Pneumatopteris afra (Christ) Holttum Invasion: Impact on Species Diversity and Soil Seed-Bank Richness in Lafia, Nigeria

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ABSTRACT Invasive species are a threat to the conservation of natural ecosystems as they compete with crops and natural vegetation, potentially reducing food quality and quantity. A study was carried out to investigate the impact of invasion by the wetland tropical fern *Pneumatopteris afra* (Christ) Holttum on species diversity and soil seed-bank richness in Lafia, North-Central Nigeria from 2020 to 2021. Community characteristics were computed from data of species sampled from three invaded and uninvaded plots, using ten 1 m x 1 m quadrats, and five 30 m line transects. Soil seed-bank richness was evaluated using the seedling emergence method. Community characteristics of plant species, such as number of species, number of individuals, Simpson Index, Evenness Index, Margalef Index, and Fisher Alpha Index, were higher in the uninvaded sites, and differed significantly from the *P. afra*-invaded sites ($p<0.05$). Seed-bank obtained from uninvaded plots contained higher species composition (n=14), compared to the uninvaded plots (n=4). The study showed that invasion by *P. afra* poses serious threats to species diversity, and the regenerative ability of invaded plant communities. Therefore, measures aimed at controlling the dominance and eventual take-over of native vegetation by invasive *P. afra* are required to preserve the species richness and diversity in the region.

KEYWORDS: *P. afra*; Species diversity; Invasive species; Native species; Seed-bank.
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INTRODUCTION

Soil seed-bank (SSB) is the collection of all seeds that are present in the soil at a given time, which are able to recompose or bring back a natural vegetation. Soil seed-banks are important in understanding the impact of invasive species on resident plants over their entire life cycles, from seed development and seedling recruitment through reproduction (Gioria & Osborne, 2010). Several studies have associated plant invasions and the consequent changes in vegetation with the removal of soil seed-bank by invasive or alien plant species (Holmes, 2002; Seabloom *et al*., 2003; Turner *et al*. 2008).

The successful invasion of alien plants is made possible by essential characteristics such as rapid growth rate, and the availability of several means of propagation by invasive plant species. Limited growth cover of native species is also identified as a major contributive factor to successful soil invasion by alien plant species (Callaway & Aschehoug, 2000). Wetlands and riparian ecosystems are more vulnerable to plant invasions due to the intensity of anthropogenic disturbances (Patten, 1998). This accounts for the higher rate of plant invasions in wetlands that have experienced disturbances over time due to a reduction in biotic interactions (Jauni *et al*., 2015).

Pneumatopteris afra (Christ) Holttum is a wetland tropical fern which originated from the old-world tropics (Holttum, 1982), but has been reported to have colonized wetlands, especially riparian habitats in West African countries, such as Nigeria, Togo, Ghana, and Republic of Benin (Oloyede, 2008). Akomolafe & Rahmad (2019) reported that *P. afra* was likely introduced to Nigeria for aesthetic purposes in the early 1960s, and has been successful in colonizing several soils in the country due to its improved adaptability to a variety of habitats and types of soil (Oloyede *et al.*, 2011).

Researches on the invasive potential of *P. afra* in Lafia, North-Central Nigeria have been focused on its species ecology and impact on above-ground vegetation (Akomolafe & Rahmad, 2021). However, not much has been done to assess its impact on the seed-bank richness of invaded soils. Therefore, investigating the impacts of invasion on the soil seed-bank will reveal the potential threats of the invader on the natural revitalization and restorative capabilities of the invaded ecosystems.

METHODOLOGY

Study Sites

The experiment was carried out in Lafia, Nasarawa State, North-Central Nigeria (Table 1).

Table 1. The descriptions of the study sites

Site	Location	Latitude (N)	Longitude (E)	Elevation (m)
Invaded site A	Beside College of AgricLafia	08.55435°N	008.54088°E	151
Invaded Site B	Shabu road, Lafia	08.57991°N	008.55573°E	145
Uninvaded Site A	Opposite College of Agriculture Lafia	08.55466°N	008.53989°E	161
Uninvaded Site B	Shabu road, Lafia	08.57863°N	008.55548°E	140

Sampling and Plant Collection

To determine the ecological impact of the weed species on the invaded plant communities, three sample plots, measuring 10 m x 10 m each were established in two invaded communities with high cover of *P. afra,* and two adjacent non-invaded plant communities where *P. afra* was not present. In each sampled plot, ten 1mx1 m quadrants were randomly sampled, and all rooted plant species in each quadrant were identified and counted.

Five 30m line transects were randomly laid using a measuring tape. All plant species along the transects were recorded and used to estimate species cover in each plot. The percentage cover was calculated as the number of 'hits' per species divided by the total number of pin drops multiplied by 100. Voucher specimen of the species which could not be identified on the field were collected and identified in the herbarium of the Department of Plant Science and Biotechnology, Federal University of Lafia.

Assessment of Soil Seed-Bank

The seedling emergence method of Thompson & Grime (1979) was used for seed-bank analysis of the investigated soil samples. Soil seed-bank samples were collected by taking three core samples of top soil (15cm depth) per plot in each invaded and uninvaded site. The soil samples were air-dried, then stone and gravels were removed by passing the soil samples through a 4 mm mesh size sieve. The soil was spread thinly in perforated 45 cm diameter plastic trays, placed in a screen house at an average temperature of 39°C, and moistened daily by sprinkling with tap water. Germinated seedlings were counted, identified and removed every week.

Statistical Analysis

Species richness was estimated as the number of species in each plot per site. The diversity indices such as the Shannon-Wiener index, Simpson index, evenness index, and Margalef index were quantified at 5% level of probability using PAST software, version 3.0. The significance differences in the diversity indices between the sites were estimated using a pairwise permutation test.

RESULTS AND DISCUSSIONS

Community characteristics of the above-ground vegetation at the uninvaded sites are presented in Table 2. The number of species at the uninvaded site A (17) was higher but not significantly different from number of species at the uninvaded site B (13). The number of individuals at uninvaded site A (90) was significantly higher that the number at uninvaded site B (29) ($p<0.05$).The Simpson (0.88), Shannon-Wiener (2.33), and Fisher alpha (7.50) indices were higher in the uninvaded site B, but not significantly different from uninvaded site A which had 0.82 Simpson index, 2.19 Shannon-Wiener index, and 5.92 Fisher alpha index ($p>0.05$). The evenness index of the uninvaded site B (0.79) was higher and significantly different from uninvaded site A (0.53), but both uninvaded sites had the same Margalef index (3.56).

Table 2. Community characteristics of above-ground vegetation at uninvaded sites A and B

Community Characteristics	Uninvaded Site A	Uninvaded Site B
Number of species	17^a	13^a
Number of individuals	90^a	29^b
Simpson index	0.82^a	0.88^a
Shannon-Wiener index	2.19^a	2.33^a
Evenness index	0.53^a	0.79^b
Margalef index	3.56^a	3.56^a
Fisher alpha index	5.92^a	7.50^a

Means followed by different superscripts within the same row are significantly different ($p\leq0.05$)

Community characteristics of the above-ground vegetation at the invaded sites are presented in Table 3. The number of species at invaded site A (11) were the same as invaded site B (11). The Number of individuals at invaded site B (43) was significantly higher than the number of individuals at invaded site A (32) ($p<0.05$). Although the Simpson (0.64), Shannon (1.58), Margalef (2.89), and Fisher alpha (5.25) indexes were higher in the invaded site A, they were not significantly different from the invaded site B, which had 0.61, 1.39, 2.66, and 4.43, Simpson, Shannon-Wiener, Margalef, and Fisher indices respectively ($p>0.05$). The evenness index of the invaded site A (0.44) was significantly higher than that of the invaded site B ($p<0.05$).

Table 3. Community characteristics of above-ground vegetation at invaded sites A and B

Community Characteristics	Invaded Site A	Invaded Site B
Number of species	11^a	11^a
Number of individuals	32^a	43^b
Simpson index	0.64^a	0.61^a
Shannon-Wiener index	1.58^a	1.39^a
Evenness index	0.44^a	0.37^b
Margalef index	2.89^a	2.66^a
Fisher alpha index	5.25^a	4.43^a

Means followed by different superscripts within the same row are significantly different ($p<0.05$)

Comparison of the community characteristics between sites invaded by *P. afra* and the uninvaded sites is presented in Table 4. The number of species (19), number of individuals (57), Simpson index (0.85), Shannon-Wiener index (2.37), Evenness index (0.57), Margalef index (4.45), and Fisher alpha index (8.86) were significantly higher in the uninvaded compared to the invaded sites which had 12, 40, 0.68, 1.68, 0.45, 2.98, and 5.22 number of species, number of individuals, Simpson index, Shannon index, Evenness index, Margalef index, and Fisher alpha index, respectively ($p<0.05$).

Table 4. Comparison of community characteristics of above-ground vegetation at *P. afra*-invaded and uninvaded sites

Community characteristics	Uninvaded Site	Invaded Site
Number of species	19[a]	12[b]
Number of Individuals	57[a]	40[b]
Simpson index	0.85[a]	0.68[b]
Shannon-Wiener index	2.37[a]	1.68[b]
Evenness index	0.57[a]	0.45[b]
Margalef index	4.45[a]	2.98[b]
Fisher alpha index	8.86[a]	5.22[b]

Means followed by different superscripts within the same row are significantly different ($p\leq0.05$)

The sites invaded by *P. afra* were found to have less species diversity compared to uninvaded sites. In a similar study, Akomolafe & Rahmad (2021) reported a decline in species diversity as a result of *P. afra* invasion of wetlands in Nigeria. In the Czech Republic, Hejda *et al.* (2009) also reported a decline in species diversity and evenness in sites invaded by alien species compared to the uninvaded sites. The lower diversity indices observed at the sampled plots as a result of the invasion of *P. afra* is a likely indication of the negative influence of the invasive species on the plant diversity of the invaded communities. This is supported by the reports of Buchanan (2000), and Wang *et al*. (2019) stating that invasive plants compete with native plants for resources, especially space, nutrients, water, and sunlight, leading to changes in the quality of resources available for efficient development of native species. In severe cases, invasive species are able to replace desired native plants and prevent the native plants from establishing due to their superior competitive abilities (Buchanan, 2000).

Plants identified at both *P. afra* invaded and uninvaded sites are presented in Table 5.A total of 19 plant species belonging to seven families, namely Amaranthaceae, Malvaceae, Poaceae, Lamiaceae, Fabaceae, Convolvulaceae, and Cyperaceae, were identified from the uninvaded sites. In the invaded sites, 12 plant species belonging to 10 families, namely Poaceae, Fabaceae, Malvaceae, Convolvulaceae, Cyperaceae, Thelypteridaceae, Malvaceae, Melastomataceae, Portulaceae, and Pandanaceae, were identified. Plants identified from the uninvaded sites were *Gomphrena celosiodes, Sida cordifolia, Sida acuta,* unidentified grass, *Hyptis lanceolata, Mimosa pudica,* unidentified legume, *Hyptis suaveolens, Oryza barthii, Cenchrus biflorus, Calopogonium mucunoides, Urena lobata, Brachiari alata, Ipomea involucrata, Elytrophorus spicatus, Heteropogon contortus, Dactyloctenium aegyptium, Sena occidentalis,* and *Ryncospora corymbosa,* The 12 plant species identified from the invaded sites were, *Oryzabarthii, Calopogonium mucunoides, Urena lobata, Ipomea involucrata, Heteropogon contortus, Sena occidentalis, Ryncospora corymbosa, Melochia corchorifolia, Heterotis rotundifolia, Talinum triangulare,* and *Pandanus candelabrum*. Seven species, namely: *Oryza barthii, Calopogonium mucunoides, Urena lobata, Ipomea involucrata, Heteropogon contortus, Sena occidentalis,* and *Ryncospora corymbosa*, were found to be common to both uninvaded and invaded above-ground vegetations.

Table 5. Plants identified at *P. afra*-invaded and uninvaded above-ground vegetations

S/N	Species	Family	Uninvaded sites	Invaded sites
1	*Gomphrena celosiodes*	Amaranthaceae	+	-
2	*Sida cordifolia*	Malvaceae	+	-
3	*Sida acuta*	Malvaceae	+	-
4	Unidentified grass	Poaceae	+	-
5	*Hyptis lanceolata*	Lamiaceae	+	-
6	*Mimosa pudica*	Fabaceae	+	-
7	Unindentified legume	Fabaceae	+	-
8	*Hyptis suaveolens*	Lamiaceae	+	-
9	*Oryza barthii*	Poaceae	+	+
10	*Cenchrus biflorus*	Poaceae	+	-
11	*Calopogonium mucunoides*	Fabaceae	+	+
12	*Urena lobata*	Malvaceae	+	+
13	*Brachiari alata*	Malvaceae	+	-
14	*Ipomea involucrate*	Convolvulaceae	+	+
15	*Elytrophorus spicatus*	Poaceae	+	-
16	*Heteropogon contortus*	Poaceae	+	+
17	*Dactyloctenium aegyptium*	Poaceae	+	-
18	*Sena occidentalis*	Fabaceae	+	+
19	*Ryncospora corymbosa*	Cyperaceae	+	+
20	*Pneumatopteris afra*	Thelypteridaceae	-	+
21	*Melochiacor chorifolia*	Malvaceae	-	+
22	*Heterotis rotundifolia*	Melastomataceae	-	+
23	*Talinum triangulare*	Portulacaceae	-	+
24	*Pandanus candelabrum*	Pandanaceae	-	+

+ = present
- = absent

Seed-bank analysis showed variations in seedling germination between soils collected from invaded and the uninvaded sites (Table 6). Fourteen out of 19 species found at the above-ground vegetation germinated from the uninvaded seed-bank, while only 4 out of 12 species found at the above-ground at the invaded site germinated from the invaded seed bank.Plant species that germinated from the uninvaded seed-bank were, *Gomphrena celosiodes, Sida cordifolia, Sena occidentalis, Heteropogon contortus, Urena lobata, Hyptis lanceolata, Mimosa pudica, Elytrophorus spicatus, Ryncospora corymbosa, Cenchrus biflorus, Brachiari alata, Dactyloctenium aegyptium, Ipomea involucrata,* and *Sida acuta*. Plant species recovered from the invaded seed-bank were *Urena lobata, Ryncospora corymbosa, Heterotis rotundifolia,* and *Oryza barthii*. The common species found at the uninvaded and invaded seed-banks were *Urena lobata* and *Ryncospora corymbosa*.

Table 6. Plant species recovered from *P. afra*-invaded and uninvaded seed-banks

S/N.	Species	Uninvaded seed-bank	Invaded seed-bank
1.	*Gomphrena celosiodes*	+	-
2.	*Sida cordifolia*	+	-
3.	*Sena occidentalis*	+	-
4.	*Heteropogon contortus*	+	-
5.	*Urena lobata*	+	+
6.	*Hyptis lanceolata*	+	-
7.	*Mimosa pudica*	+	-
8.	*Elytrophorus spicatus*	+	-
9.	*Ryncospora corymbosa*	+	+
10.	*Cenchrus biflorus*	+	-
11.	*Brachiari alata*	+	-
12.	*Dactyloctenium aegyptium*	+	-
13.	*Ipomea involucrata*	+	-
14.	*Sida acuta*	+	-
15.	*Heterotis rotundifolia*	-	+
16.	*Oryza barthii*	-	+

+ = present
- = absent

Soil seed-banks are reservoirs of seeds capable of germinating under favorable conditions (Jaganathan & Dalrymple, 2016), and are also considered to be important potential seed sources for the restoration of plant communities (Bossuyt & Honnay, 2008). Seed-bank analysis showed that sites invaded by *P. afra* showed appreciable decline in soil seed-bank richness compared to the uninvaded sites. In related studies, Holmes (2002) reported a significant decline in seed-bank density and richness on sites invaded by the Australian tree *Acacia saligna* in South Africa. The decline in seed-bank density observed in the present study is an indication that soil invasion by *P. afra* poses long term threats to the regenerative potentials of invaded sites, as invaded soils may be unable to buffer environmental changes that may occur over time.

CONCLUSION

Invasion by *P. afra* resulted in a significant decline in species diversity indices and seed-bank density. The study showed that soil invasion by *P. afra* poses serious threats on the long-term ability of invaded soils to regenerate and maintain their native vegetation. Therefore, measures aimed at controlling the dominance and eventual take-over of native vegetation by invasive *P. afra* are required to preserve the species richness and diversity in the region.

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