Indian Journal of Plant Sciences ISSN: 2319–3824
Online, International Journal, Available at http://www.cibtech.org/jps.htm
2025 Vol.14, pp.40-53/Anish
Review Article (Open Access)

IMPACT OF ECOLOGICAL FACTORS ON THE DISTRIBUTION AND DIVERSITY OF INDIAN PTERIDOPHYTES: A REVIEW

***Anish Bhattacharya**
Department of Botany, Durgapur Government College
**Author for Correspondence: anishammy@gmail.com*

ABSTRACT
Pteridophytes, as the earliest land vascular plants, have played a crucial role in shaping global vegetation for millions of years. Despite the dramatic environmental changes since their origin, they remain the second most diverse group of plants. Like other plant groups, pteridophytes depend on specific environmental conditions including soil quality, climate, and elevation for optimal growth and distribution. However, habitat fragmentation and loss have emerged as particularly rapid and significant threats. While numerous global studies have explored the impacts of these environmental factors and the effects of habitat fragmentation on pteridophyte growth with many highlighting their role as ecological indicators similar to mosses and lichens but research on these issues in India remains limited. Whereas there many diversity and species richness related works have been done in many states of India. Given the on-going challenges of urbanization and forest degradation, addressing this research gap is essential for the conservation of this vital biodiversity reservoir.

***Keywords**: Pteridophytes, Environmental gradients, Bio-indicators, Habitat Fragmentation, Ecological Indicators, India*

INTRODUCTION
Pteridophytes, the seedless vascular plants, first appeared in terrestrial ecosystems during the mid-Silurian period nearly 430 million years ago. Early vascular plants, such as *Cooksonia*-like species, pioneered the colonization of land, paving the way for later groups like *Rhynia*, *Zosterophyllum*, and *Trimerophyton* (Boyce, 2008). Over time, pteridophytes have diversified to inhabit a wide range of environments including terrestrial, aquatic, semi-aquatic, epiphytic, and lithophytic habitats. Their extensive fossil record demonstrates an impressive evolutionary adaptation, allowing them to compete with gymnosperms and angiosperms in ever-changing environments (Rowley *et al.,* 1985; Schneider *et al.,* 2004; Schuettpelz and Pryer, 2009; Watkins *et al.,* 2012). Today, they represent the second most diverse group of plants.
Many pteridophytes possess specialized photoreceptors that enable them to thrive in the low-light conditions of dense forests, a feature that has contributed to the greater diversity of leptosporangiate ferns compared to their basal eusporangiate counterparts (Schneider *et al.,* 2004). In 1964, C.N. Page introduced a classification system based on ecological preferences, distribution, and the micro-niches occupied by pteridophytes, reflecting the dynamic changes in growth forms with plant age.
Globally, several studies have examined the relationships between pteridophyte communities and a range of ecological factors including soil properties, temperature, humidity, climate, forest fragmentation, urbanization, and latitudinal and altitudinal gradients (Parashurama *et al.,* 2016; Singh *et al.,* 2017; Zuquim *et al.,* 2009; Murakami *et al.,* 2005; Paciencia and Prado, 2005; Bergeron and Pellerin, 2014; Shankar, 2001; Tripathi and Shankar, 2014). These investigations have not only highlighted the influence of environmental conditions on pteridophyte growth but also established their role as ecological indicators, akin to bryophytes and lichens (LeBlanc and Sloover, 1970). Such findings are essential for devising conservation strategies for endangered species in fragmented habitats.

In India, despite its status as one of the 17 mega-diverse countries, research focusing on the ecological interactions of pteridophytes is relatively limited. While numerous studies have addressed pteridophyte diversity and species richness, the intricate relationships between these plants and their ecological environments remain underexplored. Given the extensive occurrence of both fragmented and continuous forests in India, further investigation into these ecological dynamics is crucial for effective biodiversity conservation. This review aims to synthesize key research findings and underscore the importance of advancing studies on the ecological interactions of pteridophytes in India.

Pteridophytes have some unique characteristics those other plant groups do not have. Some of those are – a) herbivores avoid it b) they neither need any pollinator not any biotic medium for spore dispersal except water or wind c) spores allow the plants to colonize in pristine habitat (Bergeron and Pellerin, 2014) d) they show high level of polyploidy e) few species are highly sensitive to fragmentation of forest (Murakami *et al.,* 2005) f) mostly are small herbs and easy to study g) high ecological impact on forest h) easy to distinguish from other plants (Tuomisto and Ruokolainen, 1994). So, these plants are good candidate for studying ecological effect on plants and also for making it eligible to be an authentic indicator species for various ecological factors, pteridophytes also have their own selective need of ecological factors including edaphic factors (soil physical and chemical properties), climatic factors (temperature, humidity and precipitation), latitudinal gradient, altitudinal gradient, disturbances (forest fragmentation and habitat destruction). However, this requirement differs depending on different taxa. However, the effects of several factors are presented below –

Effect of soil factors

Soil is one of the most important environmental factors. Soils generally have 2 components – a) Physical - soil moisture, soil pH and soil texture and b) Chemical - available Nitrogen-Phosphorus-Potassium content, Organic matters, carbon content, calcium-magnesium ratio, sodium etc. There are many research works those found soil chemistry as the major important factor for pteridophyte distribution followed by other factors like topography, soil type and forest structural pattern (Moulatlet *et al.,* 2019; Jones *et al.,* 2008). There are also many contradictory works that shows the importance of the physical components (soil moisture, soil pH and soil texture) more than the chemical components (Tuomisto and Ruokolainen, 1993; Tuomisto and Poulsen, 1996; Ruokolainen *et al.,* 1997; Bergeron and Pellerin, 2014 etc.) Pteridophytes can be used a good indicator of soil factors as little difference in such factors can cause changing of their distribution pattern. For example, Salovaara *et al.* (2004) found total of 133 species belong to 38 genera of fern and fern allies in their study of amazonian rainforest landscape and they classified the forests depending on the pteridophyte diversity in different soil types. This work was inspired by Tuomisto and Ruokolainen (1993), Tuomisto and Poulsen (1996), Ruokolainen *et al.* (1997). The following table is showing the relation between different physical and chemical factors and some pteridiophytes by some research findings (Table – 1 and 2).

Table 1: Effect of Physical Factors of soil on pteridophytes

Author's name	Factors	Remarks on effect of factors on pteridophyte
Norton (1994)	soil drainage	Positive correlation with Well-drained soil - *Blechnum discolor* Positive correlation with Poorly drained - *Blechnum procerum* Positive correlation with Clay (by 18 taxa) Positive correlation with Sand (by 11 taxa)
	soil texture (clay and sand)	Positive correlation with both types (by 11 taxa)

Tuomisto and Ruokolainen (1994)	soil drainage	Positive correlation with Well-drained soil Positive correlation with Poorly drained soil - *Cyclodium meniscioides* and *Metaxya rostrata*
Tuomisto and Poulsen (1996)	soil texture (clay and sand)	Positive correlation with richest clay soil (by 31 taxa) Positive correlation with relatively poor clay soil (by 5 taxa) Positive correlation with intermediate soil (by 15 taxa) Positive correlation with poorly sandy soil (by 9 taxa) Positive correlation with both richest clay and intermediate soil (by 18 taxa) Positive correlation with Both poorly sandy and intermediate soil (by 18 taxa) Positive correlation all kinds of soil (by 6 taxa)
Ruokolainen *et al*. (1997)	water drainage capability	Positive correlation with the plants
Tuomisto *et al.* (1998)	Soil type	*Adiantum tomentosum* has Positive correlation with loamy soil
Tuomisto and Poulsen (2000)	soil drainage	Positive correlation with well drained soil Positive correlation with Poorly drained Positive correlation with intermediate type
Tuomisto *et al.* (2002)	soil texture (clay, sand and silt)	Positive correlation
Zuquim *et al.* (2009)	Clay content	Positive correlation
Silva and Schmitt (2015)	Soil moisture	Positive correlation

Table 2: Effect of Chemical Factors of soil on pteridophytes

Author's name	**Factors**	**Effect of factors on pteridophyte**
Greer *et al.* (1997)	Ca-Mg ratio	Positive correlation
Ruokolainen *et al.* (1997)	pH, Ca, Mg, K, Na, P and organic matter	Positive correlation
Tuomisto *et al.* (1998)	Extractable base content	*Adiantum tomentosum* has Positive correlation with low extractable base content *Adiantum terminatum*, *Adiantum pulverulentnm* and *Adiantum humile* found in high extractable base content
Richard *et al.* (2000)	pH	Positive correlation with taxa having long creeping rhizome
Tuomisto *et al.* (2002)	Ca, Mg	Positive correlation
Poulsen *et al.* (2006)	Ca, K	Positive correlation
Rodriguez-Loinaz *et al.* (2008)	Available N and K	Negative correlation
Bergeron and Pellerin (2014)	Acidic pH	Positive correlation

So, we have seen that relationship of pteridophyte species richness with soil parameters vary from place to place by different research works. Basically, these parameters can be controlled by different climatic factor and topography etc. Basically, these parameters can be controlled by different climatic factor (Singh *et al.,* 2017) and topography etc.

Effect of climate factors

Climatic variables are also important for all kinds of vegetation and the plant groups residing in it. So, pteridophytes should not be exception and there are many of them who are highly sensitive to slight climatic or microclimatic changes (Ibars and Estrelles, 2012) because soil factors are controlled by various climatic factors such as precipitation, relative humidity and temperature. Even regional climatic change can create huge species richness difference in different geographical ranges (Lehmann *et al.,* 2002; Sureshkumar *et al.,* 2020). So now we are going to see how these factors directly or indirectly impact the growth of pteridophyte. Some works are given below (**table 3**) –

Table 3: Effect of climate factors on Pteridphyte taxa

Name of Authors	**Name of climatic factors**	**Effect on Pteridphyte taxa**
Silva *et al.* (2018)	high humidity and low light	Positive correlation with Hymenophyllaceae
Padmawathe *et al.* (2004)	Humidity	Positive correlation with epiphytes
	Temperature	Negative correlation with epiphytes
	Seasonality	• Negative correlation with *Christella* sp. *Pteris* sp. *Selaginella* sp. *Diplazium* sp. • Positive correlation with *Lycopodium* sp., *Huperzia* sp., *Blechnum* sp.
Aldasoro *et al.* (2004)	Warmth index (temperature)	• Positive correlation with *Christella* sp. *Pteris* sp. *Selaginella* sp. *Diplazium* sp. • Negative correlation with *Lycopodium* sp., *Huperzia* sp., *Blechnum* sp.
	Humidity	Negative correlation with *Adiantum* sp. *Marsilea* sp. *Ophioglossum* sp. etc.
Singh (2011)	Precipitation	Positive correlation with *Platycerium wallichii*
Abotsi *et al.* (2020)	Precipitation	• Negative correlation with *Acrostichum aureum, Marsilea minuta,* and *Cyclosorus striatus* • Positive correlation with *Haploteris guineensis, Alsophila camerooniana, Asplenium biafrenum* and *Microgramma mauritiana*
	Temperature	Positive correlation with *Acrostichum aureum, Marsilea minuta* and *Cyclosorus striatus*
	Humidity	Positive correlation with *Haploteris guineensis, Alsophila camerooniana, Asplenium biafrenum* and *Microgramma mauritiana*

Patil *et al.* (2016), in their study of pteridophyte distribution at Satara district (Maharashtra) found unique species composition according to rainfall, relative humidity, temperature. They divided the factors as high, medium and low according to their intensity and then reported the species richness at that ranges. The following table is made to show the acquired data in a nutshell **(table-4).**

Table 4: Species composition according to rainfall, relative humidity, temperature

Pteridophyte species richness according to rainfall		
High (3000 mm/year)	**Medium (>1000 mm, <3000/year)**	**Low (< 1000 mm/year)**
80	50	15
Pteridophyte species richness according to humidity		
High (>70%)	**Medium (<70%, >25%)**	**Low (<25%)**
80	37	14
Pteridophyte species richness according to temperature		
High (>25 ºC)	**Medium (>18 ºC, <25 ºC)**	**Low (<18 ºC)**
72	42	12

Abotsi *et al.* (2020) worked on pteridophyte distribution accprding to ecological drivers at Togo (West Africa) and found that some pteridophytes *viz. Acrostichum aureum, Marsilea minuta,* and *Cyclosorus striatus* were mainly found in study zones having lower annual rainfall, higher temperatures. According to the CCA study (Canonical Correspondence Analysis study) it was observed that *Haploteris guineensis, Alsophila camerooniana, Asplenium biafrenum* and *Microgramma mauritiana* was mainly found in high humidity and high precipitation, lower climatic water deficit and cloudiness.

Sureshkumar *et al.* (2020) found a correlation between pteridophyte distribution and different climate variables. According to them, species richness follows two patterns: monotonic and humped. The monotonic richness pattern connected with temperature where optimum temperature was ranging from 15 to 25 ºC. Here species richness was decreased as the temperature increased and the humped pattern was correlated with precipitation and relative humidity. Here the species richness was highest at medium precipitation and relative humidity. The species richness was found very low in 750 to 800 mm rainfall region.

Effect of altitudinal gradient

Regional impact on species richness of pteridophyte is the result of many interacting factors like soil, climatic, topography, latitudinal gradient, altitudinal gradient etc. In the previous part I discussed about soil and climate. Now we will see the effect of altitudinal effect on pteridophyte distribution.

In the study of Patil *et al.* (2016), it was observed that high elevation level (above 1100 m) became the optimum altitude for pteridophyte diversity as it provided the optimum temperature, humidity and other factors. Likewise in the work of Sureshkumar *et al.* (2020), they found total 98 species from Kolli Hills where they found Aspleniaceae as the most dominating family and *Asplenium* sp. as the most diverse taxa. Altitude ranging from 1201 to 1300 m contains the most number of species followed by 1401 to 1500 m. Terrestrial pteridophytes were found maximum and aquatic pteridophytes were found least but there was a gradual decline in the terrestrial species richness above 1500 m. Epiphytic pteirdophytes were mainly found in mid-elevation (700 – 800 m). So it was showing a humped distribution of species richness throughout the elevation gradient same as observed in Kluge *et al.* (2006). But here the terrestrial species richness showed sharp declination above 2500 m and uniform distribution during the pteridophyte species distribution study on elevation gradient at Costa Rica. They did the study on effect of temperature and humidity variables at the elevation gradient for 18 months. There they found that temperature rather humidity has more impact on the limitation of pteridophyte growth. For example, low temperature in high altitude showed negative impact on pteridophyte.

In the study of elevation gradient In Costa Rica, Watkins *et al.* (2006) showed that maximum diversity was found at the elevation range from 1000 to 1600 m among 260 taxa (the elevation range was 30 to 2600 m). *Elaphoglossum* sp., *Trichomanes* sp., *Asplenium* sp., *Hymenophyllum* sp. and *Diplazium* sp. were the most diverse species. Terrestrial taxa were mostly found. Here also the distribution pattern was showing humped pattern reaching height at 1000 m and gradually decreasing at 2600 m.

Shrestha, H.S. and Rajbhandary, S (2019) studied pteridophyte distribution according to altitudinal gradient from Besishahar to Lower Manang, Central Nepal. There they found that Polypodiaceae and Pteridaceae were the most dominating and species were found in the 1000 to 2600 m range. Total species were decreasing from 2000 to 2600 m. There epiphytic species were mainly found. Terrestrial and lithophytic species were mainly found at the range from 1400 – 2000 m.

Effect of habitat disturbance and fragmentation of forest

According to MacArthur and Wilson's (1967) 'Island Biogeography Theory', there are numerous large and small patches of islands in fragmented habitat or inlets, but there is always a 'Main Land' from which the inlets were detached once. The biodiversity of large or small inlets depends on how far or close those are to the 'main land'. Despite the fact that all of the references in my review are going to be for natural and semi-natural forests, the essential principle for fragmented forest and habitat loss will be the same in terms of diversity and distribution studies. Generally, forests are fragmented by various causes *viz.* Human settlement, crop land formation, industrialization, urbanization and this directly links to habitat loss (Wilcox and Murphy, 1985). Among which Urbanization is the leading cause for habitat destruction (McKinney, 2006). Whatever the cause is, it harms the diversity and distribution of local biodiversity as it fragments the forest in many large and small patches. Generally, larger patches contain more species than smaller patches (Bergeron and Pellerin, 2014; Hattori and Ishida, 2000; Murakami and Morimoto, 2000). Most of the pteridophytes are highly sensitive to disturbance and habitat fragmentation. In fragmented and disturbed forest, the alpha diversity of pteridophytes are fewer and lesser than the undisturbed forest as disturbed forests contain less diverse micro-climatic regions (Turner *et al.,* 1994).

Barthlott *et al.* (2001) showed about direct effect of tree clearing on pteridophyte diversity. They made a disturbance intensity gradient in the basis of road transect, relict trees, newly planted tree to the freshly clearing forest clearing and found gradual reduction of epiphytic pteridophytes throughout the disturbance intensity gradient (from more to less disturbance). So this suggests that a little amount of relict trees remaining from primary level forest can be sufficient enough to conserve unique epiphytic taxa from getting locally extinct.

Generally, a fragmented forest always originated from an already existing primary forest and when it is fragmented then it divided in to multiple patches. Each patch consists of core and edge region. Core regions are less disturbed or effected by micro-environmental factors. But the edge areas face unstable environment. So, here only those people can survive those are competitive (pioneer communities and ruderal plants) in nature (LaPaix and Freedman, 2010) generally represented by exotic and invasive species (Cadenasso and Pickett, 2001). So an urban forest is not pristine and it can be easily found out which taxa need conservation the most.

Murakami *et al.* (2005) worked on 39 fragmented forests of Kyoto city. They recorded total 69 species from all the patches of the fragmented forest. The largest patch contained the highest species richness having 37 species and the smallest patch contained 2 species. This finding showed the importance of patch size on species diversity that is also proved by a linear regression by them. But they observed that the effect of patch size varies from species to species. They found in their previous study that polyploid species having simpler reproductive system were found dominantly in fragmented forest than autogamous diploid species because the former one do not need water necessarily to complete its fertilization process like the later one.

Zuquim *et al.* (2009) while working on the effect of forest fragmentation and environmental gradient on pteirdophytes of Central Amazonia, Brazil found that canopy openness due to fragmentation has particular effect on some pteridophytes. For example – pteridophytes like *Trichomanes cristatum, Trichomanes arbuscula* and *Schizaea stricta* were found in 70% canopy openness; *Lomariopsis prieuriana, Lindsaea lancea* and *Adiantum cajennense* were found in all kinds of openness condition; *Adiantum multisorum and Schizaea fluminensis* were strictly found in least open canopy.

Bergeron and Pellerin (2014) worked on the pteridophyte diversity of Hochelaga Archipelago, Canada while searching for some pteridophytes that can be treated as Urban Forest Indicator. There they found edge effect as one of major affecting factor in fragmented urbanized forest and patch size mainly effect vulnerable species as they are sensitive to disturbance. Small patches of forest are more disturbed by urbanization. They measured disturbances by using many factors *viz.* Patch density, street density, proportion of residential area, water bodies, agricultural area, urban heat islands (UHI) etc. They found 82 species among which many were specified and restricted to certain area. For example – a) Pteridophytes which reproduced by green spores (*viz.* Hymenophyllaceae) and those who are more dependent on sexual reproduction were lesser in UHI as water is a must needed thing for sexual reproduction for pteridophytes, so dry soils reduce soil moisture and are adverse situation for that purpose. b) *Equisetum arvense* was high in number towards open area and *Athyrium filix-femina* was less in number at that area. c) Species richness was lesser towards water bodies.

Silva *et al.* (2014) worked on 11 fragmented forests of Alagoas, North-Eastern Brazil. There they found huge differences between large forest from small forest and interior region of forest from edge area of forest. They found total 88 species and the species diversity showed positive correlation with patch size and negative correlation with edge environment as 60.2 % species were found from the interior region of forest among 88 species and 11.3 % belonged to edge area and 28.5 % from both the regions. They reported some species those were restricted to interior region of forest. Those are *Diplazium celtidifolium, Diplazium striatum* and *Hymenoplyllum polyanthus. Pteridium arachnoideum* was exclusively found in edge areas and *Adiantum macrophyllum, Cyathea corcovadensis, Cyathea praecincta, Diplazium plantaginifolium* and *Didymochlaena truncatula* were found in both the regions.

Silva and Schmitt (2015) worked on a fragmented *Aurocaria* forest and found total 33 pteridophyte taxa. The mostly found species belong to was Dryopteridaceae. They divided the study area in to Cravina and Macaco Branco, among which former one was fragmented by agricultural purpose. It was surprising to observe that though in both the cases the species richness gradually reduced from interior of forest to edge but in case of Carvina study area the species richness reduced to half. It showed agricultural impact on forest fragmentation had more effect then other causes in this study. They found the cause for that is in case on interior the soil moisture and thinner plant litter provide favourable condition for pteridophytes and their gametophytic generation whereas at the edge the soil moisture is less the litter layer is thick that can easily catch fire, hence, the environment is unstable. Abotsi *et al.* (2020) also found agricultural impact on pteridophyte when they found agroforestry as major disturbing agent in rain forest included in their study area and the impact mainly affected the epiphytic taxa. According to them, pteridophyte species were more found in homogenous vegetation rather than heterogenous and unstable vegetation.

Silva *et al.* (2018) worked on the edge effect of 2 Mexican forests (2 Montane cloud forests and 2 low land rain forests) on pteridophyte diveristy. They found that the species richness found in the interior and the edge was differing. In every case, the species richness was gradually reducing from interior to edge of forest. But the difference was varying. In case of low land rain forests the difference of species richness between interior to edge area was huge but in case of Montane cloud forests there was not much difference. In all the cases they found that *Pteridium* sp. was mostly found in the edge area as this species is adaptive to disturbance.

Paciencia and Prado (2005) mentioned the effect of habitat loss by forest fragmentation on the species richness in their study of forest fragmentation in a tropical rain forest of Brazil. They found it by comparing different aspects of fragmented forests. For example- small forest v/s large forest, interior of forest v/s forest edge, small edge type v/s large edge type and mature forest v/s fragmented forest etc. Here large forest showed more species than small forest; forest interior showed more species than edge of forest; large edge showed more species than small edge of forest and mature forest showed more species than matrix forest. They found some species those showed the presence of mature forest before fragmentation because those are found in all kinds of forest fragments (both large and small). Those are *Cyathea corcovadensis, Cyclodium heterodon var. abbreviatum, Lomagramma guianensis, Lomariopsis marginata* and *Triplophyllum funestum.* Few had preference for disturbed habitats like edge areas *viz. Lygodium volubile*.

***Can pteridophytes be actively used as Ecological Indicator*?**

Pteridophytes can grow in different environments including different climates, soil conditions and natural habitats. But wherever these plants grow, these are very much susceptible to habitat loss, pollution and fragmentation (if they grow in forest). Previously, lower groups of plants like bryophytes and lichens were used to indicate such kind of disturbances (LeBlanc and De Sloover, 1970; Oishi and Morimoto, 2016). But for few years pteridophytes are also introduced in the scene. Basically, all the records of pteridophyte diversity according to different environmental factors can be used as indicating orgnanisms if their growths are restricted to those factors. For example, the fragmentation causing patch area mainly effect on vulnerable species and locally rare species (Bergeron and Pellerin, 2014).

There is a condition for making the taxa of any community as an indicator. If the species richness of any forest is least then no taxa can be used as indicator species (Bergeron and Pellerin, 2014). A taxon can be either negative or positive indicator. Bergeron and Pellerin (2014) had almost 18 species in their work those can be used as indicator species. Among which *Equisetum arvense* and *Pteridium aquilinum* were indicating dry soil, intense light and disturbed habitat; *Athyrium filix-femina* and *Dryopteris carthusiana* were indicating specifically moist and shady habitats; *Onoclea sensibilis, Osmundastrum cinnamomeum* and *Osmunda claytoniana* were indicating Low Urban Heat Islands.

Zuquim *et al.* (2014) studied about the environmental gradient effect on Pteridophyte in the Brazillian Amazonia. There they found numerous species showed distribution in specific factors like annual rainfall, clay content, slit content, cation base etc. For example – *Trichomanes pinnatum* along with few *Adiantum* and *Lindsea* species indicated poorer soils and total high annual rainfall.

Among all the articles I was vastly enriched by going through the overview of Pteridophytes as indicator species by Della and Falkenberg (2019). In their study they listed many journals having numerous pteridophytes those taken as indicator species.

Mehrabian *et al.* (2020) showed a list of pteridophytes showing specific elevation range of Iranian pteridophytes. For example - *Asplenium ceterach subsp. ceterach* showed elevation range from 20 – 2500 m.; *Pteridium aquilinum* showed elevation range from 0 – 2047 m., *Dryopteris filix-mas* showed elevation range from 20- 3000 m. etc. and 57 more. So these species can be used as elevation indicator. In their study they also found *Pteirdium aquilinum* as mostly found in secondary and disturbed habitat.

According to Abotsi *et al.* (2020), indicator species grow well in homogenous vegetation and epiphytic pteridophytes got extinct more in disturbed forests. They used the indicator species to distinguish 5 ecological zones of Togo (a country situated in Gulf of Guinea in West Africa) those they divided according to topography and mean annual rainfall. For example- there was no proper indicator species for Zone-1 and Zone-4 but Zone-2 was denoted by presence of *Anemia sessilis*; Zone-3 was denoted by presence of *Platycerium elephantotis*; Zone-2 and zone-3 were denoted by presence of *Adiantum soboliferum* and Zone-5 was denoted by many species like *Cyclosorus striatus, Acrostichum aureum, Ceratopteris thalictroides, Marsilea minuta, Salvinia auriculata* and *Salvinia nymphellula*. They also used some indicator species in showing some specific type of forests. For example – Rainforest was indicated by *Pellaea doniana*; Agroforest was indicated by *Pteris togoensis*; Dry forest was indicated by *Adiantum soboliferum*; Palm grove was indicated by *Nephrolepis bisserata, Microsorum scolopendria* and *Nephrolepis undulata*; Savanna or Woodland was indicated by *Nephrolepis cordifolia*; Meadow was indicated by *Salvinia auriculata*; Mangrove forest was indicated by *Acrostichum aureum*. Finally some species were used as disturbance indicator *viz. Pellaea doniana* was used for minor disturbed habitat, *Pteris togoensis* was used for moderately disturbed habitat and *Selaginella myosurus* was used for maximum disturbed habitat.

Priambudi *et al.* (2022) worked on 2 forests of Belitung, Indonesia and they showed that *Dicranopteris linearis* as indicator of highly disturbed habitats. They also mentioned about some indicator species those were sensitive to some specific environmental factors. For example – *Lycopodium clavatum* was affected by temperature; *Palhinhaea cernua* was affected by humidity and altitude; *Pronephrium asperum* and *Pteris semipinnata* was affected by humidity and temperature; *Diplazium angustipinna, Palhinhaea cernua, Pteris vittata, Selaginella ciliaris* and *Tectaria heracleifolia* were affected by altitude.

Costa *et al.* (2023) used some epiphytic species as indicator species of specific altitude of 2 slopes of a mountain of Atlantic forest (Brazil) in the study of epiphytic pteridophytic species through to altitudinal gradient. For example - *Campyloneurum herbaceum* and *Polyphlebium angustatum* mainly grew at 1200 m. of eastern slope but there was no indicator species for western slopes; *Asplenium oligophyllum* and *Asplenium scandicinum* mainly grew at 1400 m. in eastern slope and *Campyloneurum nitidum* mainly grow at 1400 m. in western slopes; *Pleopeltis macrocarpa* grew at 1600 m. in western slope but no indicator species were there for eastern slope etc. so, it showed that the species growth vary in same altitude if they grow in different slopes.

The Scenario in India:

In India, few studies have examined the effects of ecological factors on pteridophyte distribution, and there is a notable lack of research identifying specific indicator species. For example, Sureshkumar et al. (2020) investigated the influence of elevation gradients on pteridophyte richness, focusing primarily on various life forms and overall species diversity, without designating any species as indicators. Similarly, Patil et al. (2016) studied the relationships between pteridophyte species richness and factors such as elevation, rainfall, temperature, and humidity, yet they did not identify any particular pteridophyte as indicative of specific environmental conditions.

In another study, Sharma and Uniyal (2016) focused on a single taxon, *Pyrrosia flocculosa*, in the Kangra district of Himachal Pradesh (Western Himalaya) to assess its potential as a bioindicator for heavy metal accumulation. They categorized areas into urban (highly disturbed, adjacent to roads), village (moderately disturbed), and interior (least disturbed), finding that heavy metal accumulation increased with the level of disturbance. Despite this, the study did not extend to a broader evaluation of ecological variants across different pteridophyte species. Similarly, Padmawathe et al. (2004) explored vascular epiphytes in the moist lowland forests of the Eastern Himalaya, identifying correlations between species richness, humidity, and temperature, but without singling out any species as an ecological indicator. Additionally, Singh (2011) noted a relationship between *Platicerium wallichii* and rainfall; however, this association was not statistically validated.

Sen *et al.* (2011) did research on the diversity and they analysed some edaphic factors where the pteridophytes were found. This study was done in Nadia district, West Bengal. However there is no correlation between the taxa and the edaphic factors was shown in the study. Many others works

A review by Della and Falkenberg (2019) on pteridophytes as ecological indicators provided valuable insights by synthesizing global research, including some studies from India that focused on ecological factors affecting pteridophyte richness. Nevertheless, their work was largely descriptive and concentrated on individual species rather than addressing broader ecological gradients.

Habitat fragmentation, a major driver of environmental change in India, is increasingly impacting both natural and semi-natural forests that harbour many rare and ecologically significant pteridophytes. While numerous studies worldwide have addressed the effects of forest fragmentation on pteridophytes, similar research in India remains scarce. Given the critical role of pteridophytes in forest ecology and conservation, it is imperative to conduct further studies to understand how ecological factors, particularly habitat fragmentation, affect their distribution. Such research is essential for developing effective conservation strategies to protect these valuable components of India's biodiversity (Chan *et al.,* 2016).

CONCLUSIONS

Collectively, evidence from around the world demonstrates that pteridophytes are reliable bio-indicators of ecological change, owing to their pronounced sensitivity to soil properties, climate variability, elevation gradients, and disturbance regimes. Although a few stress-tolerant species—most notably *Pteris vittata*, *Equisetum arvense* and *Pteridium aquilinum*—can persist across a range of conditions, the majority of ferns and lycophytes respond sharply to even subtle environmental shifts. In the context of escalating conservation concerns, habitat loss—especially through forest fragmentation—emerges as a principal threat to their diversity. Notably, while much research has concentrated on biodiversity hotspots such as the Himalayas, the Indo-Burma region, and large tracts of primary forest (e.g. the Sundarbans and Eastern Ghats), smaller or managed woodlands—including planted, secondary and remnant patches—also support rare and vulnerable pteridophyte taxa. As these local populations face increasing pressures from rapid urbanization, there is a pressing need to expand our understanding of pteridophyte ecology. In particular, identifying new indicator species and clarifying their responses in both natural and urban-forest settings will be critical for informing conservation strategies and promoting the sustainable stewardship of our botanical heritage.

ACKNOWLEDGMENTS

I wish to express my sincere gratitude to Dr. Sandip More (Asst. Prof.,Dept. of Botany, Murshidabad University) whose continuous guidance and support helped me to complete the review work.

REFERENCES

Abotsi KE, Bose R, Adjossou K, Deblauwe, V, Rouhan G, Segla K.N, Atsri KH and Kokou K (2020). Ecological drivers of pteridophyte diversity and distribution in togo (West Africa). *Ecological Indicators*, *108*, p.105741

Aldasoro JJ, Cabezas F and Aedo C (2004). Diversity and distribution of ferns in sub-Saharan Africa, Madagascar and some islands of the South Atlantic. *Journal of Biogeography*, *31*(10), pp.1579-1604.

Acebey AR, Krömer T and Kessler M (2017). Species richness and vertical distribution of ferns and lycophytes along an elevational gradient in Los Tuxtlas, Veracruz, Mexico. *Flora*, *235*, pp.83-91.

Acuña-Tarazona M, Mehltreter K, Toledo-Aceves T, Sosa VJ, Flores-Palacios A and Kessler M (2022). Effects of microenvironmental factors on the diversity and composition of fern and orchid assemblages in an Andean paramo in Peru. *Flora*, *293*, p.152107.

Bandyopadhyay S and Mukherjee SK (2014). A contribution to the fern flora of Howrah District in West Bengal, India. *International Journal of Pharmacological Screening Methods*, *4*(1), pp.1-3

Barthlott W, Schmit-Neuerburg V, Nieder J and Engwald S (2001). Diversity and abundance of vascular epiphytes: a comparison of secondary vegetation and primary montane rain forest in the Venezuelan Andes. *Plant ecology*, *152*, pp.145-156

Bergeron A and Pellerin S (2014). Pteridophytes as indicators of urban forest integrity. *Ecological Indicators*, *38*, pp.40-49

Boyce CK (2008). How green was *Cooksonia*? The importance of size in understanding the early evolution of physiology in the vascular plant lineage. *Paleobiology*, *34*(2) pp.179-194

Cadenasso ML and Pickett ST (2001). Effect of edge structure on the flux of species into forest interiors. *Conservation Biology*, *15*(1), pp.91-97

Chan KM, Balvanera P, Benessaiah K, Chapman M, Díaz S, Gómez-Baggethun E, Gould R, Hannahs N, Jax K, Klain S and Luck GW (2016). Why protect nature? Rethinking values and the environment. *Proceedings of the national academy of sciences*, *113*(6), pp.1462-1465
Chowdhury A, Sarkar S and Chowdhury M (2016). Diversity, Ecology and Utilization of Tea Garden Pteridophytes at Duars in West Bengal, India. *Int. Res. J. Biological Sci*, *5*(1), pp.47-53
Costa TV, Nunes-Freitas AF and Sylvestre LDS (2023). Understory epiphytic pteridophytes along altitudinal gradients on opposite slopes in the Atlantic Forest. *Rodriguésia*, *74*, p.e00702023
Deepa J, Parashurama TR, Krishnappa M and Nataraja S (2013). Distribution of pteridophytes in kigga forest, Central western Ghats, Karnataka, South India. *Indian Fern Journal*, *30*, pp.18-24
Della AP and Falkenberg DDB (2019). Pteridophytes as ecological indicators: an overview. *Hoehnea*, *46*, p.e522018
Fraser-Jenkins CR, Gandhi KN, Kholia BS and Benniamin A (2017). *An annotated checklist of Indian Pteridophytes*. Dehra Dun: Bishen Singh Mahendra Pal Singh. pp. 562
Holttum RE (1938). The ecology of tropical pteridophytes in the *Manual of pteridology* (pp.420-450). Dordrecht: Springer Netherlands.
Greer GK, Lloyd RM and McCarthy BC (1997). Factors influencing the distribution of pteridophytes in a southeastern Ohio hardwood forest. *Journal of the Torrey Botanical Society*, pp.11-21.
Ibars AM and Estrelles E (2012). Recent developments in ex situ and in situ conservation of ferns. *Fern gazette*, *19*(3), p.67
Hattori T, Ishida H (2000). Relationship between species diversity, species composition and forest area of fragmented Lucidophyllous forests in central Miyazaki prefecture. *Japanese Journal of Ecology*, 50, 221–234.
Jones MM, Tuomisto H, Borcard D, Legendre P, Clark DB and Olivas PC (2008). Explaining variation in tropical plant community composition: influence of environmental and spatial data quality. *Oecologia*, *155*, pp.593-604
Kluge J, Kessler M and Dunn RR (2006). What drives elevational patterns of diversity? A test of geometric constraints, climate and species pool effects for pteridophytes on an elevational gradient in Costa Rica. *Global ecology and biogeography*, *15*(4), pp.358-371
Kreft H, Jetz W, Mutke J and Barthlott W (2010). Contrasting environmental and regional effects on global pteridophyte and seed plant diversity. *Ecography*, *33*(2), pp.408-419
LaPaix R, Freedman B (2010). Vegetation structure and composition within urban parks of Halifax regional municipality, Nova Scotia, Canada. Landsc. *Urban Planning,* 98,124–135
LeBlanc SF and Sloover JD (1970). Relation between industrialization and the distribution and growth of epiphytic lichens and mosses in Montreal. *Canadian journal of botany*, *48*(8), pp.1485-1496
Lehmann A, Leathwick JR and Overton JM (2002). Assessing New Zealand fern diversity from spatial predictions of species assemblages. *Biodiversity & Conservation*, *11*, pp.2217-2238
McKinney ML (2006). Urbanization as a major cause of biotic homogenization. *Biological Conservation*, 127, pp.247–260
Mehltreter K, Walker LR. and Sharpe JM (2010). *Fern ecology*. Cambridge University Press
Mehrabian A, Nasab FK, Fraser-Jenkins CR and Tajik F (2020). Distribution Patterns and Priorities for Conservation of Iranian Pteridophytes. *Fern gazette*, *21*(4), pp. 141-160
Moulatlet G, Zuquim G and Tuomisto H (2019). The Role of Soils for Pteridophyte Distribution In Tropical American Forests. *Fern Gazette*, *21*(1)
Murakami K, Maenaka H and Morimoto Y (2005). Factors influencing species diversity of ferns and fern allies in fragmented forest patches in the Kyoto city area. *Landscape and Urban Planning*, *70*(3-4), pp.221-229

Murakami K and Morimoto Y (2000). Landscape ecological study on the woody plant species richness and its conservation in fragmented forest patches in the Kyoto city area. *Journal of the Japanese Society of Revegetation Technology*, 25 (4), 345–350

Norton DA (1994). Relationships between pteridophytes and topography in a lowland South Westland podocarp forest. *New Zealand Journal of Botany*, *32*(4), pp.401-408

Oishi Y and Morimoto Y (2016). Identifying indicator species for bryophyte conservation in fragmented forests. *Landscape and Ecological Engineering*, *12*, pp.107-114

Paciencia MLB and Prado J (2005). Effects of forest fragmentation on pteridophyte diversity in a tropical rain forest in Brazil. *Plant Ecology*, *180*(1), pp.87-104

Padmawathe R, Qureshi Q and Rawat GS (2004). Effects of selective logging on vascular epiphyte diversity in a moist lowland forest of Eastern Himalaya, India. *Biological Conservation*, *119*(1), pp.81-92

Page C (1964). Ecological notes on the Pteridophytes in the north-eastern area of La Palma. *Expedition to La Palma (Canary Islands)*, pp.44-47

Patil S, Lavate R, Rawat V and Dongare M (2016). Diversity and distribution of pteridophytes from Satara District, Maharashtra (India). *Plant Science Today*, *3*(2), pp.149-156.

Poulsen AD, Tuomisto H and Balslev H (2006). Edaphic and Floristic Variation within a 1-ha Plot of Lowland Amazonian Rain Forest 1. *Biotropica*, *38*(4), pp.468-478

Parashurama TR, Deepa J and Kariyajjanavar P (2016). Pteridophyte diversity in mudigere taluk, Central Western Ghats, Karnataka, South India. *International Journal of Current Research*, *8*(10), pp.40339-42

Priambudi AS, Chikmawati T, Sulistijorini S and Fakhrurrozi Y (2022). Diversity and ecology of Pteridophytes in Cendil heath forest and Gurok Beraye tropical rainforest, Belitung Island, Indonesia. *Biodiversitas Journal of Biological Diversity*, *23*(9)

Richard M, Bernhardt T and Bell G (2000). Environmental heterogeneity and the spatial structure of fern species diversity in one hectare of old-growth forest. *Ecography*, *23*(2), pp.231-245

Robinson RC (2000). The means to large-scale, effective bracken clearance in the UK. *Bracken Fern: toxicity, biology and control*, pp.156-162.

Rodriguez-Loinaz G, Onaindia M, Amezaga I, Mijangos I and Garbisu C (2008). Relationship between vegetation diversity and soil functional diversity in native mixed-oak forests . *Soil Biology and Biochemistry*, *40*(1), pp.49-60

Rowley DB, Raymond A., Parrish JT, Lottes AL, Scotese CR and Ziegler AM (1985). Carboniferous paleogeographic, phytogeographic, and paleoclimatic reconstructions. *International Journal of Coal Geology*, *5*(1-2), pp.7-42.

Ruokolainen K, Linna A and Tuomisto H (1997). Use of Melastomataceae and pteridophytes for revealing phytogeographical patterns in Amazonian rain forests. *Journal of Tropical Ecology*, *13*(2), pp.243-256.

Salovaara KJ, Cárdenas GG and Tuomisto H (2004). Forest classification in an Amazonian rainforest landscape using pteridophytes as indicator species. *Ecography*, *27*(6), pp.689-700

Schneider H, Schuettpelz E, Pryer KM, Cranfill R, Magallón S and Lupia R (2004). Ferns diversified in the shadow of angiosperms. *Nature*, *428*(6982), pp.553-557.

Schuettpelz E and Pryer KM (2009). Evidence for a Cenozoic radiation of ferns in an angiosperm-dominated canopy. *Proceedings of the National Academy of Sciences*, *106*(27), pp.11200-11205.

Sen T, Sen U, Chakraborty K, Rahaman S and Paul R (2011). Floral survey of ferns of Nadia district, West Bengal. *Indian Fern J*, *28*, pp.85-104

Sen UK (2018). Assessment of diversity, population structure, regeneration and conservation status of tree species in a sacred grove of west Midnapore district, West Bengal, India. *Assessment*, *3*(3)

Shankar U (2001). A case of high tree diversity in a sal (Shorea robusta)-dominated lowland forest of Eastern Himalaya: Floristic composition, regeneration and conservation. *Current Science*, pp.776-786

Sharma A and Uniyal SK (2016). Heavy metal accumulation in *Pyrrosia flocculosa* (D. Don) Ching growing in sites located along a vehicular disturbance gradient. *Environmental monitoring and assessment*, *188*, pp.1-12

Sheffield E, Robinson RC, Sharpe JM, Mehltreter K and Walker LR (2010). Problem ferns: their impact and management. In *Fern Ecology* .Cambridge University Press. pp. 255-322

Silva IA, Pereira AFDN and Barros IC (2014). Fragmentation and loss of habitat: consequences for the fern communities in Atlantic forest remnants in Alagoas, north-eastern Brazil. *Plant Ecology & Diversity*, *7*(4), pp.509-517

Silva VLD. and Schmitt JL (2015). The effects of fragmentation on Araucaria forest: analysis of the fern and lycophyte communities at sites subject to different edge conditions. *Acta Botanica Brasilica*, *29*(2), pp.223-230

Silva VL, Mehltreter K and Schmitt JL (2018). Ferns as potential ecological indicators of edge effects in two types of Mexican forests. *Ecological indicators*, *93*, pp.669-676

Singh HB (2011). Plants associated in forecasting and beliefs within the Meitei community of Manipur, Northeast India; 10, pp. 190-193

Singh C, Kumar B, Rani A, Dhyani K and Singh R (2017). Biodiversity and conservation Ferns Diversity in different forests of Dehradun district. *International Journal of Pharmacy Research & Technology (IJPRT)*, *7*(2), pp.1-7

Shrestha HS and Rajbhandary S (2019). Floristic study of fern and fern allies along altitudinal gradient from Besishahar to lower Manang, Central Nepal. *Journal of Plant Resources*, *17*(1), pp.29-34

Sureshkumar J, Ayyanar M and Silambarasan R (2020). Pteridophyte species richness along elevation gradients in Kolli Hills of the Eastern Ghats, India. *Journal of Asia-Pacific Biodiversity*, *13*(1), pp.92-106

Tripathi AK and Shankar U (2014). Patterns of species dominance, diversity and dispersion in 'Khasi hill sal'forest ecosystem in northeast India. *Forest Ecosystems*, *1*, pp.1-20.

Tuomisto H and Poulsen AD (1996). Influence of edaphic specialization on pteridophyte distribution in neotropical rain forests. *Journal of biogeography*, *23*(3), pp.283-293

Tuomisto H, Poulsen AD and Moran RC (1998). Edaphic Distribution of Some Species of the Fern Genus *Adiantum* in Western Amazonia 1. *Biotropica*, *30*(3), pp.392-399

Tuomisto H and Poulsen AD (2000). Pteridophyte diversity and species composition in four Amazonian rain forests. *Journal of vegetation Science*, *11*(3), pp.383-396

Tuomisto H, Poulsen AD, Ruokolainen K, Moran RC, Quintana C, Celi J and Cañas G (2003). Linking floristic patterns with soil heterogeneity and satellite imagery in Ecuadorian Amazonia. *Ecological applications*, *13*(2), pp.352-371.

Tuomisto H and Ruokolainen K (1994). Distributionof Pteridophyta and Melastomataceae along an edaphic gradient in an Amazonian rain forest.*Journal of vegetation Science*,*5*(1),pp.25-34

Tuomisto H, Ruokolainen K, Poulsen AD, Moran RC, Quintana C, Can˜as G, and Celi J (2002). Distribution and Diversity of Pteridophytes and Melastomataceae along Edaphic Gradients in Yasunı´ National Park, Ecuadorian Amazonia. BIOTROPICA 34(4): 516–533

Turner IM, Tan HT W, Wee YC, Ibrahim AB, Chew PT and Corlett RT (1994). A study of plant species extinction in Singapore: Lessons for the conservation of tropical biodiversity. Cons. Biol. 8(3): 705–712

Watkins Jr, J.E, Cardelús C, Colwell RK and Moran RC (2006). Species richness and distribution of ferns along an elevational gradient in Costa Rica. *American Journal of Botany*, *93*(1), pp.73-83

Watkins Jr, JE and Cardelús CL (2012). Ferns in an angiosperm world: Cretaceous radiation into the epiphytic niche and diversification on the forest floor. *International Journal of Plant Sciences*, *173*(6), pp. 695-710.

Wilcox BA and Murphy DD (1985). Conservation strategy: the effects of fragmentation on extinction. *The American Naturalist*, *125*(6), pp. 879-887

Wilson EO and MacArthur RH (1967). *The theory of island biogeography* (Vol. 1). Princeton, NJ: Princeton University Press

Ziegler AM (1990). Phytogeographic patterns and continental configurations during the Permian Period. *Geological Society, London, Memoirs*, *12*(1), pp.363-379

Zuquim G, Costa FR, Prado J and Braga-Neto R (2009). Distribution of pteridophyte communities along environmental gradients in Central Amazonia, Brazil. *Biodiversity a.* 18(1):151-166

Zuquim G, Tuomisto H, Jones MM, Prado J, Figueiredo FO, Moulatlet GM, Costa FR, Quesada CA and Emilio T (2014). Predicting environmental gradients with fern species composition in Brazilian Amazonia. *Journal of Vegetation Science*, *25*(5), pp.1195-1207