect I

	1	2	3	4	5	6	7	8	9	10
1		0.571	0.75	0.8	0.176	0.333	0.889	0.538	0.529	0
2			0.27	0.667	0.846	0.818	0	0	0	0
3				0.714	0.571	0.5	0.714	0.6	0.714	0
4					0.778	0.714	0	0	0	0
5						0.142	0.778	0.454	0.5	0
6							0.714	0.6	0.714	0
7								0.6	0.778	0
8									0.333	0.818
9										0.467
10										

Transect II

	1	2	3	4	5	6	7	8	9	10
1		0.6	0.69	0.6	0.467	0.6	0.294	0.771	0.667	0.379
2			0	0.22	0	0.375	0	0.454	0.454	0.481
3				0	0.33	0	0.5	0	0.73	0.8
4					0	0.11	0	0.454	0.363	0.629
5						0	0.2	0	0.529	0.636
6							0	0.515	0.363	0.629
7								0	0.579	0.583
8									0.675	0.523
9										0.161
10										

Transect III

	1	2	3	4	5	6	7	8	9	10
1		0	0.15	0.304	0.677	0	0	0.567	0.515	0.459
2			0.64	0	0.6	0.752	0.636	0.692	0	0.69
3				0.47	0.47	0.909	0.78	0.4	0.56	0.3
4					0.357	0	0.73	0.29	0.47	0.529
5						0.9	0.35	0.21	0.705	0.368
6							0.9	0.92	0.72	0.69
7								0.4	0.89	0.65
8									0.6	0.363
9										0.35
10										

Transect VI

	1	2	3	4	5	6	7	8	9	10
1		0	0.67	0	0.5	0	0	0.57	0.27	0.2
2			0	0	0	0	0	0	0	0
3				0.375	0.375	0.53	0	0.142	0.7	0.53
4					0	0.36	0	0.62	0	0
5						0	0	0.26	0.57	0.33
6							0	0.6	0	0
7								0	0	0
8									0.636	0.42
9										0.38
10										

Transect V

	1	2	3	4	5	6	7	8	9	10
1		0	0	0	0	0	0	0	0	0
2			0	0	0	0	0	0	0	0
3				0	0	0	0	0	0	0
4					0	0	0	0	0	0
5						0	0	0	0	0
6							0.5	0	0.27	0
7								0	0.63	0.5
8									0	0
9										0.27
10										

Transect VI

	1	2	3	4	5	6	7	8	9	10
1		0	0	0	0	0	0	0	0	0
2			0.53	0	0.157	0.25	0	0.3	0.22	0.56
3				0	0.5	0	0	0	0	0
4					0	0	0	0	0	0
5						0.33	0	0.47	0.41	0.52
6							0	0.25	0.14	0.42
7								0	0	0
8									0.11	0.56
9										0.5
10										

The research pivots its lens specifically toward ferns, unraveling their responses to the evolving environmental narrative within the Zerafshan Valley, a terrain shared by the Urgut region. The altitudinal ascent from the base to the summit of the mountain emerges as a climatic odyssey, marked by an escalation in precipitation and a concurrent decrease in temperature. Ferns, in their adaptive choreography, exhibit a positive correlation with elevation, a testament to their intricate dance with atmospheric conditions. The crescendo of species richness further amplifies amidst the valley's rich symphony of habitat heterogeneity. Intriguingly, even in the absence of direct human intervention, the current panorama of these landscapes diverges significantly from their original patterns, acting as poignant evidence of the transformative impact of climate change.

Raising away from the small-scale world of fern ecology, the changing dynamics of the Zerafshan Valley reveal a complex story about the relationship between elevation, fern diversity, and the wider effects of climate change on the local ecosystems. This narrative transcends the realms of mere biodiversity studies, encapsulating a tale of ecological resilience, adaptation, and vulnerability. It prompts a profound contemplation on how these environmental factors intricately shape the delicate equilibrium of biodiversity in these altitudinal landscapes, unveiling a trove of knowledge that transcends disciplinary boundaries. This nuanced exploration serves as a testament to the interdisciplinary importance of understanding the delicate dance between elevation, ecological communities, and the sweeping forces of climate change, offering a holistic perspective that weaves together the intricate threads of nature's resilience and vulnerability in the face of dynamic environmental shifts between elevation, ecological communities, and the sweeping forces of climate change.

In conclusion, the Zerafshan Valley, characterized by a drier and warmer climate, has experienced a noticeable decline in vegetation, combined with soil degradation, marking a stark departure from its once flourishing green landscape in recent decades. Therefore, it becomes imperative to delve into the symbiotic relationship between the habitat and its resident species to unravel the intricacies of this ecological shift. A focal point of this ecological narrative is the nuanced category of ferns, renowned for their heightened sensitivity to environmental conditions and the intricacies of their upbringing.

The study employs a meticulous approach to decipher the mechanisms at play in this ecological transformation. Plots and intensive transects, strategically designed as surrogates, step into the role of proxies, offering insights into the growth patterns of ferns and their intimate connection with their natural environments. These designated areas serve as microcosms, enabling researchers to closely observe and analyze how ferns respond to the evolving conditions within the Zerafshan Valley. This methodological design facilitates a comprehensive understanding of fern behavior. It provides a window into the broader ecological dynamics underpinning the intricate combination of vegetation and environmental shifts in this unique geographical setting. The choice of plots and transects emerges as a deliberate strategy, allowing for a more nuanced exploration and interpretation of the multifaceted interplay between ferns and their surroundings, ultimately contributing to a higher knowledge tapestry regarding the ecological evolution of the Zerafshan Valley.

ACKNOWLEDGEMENTS

The authors are grateful to the Laboratory of Botanical Scientific-Research and Herbarium of Samarkand State University (SAMDU), Uzbekistan, for the facilities used during the research.

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