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Habitat preferences of cosmopolite ferns in lowland abandoned rice fields of Manokwari: Potential risks of population outbreak

Slamet Arif Susanto[1*], *Heru Joko* Budirianto[1], *Pramesty Wulan* Ramadhanty[1], *Simon* Sutarno[1], *Paskalina Theresia* Lefaan[1], *Fajar Ria Dwi Natalia* Sianipar[1], *Agatha Cecilia* Maturbongs[1], *Johanis Paulus* Kilmaskossu[2], and *Afri* Irawan[3]

[1]Universitas Papua, Department of Biology, 98314 Jalan Gunung Salju Amban, Manokwari, Papua Barat, Indonesia
[2]Universitas Papua, Department of Biology Education, 98314 Jalan Gunung Salju Amban, Manokwari, Papua Barat, Indonesia
[3]Universitas Pendidikan Indonesia, Biology Study Program, Jalan Dr. Setiabudhi No. 229 Bandung, Indonesia

Abstract. Ecological studies of cosmopolite ferns are necessary to predict population explosions and potential invasions in an ecosystem. This study investigated habitat preferences, abundance, and adaptation of three cosmopolite fern species, *Stenochlaena palustris* (Burm. f) Bedd., *Thelypteris interrupta* (Willd.) K. Iwats., and *Nephrolepis biserrata* (Sw.) Schott in abandoned lowland rice fields in Sidey District, Manokwari Regency, West Papua Province, Indonesia. Field observations were conducted using vegetation analysis with quadrats. The results showed that the abundance of *S. palustris*, *T. interrupta*, and *N. biserrata* was 76 ± 12, 77 ± 14, and 57 ± 9 individuals/m^2, respectively. The study revealed that *S. palustris* and *T. interrupta* preferred open habitats with high light intensity, high moisture, and acidic soils (pH < 5), whereas *N. biserrata* had distinct habitat preferences. Multivariate analysis showed that environmental factors explained 93.7% of the data variation, and habitat-sharing was observed between *S. palustris* and *T. interrupta*. These findings suggest that *S. palustris* and *T. interrupta*, which prefer open habitats and acidic soils, may be able to invade abandoned rice fields. This study provides insights into the ecological adaptations of these fern species and their potential invasions.

1 Introduction

Ferns exhibit remarkable habitat variability owing to their spore-based reproduction, making them often used as ecological indicators for ecosystem recovery. The habitats of ferns include their ability to thrive epiphytically on other plants [1], adapt to areas contaminated with heavy metals [2], survive in high-altitude environments [3], and tolerate nutrient-poor soils with extremely acidic pH levels [4]. In tropical rainforest ecosystems, ferns are adapted to environments with high humidity, high water content, and intense light. Terrestrial ferns with cosmopolite properties tend to dominate various habitats in tropical rainforest ecosystems, potentially leading to invasion of other ecosystems.

Changes in ecological landscapes can alter the biophysical characteristics of an ecosystem. Such changes can also drive ecological succession and modify the vegetation cover. Terrestrial ferns with cosmopolite properties tend to fill ecological niches during landscape changes. These plants rapidly adapt by increasing their abundance and biomass. For example, the fern *Stenochlaena palustris* (Burm.f.) Bedd dominates peatland areas that were previously rice fields with extreme soil acidity levels [5], and this species has also been reported to invade areas in Bukit Duabelas National Park in Jambi [6]. In shaded areas, *Nephrolepis biserrata* (Sw.) Schott can become difficult to control in palm oil plantations, but it can also inhibit the growth of other weeds [7]. Another cosmopolite fern species, *Thelypteris interrupta* (Willd.) K. Iwats can thrive in areas prone to flooding. Recently, it was reported that *T. interrupta* prefers wetland habitats with high light intensity in swampy areas [8]. Therefore, habitat preferences of cosmopolite ferns are of great interest for further study.

Investigating the habitat preferences of cosmopolite ferns is crucial in the Manokwari Regency, West Papua Province, Indonesia. Facts show that several lowland wetland areas in Manokwari have undergone transformation into rice fields since the 1980s as part of the government's efforts to redistribute the population through a transmigration program. However, many of these rice fields have been abandoned and no longer used for agricultural purposes. These abandoned areas have undergone ecological succession, resulting in the dominance of cosmopolite ferns such as *S. palustris* and *Lygodium microphyllum* (Cav.) R.Br. [9], and *T. interrupta* and *N. biserrata*. The dominance of these fern species is suspected to be due to their rapid growth rate through vegetative reproduction via rhizomes and generative reproduction via spores, which could potentially lead to the invasion of abandoned rice fields. Despite this, no studies have examined the habitat preferences of these three fern species in abandoned

* Corresponding author: s.susanto@unipa.ac.id

lowland rice fields in Manokwari, West Papua. Therefore, this study aimed to analyze and determine the abundance, habitat preferences, and adaptations of the cosmopolite ferns *S. palustris*, *T. interrupta*, and *N. biserrata* in the abandoned lowland rice fields in Manokwari Regency, West Papua Province, Indonesia.

2 Materials and Methods

2.1 Research location

This study was conducted in an abandoned lowland rice field area in Sidey District, Manokwari Regency, West Papua Province, Indonesia (0° 45' 35.3″ S to 0° 45' 36.7″ S; 133° 26' 35.5″ E to 133° 33' 17.3″ E) in January 2025. The research locations are shown in Fig 1.

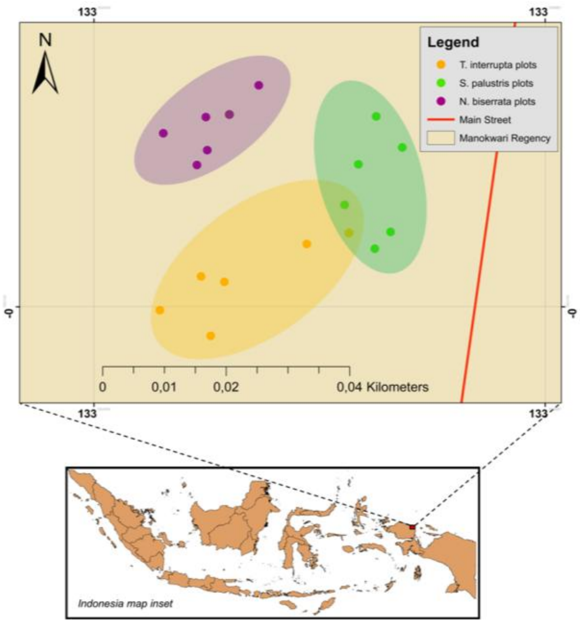

Fig 1. Sampling points and research location coordinates.

The entire study area consists of abandoned rice fields that had been left for approximately eight years. The dominant vegetation type in the area is shrub-like with a height of 1-2 meters. Almost 90% of the study area is intensively exposed to sunlight, except for the edges of the area that are shaded by vegetation such as coconut (*Cocos nucifera* L.), mango (*Mangifera indica* L.), and kapok (*Ceiba pentandra* (L.) Gaertn.), teak (*Tectona grandis* L.), *Nauclea orientalis* (L.) L., and *Premna odorata* Blanco.

The study area has a tropical rainforest climate (Af type), characterized by a high annual rainfall of 1500-3500 mm [10]. The soil type was predominantly red-yellow podzolic with high clay content. Additionally, the climate of the location is influenced by the Pacific Ocean because of its proximity.

2.2 Research procedures

First, we determined the age and history of the land being studied, based on information from landowners. Next, we explored the land. The area we studied covered 0.75 ha, dominated by cosmopolite ferns such as *S. palustris*, *T. interrupta*, and *N. biserrata*. Other plant species abundant in the study area included *Merremia peltata* Merr., *Mikania micrantha* Kunth, *Mimosa pudica* L., and *Ludwigia grandiflora* (Michx.) Greuter & Burdet. The third step involved purposive sampling of the habitats occupied by *S. palustris*, *T. interrupta*, and *N. biserrata*. Within the 0.75 ha area, we established six sampling points for each studied fern species (resulting in a total of 18 sampling points). Each sampling point used a 0.5 m^2 quadrat. Our observations relied exclusively on visual assessments of fern dominance; therefore, some degree of habitat overlap may have occurred, although efforts were made to minimize this overlap. The final step involved recording and counting the ferns within each quadrat and measuring environmental parameters, such as soil temperature, soil moisture, soil pH, and light intensity.

2.3 Data analysis

All the data collected from the field were validated and subjected to a series of normality and reliability tests. The abundances of *S. palustris*, *T. interrupta*, and *N. biserrata* were compared using analysis of variance (ANOVA) followed by Tukey's test at a p-value < 0.05. Meanwhile, to determine the habitat preferences of the three cosmopolite fern species studied, principal component analysis (PCA) based on eigenvalues was employed. All data visualizations and analyses were performed using SPSS v. 27 and Past 4.03 software.

3 Result and Discussion

3.1 Overview of the study area

The biophysical parameters measured revealed distinct differences in the habitats of the three fern species. *S. palustris* and *T. interrupta* thrived in conditions of high soil moisture and high light intensity, whereas *N. biserrata* preferred habitats with lower soil moisture and reduced light intensity. The measurements of the environmental parameters are summarized in Table 1.

From habitat observations, it is clear that *S. palustris* and *T. interrupta* have similar habitat preferences. As shown in Fig 2, our observations indicate that *S. palustris* and *T. interrupta* tend to prefer habitats with direct sunlight, whereas *N. biserrata* prefers areas with partial shade. The results confirmed that the purposively selected sampling points (Fig 1) were representative of the study area. The grouping of fern habitats shows that each cosmopolitan fern species has a different adaptation capacity; therefore, its distribution potential will also be different, as reported by Alcala et al. [11], who studied fern habitats at different altitudes.

Table 1. Environmental parameter ranges measured in plots of cosmopolite ferns.

No	Environmental parameters	Species		
		S. palustris	*T. interrupta*	*N. biserrata*
1	Soil temperatures (ºC)	28–30	27–29	25–28
2	Soil humidity (%)	85–87	81–89	62–70
3	Soil pH	4.0–5.5	4.5–5.5	6.0–6.8
4	Light intensity (lux)	1210–1885	1196–1968	398–789

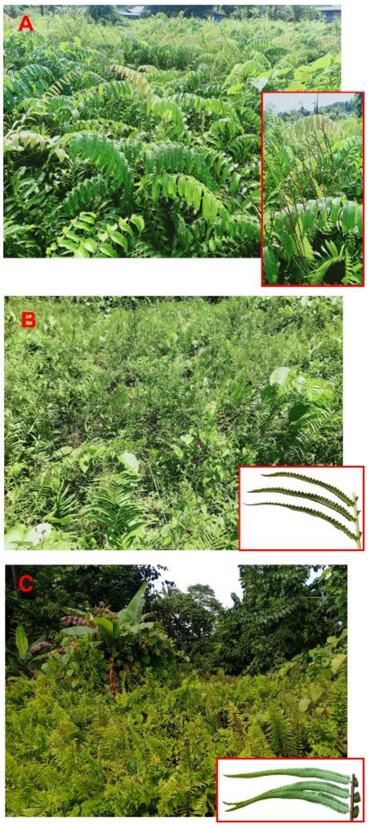

Fig 2. Research location conditions and habitat preferences of cosmopolite ferns. Note: A. *S. palustris*; B. *T. interrupta*; and C. *N. biserrata*. Inset photos show the characteristics of sporophylls (spore-producing leaves).

3.2 Abundance of cosmopolite ferns

Within a small study area, *S. palustris* and *T. interrupta* reached densities of approximately 100 individuals per square metre (Fig 3). No significant difference was found in the abundance of *S. palustris* and *T. interrupta* ($p > 0.05$); however, both species differed significantly from *N. biserrata* ($p < 0.05$) (Fig 3). The abundance of *S. palustris* ranged from 64 to 88 individuals/m², while *T. interrupta* ranged from 63 to 90 individuals/m², suggesting similar abundance patterns in the ecosystem. In contrast, *N. biserrata* had a lower abundance, ranging from 48 to 66 individuals/m². This difference suggests that *N. biserrata* has narrower habitat preferences, lower competitiveness, and more limited environmental tolerance than *S. palustris* and *T. interrupta*.

The high abundance of *S. palustris* and *T. interrupta* in abandoned rice fields was predicted to enable them to invade other abandoned rice fields. Previous studies have shown that *S. palustris* and *T. interrupta* can tolerate highly acidic soil conditions and full sunlight [6], [8], [11]. Relatively acidic soil and high light intensity are characteristic of abandoned rice fields, making them susceptible to invasion by these species. Therefore, the invasive potential of both ferns is high. Moreover, we hypothesized that residual fertilizers and pesticides in the soil may trigger population explosions of *S. palustris* and *T. interrupta*, as they can accumulate heavy metals, including pesticide residues, to build their biomass [2], [12]. Specifically, *S. palustris* has a sprawling rhizome that can rapidly produce new individuals, further increasing its invasive potential.

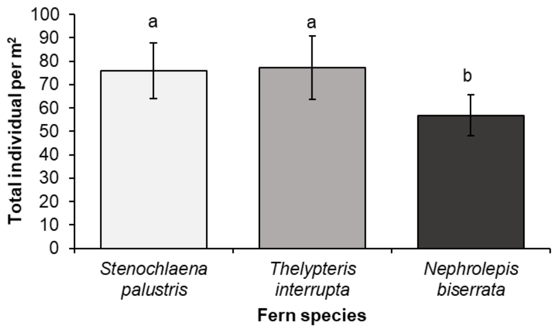

Fig 3. Abundance of *S. palustris*, *T. interrupta*, and *N. biserrata* (mean ± SD). Error bars indicate standard deviation. Different letters above the error bars indicate significant differences based on Tukey's test ($p < 0.05$).

3.3 Habitat sharing phenomenon: empirical evidence and quantitative multivariate analysis

We found a habitat-sharing phenomenon between *S. palustris* and *T. interrupta* (Fig 4), which was observed in two out of six sampling locations. However, the environmental parameters of the habitats occupied by *S. palustris* and *T. interrupta* were similar across all four sampling points studied. The habitat-sharing phenomenon between *S. palustris* and *T. interrupta* can be attributed to their similar adaptation patterns and relatively similar habitat tolerance. Observations showed that the habitats of *S. palustris* and *T. interrupta* tended to be more waterlogged, humid, and exposed to intense light, resulting in lower soil pH compared to areas occupied by *N. biserrata*. Habitat sharing has also been reported in previous studies, and is common among several fern species, such as *Athyrium filix-femina* L. Roth with *Osmunda regalis* L., which forms alliances that dominate riparian areas [13].

Biplot analysis showed that *S. palustris* and *T. interrupta* clustered together and were distinct from *N.*

biserrata. The principal component analysis revealed that environmental factors accounted for 93.7% of the influence on the abundance of the three fern species (Fig 5). The first axis explained 82.9% of the influence of environmental factors, whereas the second axis explained 10.8%. This analysis indicated that *S. palustris* and *T. interrupta* were strongly influenced by high light intensity, high soil moisture, and low soil pH. In contrast, *N. biserrata* tended to prefer high pH levels.

Fig 4. The phenomenon of habitat sharing between *S. palustris* and *T. interrupta*. White color represents clusters of *T. interrupta*. The inset illustrates the flooded soil conditions.

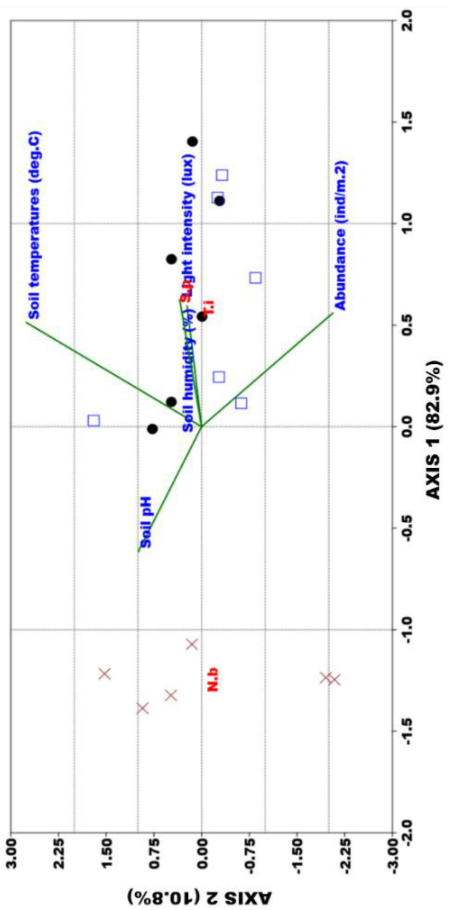

Fig 5. Two-dimensional biplot showing the relationship between environmental factors and the abundance of *S. palustris*, *T. interrupta*, and *N. biserrata*. Species codes: N.b (*Nephrolepis biserrata*), S.p (*Stenochlaena palustris*), and T.i (*Thelypteris interrupta*). Symbols: × (N.b), □ (T.i), and ● (S.p).

Our results showed that *S. palustris* and *T. interrupta* populations are strongly influenced by soil moisture and light intensity, with both species thriving under conditions of 60-90% humidity and high light intensity. Soil temperature also affects *S. palustris* and *T. interrupta* populations, but to a lesser extent, with optimal growth occurring between 18 and 35°C [8-9], [14]. In contrast, *N. biserrata* is strongly influenced by soil pH, with optimal growth occurring in soils with a pH range of 6-6.8, or near-neutral conditions. *S. palustris* and *T. interrupta* can thrive under acidic soil conditions [15]. Other environmental factors that influence *N. biserrata* include lower soil moisture, soil temperature, and light intensity compared with the habitats of *S. palustris* and *T. interrupta*.

4 Conclusions

In our study area of 0.75 hectares of abandoned rice fields, we demonstrated that cosmopolite ferns exhibit distinct habitat preferences. Based on spatial data of individual abundance and environmental parameters, we empirically and statistically proved that *S. palustris* and *T. interrupta* share habitats because their preference for acidic soils, high soil moisture, and intensive sunlight exposure. We speculate that these two species have high potential for invasion in larger areas of abandoned rice fields. In contrast, *N. biserrata* tends to prefer shaded habitats with moderate soil moisture, and is rarely found in areas with intense waterlogging. Further habitat modeling in different ecosystem types may provide a more comprehensive understanding of the habitat-sharing phenomenon between *S. palustris* and *T. interrupta*.

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