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Short Communication

Fern Communities in Post-Gold Mining Sites of West Kalimantan, Indonesia

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ABSTRACT

Understanding changes in plant communities in post-mining sites is important for managing a degraded landscape. Ferns have been known as species indicators for heavy metals-contaminated environments. However, research focusing on fern communities in post-mining environments is scarce. This study investigates fern communities in post-mining areas that have been abandoned for 1, 6, and 10 years in West Kalimantan, Indonesia. The results show that the composition and abundance of fern species differed among post-gold mining sites. *Stenochlaena palustris*, *Pityrogramma calomelanos*, *Dicranopteris linearis*, and *Nephrolepis cordifolia* are four species recognised as species indicators for post-mining sites aged six and ten years.

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While gold mining contributes positively to the economy, it tends to leave behind landscapes that are severely degraded and exhibit different ecological characteristics. Changes in the composition and structure of vegetation, soil and water pollution, and sediment contamination are notable ecological impacts of gold mining (Mambou Ngueyep et al. 2021; Dzoro et al. 2023; Laker 2023). These adverse ecological consequences are challenging for managing degraded landscapes. Although ferns and fern allies represent only 4 % of the 350,000 vascular plants, they have the ability to occupy degraded landscapes and resist extreme environments (Sharpe et al. 2010). Some ferns, e.g. *Pityrogramma calomelanos*, *Pteris vittata, and Pteris melanocaulon*, are even recognized as ecological indicators for heavy metal-contaminated environments (Claveria et al. 2020). In addition, researchers have found that some ferns have been known as phytoremediation agents for heavy metal pollutants. *Asplenium nidus*, *Pteris umbrosia*, *Polypodium vulgare* and *Pteris cretica* possess the ability to uptake and accumulate As from As-contaminated environments in northern Iran (Saffari et al. 2009).

Despite the fact that ferns have the ability to colonize disturbed environments, studies focusing on fern communities in post-mining areas remain scarce. Existing research on fern and post-mining areas has predominantly emphasized fern identification as a potential ecological indicator, as well as their capacity for heavy metal accumulation and tolerance (Kachenko et al. 2007; Yu et al. 2020). The knowledge gap that has been mentioned is particularly evident in Indonesia, where gold mining activities have changed the natural environment. West Kalimantan, Indonesia, hosts gold mining activities in the country, and these spread across six districts in the province (Nafsiatun et al. 2012).

Here, we examined fern communities in post-gold mining sites that had represented different years since mining ceased in Sintang, West Kalimantan, Indonesia. We attempt to compare fern composition and abundance among three post-gold mining sites and to identify potential ferns as ecological indicators for heavy metal-contaminated environments. We hypothesize that fern communities in post-gold mining sites will exhibit significant differences in composition and abundance based on years since mining operations ceased, with certain fern species identified as reliable ecological indicators of heavy metal contamination. The present study's findings will help us better understand how fern communities respond to mining-induced disturbances.

To investigate fern communities, three post-gold-mining sites were selected in Sintang, West Kalimantan, Indonesia. Sintang is situated approximately 300 km to the east of Pontianak, the capital city of West Kalimantan (Figure 1). The research was conducted in two villages, Tembulan and Sengkuang. The first two sites are in Tembulan and have been inactive for one and six years, respectively. The third site is in Sengkuang village and has been abandoned for 10 years. The selection of 1-, 6-, and 10-year post-mining sites is related to ecological succession which allow researchers to observe changes in fern communities.

The fern community was studied by establishing 1 m x 1 m plots of 10 to 15 plots placed adjacent to the former mining pond. At the first and third sites with ponds having an area of 0.66 and 0.6 hectares respectively, 15 plots were placed around the ponds. At the second site, with a pond of 0.42 hectares, 10 plots were placed adjacent to the pond. The number of plots at each site was determined based on an initial assessment of the former mining area's condition and the pond's size in the former mining area. All ferns found in each plot were counted and identified at the species level in the field. In the present study, we counted each individual stem or that surfaced from the ground as an individual plant. We also looked at natural separations in the plant's growth. If fronds are growing in distinct clusters with visible gaps be-

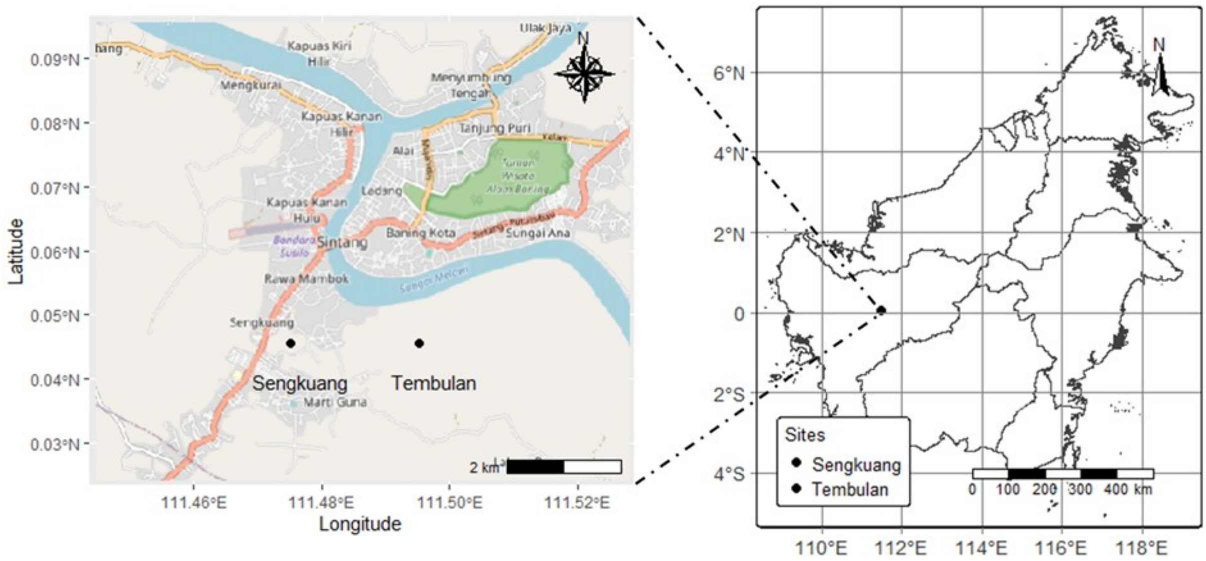

Figure 1. Sampling sites in Sengkuang and Tembulan villages within Sintang District, West Kalimantan, Indonesia.

tween them, we counted them as separate plants. The unidentified ferns were collected and taken to the Laboratory of Ecology, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Tanjungpura, for further identification. Voucher specimens are deposited in the herbarium of the Department of Biology, Universitas Tanjungpura. Identification of sampled ferns relied on examining the physical features of their rhizomes, stems, fronds, and spores, with reference to Holttum et al. (1991), Holttum (1968) and Holttum et al. (1959). The updated taxa revision with accepted nomenclature aligns with Plants of the World Online, Royal Botanic Gardens Kew (POWO 2024).

Shannon-Wiener Index (H'), Simpson's Dominance Index (D), and Pielou's Evenness Index (J') were calculated for each post-gold mining site. Multiple Hutcheson t-tests comparisons between fern communities were used to detect differences in H' between post-gold mining site (Hutcheson 1970). Multiple Hutcheson t-tests comparisons was completed using ecolTest package in R (Salinas & Ramirez-Delgado 2021). Non-Metric Multidimensional Scaling (NMDS) and Analysis of Similarity (ANOSIM) were employed to analyze differences in the composition and abundance of ferns among post-gold mining sites. We used the Jaccard and Bray-Curtis matrices for the NMDS analysis for compositional and abundance data, respectively. This study demonstrated that the NMDS analysis effectively achieved optimal solutions with low-stress levels (below 0.2) for both compositional and abundance datasets, as illustrated in Figures 3 and 4. Indicator species analysis was conducted to detect indicator species for post-gold mining sites with varying ages. The *vegan* package in R was used to compute NMDS and ANOSIM (Oksanen et al. 2022), while the visualization of NMDS analysis was completed using the *ggplot2* package in R (Wickham 2016). Indicator species analysis was computed using the *indicspecies* package in R (De Cáceres & Legendre 2009).

A total of 1,123 individual ferns were recorded from the three post-gold mining sites. In total, there were eight species belonging to seven families. Figure 2 displays eight species recorded in all post-mining sites. *Dicranopteris linearis* was the most abundant fern for the one-year post-mining site (0.56 ± 0.29 individuals/m^2) and the 10-year post-mining site (1.21±0.55 individuals/m^2) (Table 1). However, this species was not numerically dominant in the six-year post-mining site. The six-year post-mining was dominated by *Lycopodium cernuum* L. (1.12±0.83 individuals/m^2) (Table 1). Moreover, this study

Table 1. Fern diversity and abundance (number of individuals/m²) (±SD) for each post-gold mining site in Sintang, West Kalimantan, Indonesia.

No	Taxa	Abundance (individual fern/m²) at three post-mining sites representing different years since mining ceased		
		1	6	10
1	Blechnaceae			
	Blechnum orientale L.	0.07 ± 0.09	0.06 ± 0.11	0.06 ± 0.10
	Stenochlaena palustris (Burm.f.) Bedd.	0	0.32 ± 0.32	0.16 ± 0.19
2	Dennstaedtiaceae			
	Pteridium esculentum (G.Forst.) Cockayne	0.12 ± 0.17	0.05 ± 0.11	0.04 ± 0.07
3	Gleicheniaceae			
	Dicranopteris linearis (Burm.f.) Underw.	0.56 ± 0.29	1.01 ± 0.39	1.21 ± 0.55
4	Lycopodiaceae			
	Lycopodiella cernua (L.) Pic.Serm.	0.46 ± 0.40	1.12 ± 0.83	0.76 ± 0.75
5	Lygodiaceae			
	Lygodium microphyllum (Cav.) R.Br.	0.06 ± 0.15	0	0.05 ± 0.13
6	Nephrolepidaceae			
	Nephrolepis cordifolia (L.) C.Presl	0	0.18 ± 0.23	0.13 ± 0.21
7	Pteridaceae			
	Pityrogramma calomelanos (L.) Link	0	0.14 ± 0.21	0.05 ± 0.11

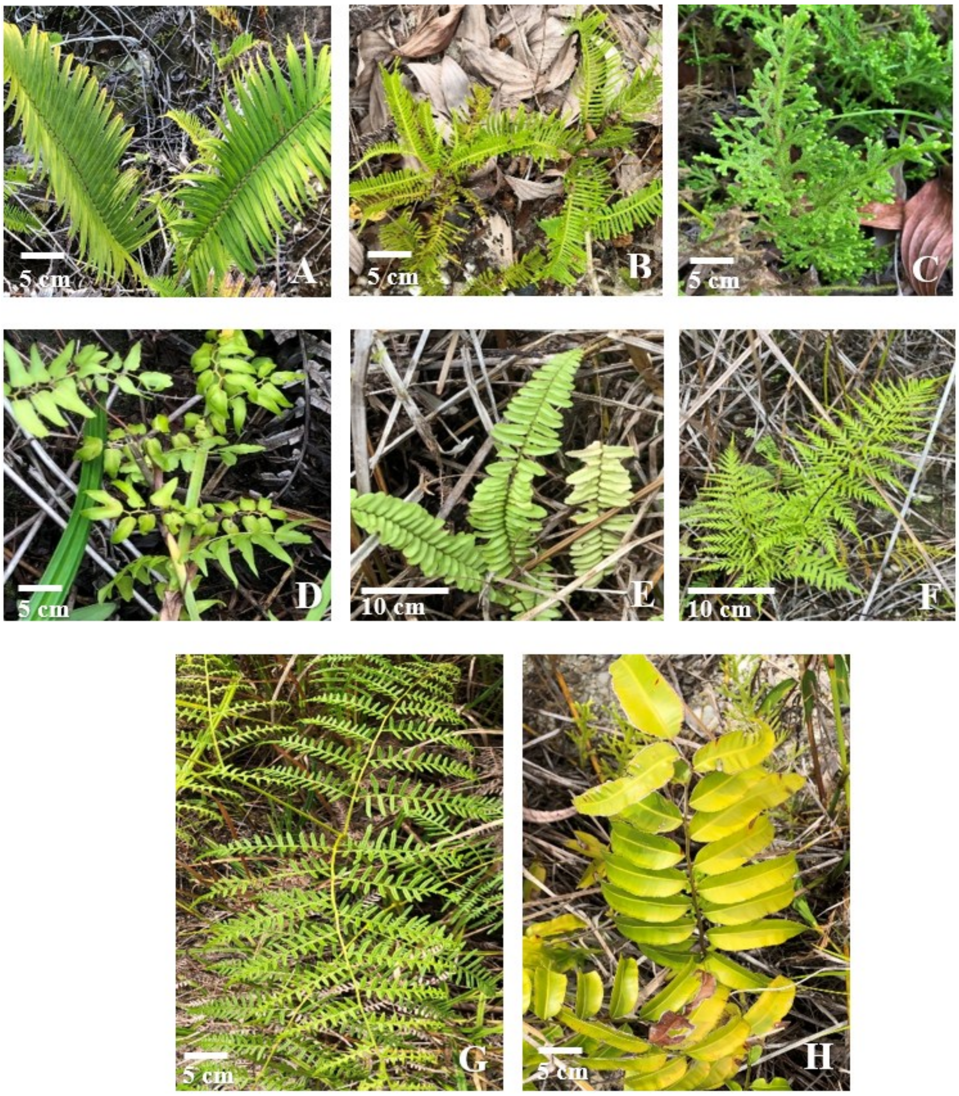

Figure 2. Eight fern species found in three post-gold mining sites representing different years since mining ceased in Sintang, West Kalimantan, Indonesia (A. *Blechnum orientale* L., B. *Dicranopteris linearis* (Burm.f.) Underw., C. *Lycopodiella cernua* (L.) Pic.Serm., D. *Lygodium microphyllum* (Cav.) R.Br., E. *Nephrolepis cordifolia* (L.) C.Presl, F. *Pityrogramma calomelanos* (L.) Link, G. *Pteridium esculentum* (G.Forst.) Cockayne, H. *Stenochlaena palustris* (Burm.f.) Bedd.)

found that some ferns occurred across three post-gold mining sites. These ferns were *Blechnum orientale*, *Dicranopteris linearis*, *Lycopodium cernuum*, and *Pteridium esculentum* (Table 1). This observed pattern indicates that some ferns can persist for a more prolonged duration since they initial establishment in heavy metal contaminated environments.

Plant species diversity is a commonly used measure of ecological diversity and can be assessed through species richness and relative abundance of individuals in each species (Hamilton 2005). In this study, the Shannon-Wiener index (H') is employed to assess species diversity in abandoned gold mining sites. The highest value of the Shannon-Wiener index value (H') is documented in a post-mining site that has been abandoned for six years (1.45), whereas a site that has been abandoned for a year records the lowest value of 1.26 (Table 2). We employed multiple Hutcheson t-tests comparisons between fern communities to detect significant differences between communities. Our study found that the Shannon-Wiener index of the site that has been abandoned for a year significantly differed from that has been abandoned for six years. However, no significant difference was detected between one-year and 10 years, and between six and 10 years (Table 2). Differences in the Shannon-Wiener index among the three post-mining sites reflect differences in the composition and abundance of ferns. Furthermore, J' values range from 0 to 1, with larger values indicating a more even distribution in abundance among species (Zhang et al. 2012). Pielou's evenness index (J') reported in this research ranged from 0.65 to 0.78 (Table 2), but the highest J' value was documented at a 1-year-old post-mining site (0.78). This suggests that a 1-year-old post-mining site has a more even distribution in abundance among species than the other post-mining sites.

Table 2. Species richness, Shannon-Wiener Index (H'), Pielou's Evenness Index (J'), and Simpson Index (D) in post-gold mining sites representing different years since mining ceased in Sintang, West Kalimantan, Indonesia. Lower case letters indicate significant differences from $P<0.05$ using multiple Hutcheson t-tests comparisons between communities.

Post-mining sites representing different years since mining ceased	Species richness	Indices		
		H'	J'	D
1	5	1.26^{a}	0.78	0.34
6	7	1.45^{b}	0.74	0.39
10	8	1.35^{ab}	0.65	0.35

We used Non-Metric Multidimensional Scaling (NMDS) and Analysis of Similarity (ANOSIM) to investigate compositional differences in fern communities among post-gold mining sites with varying ages. The NMDS plot displays that fern communities differed among post-mining sites, as shown by the clustering pattern (Figure 3). This visual pattern is confirmed by the results of ANOSIM ($p < 0.01$, ANOSIM R = 0.20). Differences in compositional data may reflect differences in tolerance levels to heavy metal contamination. Some fern species have been known for tolerating high levels of heavy metal contamination in their environment (Chang et al. 2009). Similarly, the abundance of fern communities differed among post-mining sites. The NMDS ordination indicates a distinct clustering of abundance data across post-mining sites (Figure 4). The results of ANOSIM confirm this pattern; fern abundance significantly differed among post-mining sites ($p < 0.01$, ANOSIM R = 0.20). These findings might suggest that fern species found on a 1-year-old abandoned mining site are more tolerant of heavy metal contamination than those found on 6-year-old and 10-year-old abandoned mining sites. It should be noted, however, that this argument is based on the assumption that recently abandoned mining sites exhibit higher levels of heavy metals than older sites, as reported by Mensah and Addai (2024).

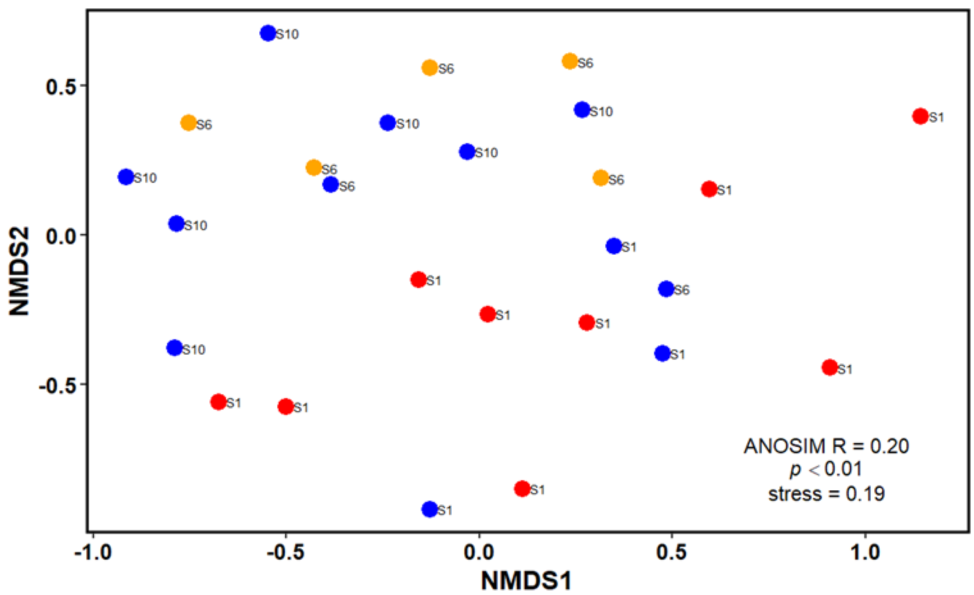

Figure 3. The ordination of Non-metric Multidimensional Scaling (NMDS) illustrates fern composition on three post-gold mining sites representing different years since mining ceased in Sintang, West Kalimantan, Indonesia. Colored dots indicate different post-mining sites with varying ages: S1: ● 1 year, S6: ● 6 years, S10: ● 10 years.

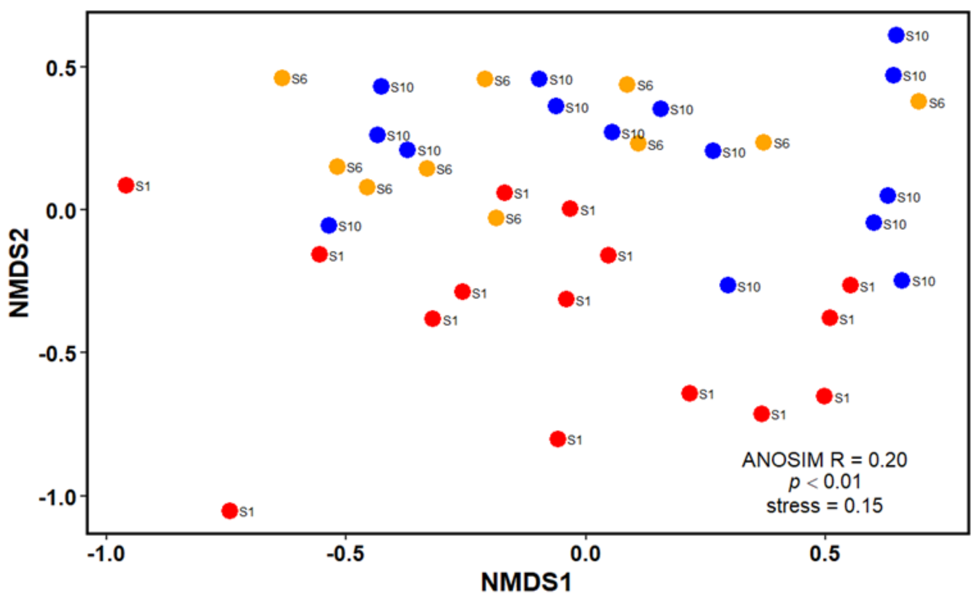

Figure 4. The ordination of Non-metric Multidimensional Scaling (NMDS) for fern abundance on three post-gold mining sites representing different years since mining ceased in Sintang, West Kalimantan, Indonesia. Colored dots indicate different post-mining sites with varying ages: S1: ● 1 year, S6: ● 6 years, S10: ● 10 years.

To examine indicator species for post-gold mining sites with varying ages, the analysis of indicator species was employed. The analysis used in the present study allows us to detect multispecies ecological indicators as shown in Table 3 (De Cáceres et al. 2012). The indicator species analysis demonstrates that there were four species for different ages of post-mining sites. The four species are *Stenochlaena palustris*, *Pityrogramma calomelanos*, *Dicranopteris linearis*, and *Nephrolepis cordifolia* (Table 3). The four species have been known to be an ecological indicator for heavy metal-contaminated environments. *Stenochlaena palustris* and *Dicranopteris linearis* have the ability to tolerate a high concentration of Al and Fe in three different sites in Malaysia

Table 3. Indicator species analysis for three post-mining sites representing different years since mining ceased in Sintang, West Kalimantan, Indonesia.

Species	Post-mining sites representing different years since mining ceased	*p - value*
Stenochlaena palustris	6	0.0079
Pityrogramma calomelanos	6	0.0338
Dicranopteris linearis	6, 10	0.0019
Nephrolepis cordifolia	6, 10	0.0362

(Latiff et al. 2022). Chang et al. (2009) made a list of ecological indicators of arsenic-contaminated environments from a number of published studies, and they found that *Pityrogramma calomelanos* is one of the indicator species for arsenic-contaminated environments. Moreover, *Nephrolepis cordifolia* has been identified as the hyperaccumulator plant of Hg in an active mining site in Indonesia (Fasya et al. 2024).

The present study has limitations which might affect the interpretation of our results. First, our findings may not be widely applicable due to the restricted sample size of post-mining sites (comprising just three sites). Hence, more research is needed with a larger sample size to allow the generalizability of the findings. Second, no measurements of key environmental variables (e.g. soil pH and heavy metal concentrations) restrict the conclusions we can draw. Thus, we recommend future studies include measurements of environmental variables and correlate them with fern composition and abundance. Although this study has limitations, our study provides new insights for understanding indicator fern species for a degraded landscape caused by gold mining in Kalimantan, Indonesia.

This research shows that the composition and abundance of fern species were affected by the ages of post-gold mining sites. The species richness and diversity index were higher at 6- and 10-year post-mining sites compared to the one-year post-mining site. Four species, which are *Stenochlaena palustris*, *Pityrogramma calomelanos*, *Dicranopteris linearis*, and *Nephrolepis cordifolia*, can be used as ecological indicator for 6- and 10-years post-mining sites. To clarify the underlying causes of the differences observed in fern composition and abundance, more research is needed. Future research could explore correlation between fern occurrence and soil metal concentrations, the uptake and accumulation of heavy metals of identified indicator species through experimental trials and fern succession in post-mining sites.

AUTHOR CONTRIBUTION

A.O.S. collected and analysed data and wrote the manuscript, I.L. designed the research, analysed data, supervised all the processes and wrote the manuscript, D.G. supervised all the processes and wrote the manuscript, A.R. supervised fern identification and wrote manuscript.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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