

Original Article

Wetlands invaded by *Pneumatopteris afra* (Christ.) Holttum are less diverse and more threatened than non-invaded ones in Nigeria

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Abstract

We compared the diversity indices of wetlands invaded by a fern, *Pneumatopteris afra*, and those that were not invaded. Six wetlands chosen for this study were each the size of 500×500 m² which included 3 invaded and 3 non-invaded wetlands. A total of 240 quadrats of size 1.5×1.5 m² were established at all sites for estimation of abundance and diversity indices. A total of 1634 individual plants of 9 species were observed at the invaded sites while 1032 individuals of 14 species were observed at the non-invaded sites. The non-invaded sites exhibited significantly higher diversity indices than the invaded ones. Non-invaded sites are richer and more diverse than the invaded sites. None of the plant species at the non-invaded sites exhibited strong dominance over others. The lower species diversity of the invaded sites is also an indicator of the threat level posed on the wetlands by *P. afra*.

Keywords: *Calopogonium mucunoides*, *Cyclosorus afer*, invasive plants, Lafia, wetlands

1. Introduction

Invasions of natural communities by plants have been described to have a direct relationship with a reduction in species diversity and alteration of the structure and function of ecosystems worldwide (Gooden, French, & Turner, 2009; Levine *et al.*, 2003; Martín-Forés, Guerin, & Lowe, 2017). This usually translates into a threat to the conservation of natural ecosystems (Usher, 1988). The successful invasion of alien plants is made possible by a lot of intrinsic characteristics such as rapid growth rate, phenotypic

plasticity, several means of propagation, and limited growth of native species (Callaway & Aschehoug, 2000; Vitousek, 1990). Some native communities are prone to invasion by non-native plants when there is an unoccupied niche, lack of natural enemies, ecosystem disturbances, and unavailability or fluctuations of ecosystem resources (Davis, Grime, & Thompson, 2000; Hobbs & Huenneke, 1992; Keane & Crawley, 2002).

Wetlands and riparian ecosystems are more vulnerable to plant invasions due to the intensity of anthropogenic disturbances (Patten, 1998). The rate of plant invasions is usually higher in wetlands that have experienced disturbances over time due to a reduction in biotic interactions (Aragón & Morales, 2003; Catford *et al.*, 2012; Jauni, Gripenberg, & Ramula, 2015). Biotic interaction among different species in a community do not favour invasion.

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Therefore, disturbances limit this interaction among different plant species by preventing their survival in a community. As a result only the species with better adaptive strategies will eventually dominate. Considering the importance of wetlands in arid and sub-humid regions such as the savannahs, more attention is needed to be placed on preventing and controlling non-native invasions in order to salvage them (Kondolf & Keller, 1991). Wetlands generally are important for the completion of life cycles of many animal species; therefore, they need to be conserved (Kondolf & Keller, 1991). Investigating the ecological impacts of invaders on the invaded communities compared with non-invaded communities will provide a better understanding of the mechanisms of their invasion success (Wang *et al.*, 2018a).

There have been several hypotheses on the impacts of invasive plant richness on plant diversities of communities invaded compared with non-invaded communities. Some researchers hypothesized that an increase in invasive plant abundance reduces plant diversities of communities invaded at smaller geographical scales (Gornish & Ambrozio dos Santos, 2016; Wang *et al.*, 2018b) and increases on larger geographical scales (Driscoll, 2017; Martín-Forés *et al.*, 2017). Another hypothesis states that, at smaller geographical scales, invasive plants may not have any effect on the plant diversities of invaded communities compared with non-invaded ones (Bart, Davenport, & Carpenter, 2015; Meffin *et al.*, 2010). Therefore, it is necessary to resolve these hypothetical disagreements by investigating the threats posed by invasive plants on plant diversities of invaded communities compared with non-invaded communities (Dong, Yu, & He, 2015).

Pneumatopteris afra (Christ.) Holttum is a wetland tropical fern reported to have colonized wetlands in north-central Nigeria (Akomolafe, Oloyede, & Chukwu, 2017). This plant is found across some West African countries, such as Togo, Ghana, Republic of Benin, and Nigeria, and was reported to have originated from the old world tropics (Holttum, 1982). Akomolafe and Rahmad (2019) reported that it was likely introduced to Nigeria for aesthetic purposes in the early 1960s. This could have possibly been enhanced by its adaptability to a variety of habitats and types of soil (Oloyede, Aponjolosun, & Ogunwole, 2011). Despite being able to survive in various types of habitats, it has a high preference for riparian habitats (Oloyede, 2008). *P. afra* is a plant that could be described to have high phenotypic plasticity by being able to respond positively to different environmental conditions, thereby favouring its establishment (Kelly, Panhuis, & Stoehr, 2011). Its recent rate of rapid colonization of these wetlands in Lafia, Nigeria has generated serious concerns for the inhabitants of areas closer to the wetlands and ecologists. The wetlands in Lafia are generally sources of water supply for several indoor and outdoor activities such as washing, cooking, fishing, drinking, cattle rearing and relaxation by the local dwellers (Akomolafe, Ombugadu, & Joseph, 2017). Most importantly, due to the arid nature of this region, many local farmers usually engage in wetland or irrigation farming during the dry season. The massive growth of *P. afra* on these wetlands, which is an agent of secondary succession, has created a lot of setbacks for the locals who depend on the water supply for their daily activities. Invariably, this could also adversely affect the economic growth of these areas. This study then intended to

assess the threats posed by the invasion of *P. afra* on plant diversity of invaded wetlands compared with non-invaded wetlands in Lafia in north-central Nigeria.

2. Materials and Methods

2.1 Study area

Lafia which lies between latitude 8°25'40"N to 8°34'15"N and longitude 8°24'25"E to 8°39'19"E in north-central Nigeria was chosen as the study area due to the prominence *P. afra* colonization (Figure 1). The annual rainfall and growing period, i.e. the period between the onset of rainy season and middle of dry season when the plants produce their vegetative and reproductive parts, ranges from 1000 to 1500 mm and 200 to 300 days, respectively. Lafia usually experiences a rainy season between early May and late September and a dry season between October and April. Being a guinea savannah region, the dominant vegetation in Lafia includes grasses, shrubs, and a smaller number of trees.

2.2 Sampling and plant collection

A total of six wetlands, which are separated from each other by a minimum of 1 km, were chosen as the sampling sites in Lafia, Nigeria. These wetlands included three invaded and three non-invaded sites. An area of 500×500 m² was demarcated in each site for this study. At the climax of the growing period of the plants in Lafia, i.e. from August to January, the relative abundance of the plant species and diversity indices of each site were estimated. This was done using 10 consecutive 1.5×1.5 m² square quadrats laid at 10 m intervals along a 200 m transect at each side of the site, thereby making a total of 40 quadrats and 4 transects at each site. This gave a total of 240 quadrats in all six study sites. The quadrat size and shape were determined by considering the clumpy/spread nature of individual species and the average size of neighbouring plants in the wetlands (Elzinga, Salzer, & Willoughby, 1998). In this case, the plants were homogeneously spread and the life forms were comprised mostly of herbs and grasses at the study sites. In each quadrat, individual plant species were counted, collected, and identified using the herbarium specimens of Department of Botany, Federal University Lafia, Nigeria. The plant nomenclatures were determined using the International Plant Names Index. The following diversity indices were determined at each study site using the data collected in the quadrats.

$$1) \text{ Shannon Index, } H = -\sum \pi_i (\ln \pi_i)$$

where $\pi_i = n_i/N$, n_i is the number of individuals in the i th species of the area and N is total number of individuals (Shannon & Weaver, 1949).

$$2) \text{ Margalef Index} = \frac{S}{\sqrt{N}}$$

where S is total number of species (Margalef, 1969).

$$3) \text{ Evenness Index} = \frac{H}{\log S}$$

where H is the species diversity (Whittaker, 1972)

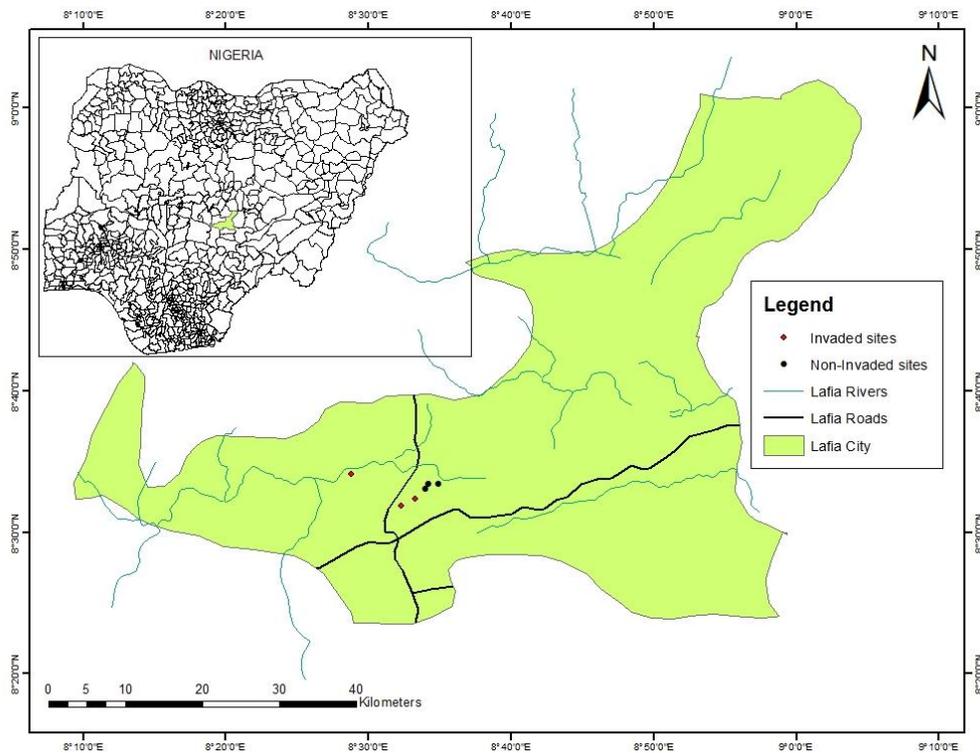


Figure 1. Map of the study area showing the invaded and non-invaded sites.

4) $Simpson\ Index = \frac{1}{\sum (\frac{n_i}{N})^2}$ (Simpson, 1949)

- 5) The Sorensen similarity coefficient (S_c) was calculated to indicate the floristic similarities between the invaded and non-invaded sites:

$$S_c = \frac{2W}{a + b} \times 100$$

where, W is the number of species similar to both sites under consideration, a is the number of species found at invaded sites and b is the number of species found at non-invaded sites.

These indices were used to quantify the diversity of plants at the study sites. They could be regarded as the community characteristics. The species richness explains the richness of the sites in terms of the number of different species, i.e. wealth of species. The Shannon index (heterogeneity index) explains how varied the plants are at the sites or they are more of the same species. The Simpson index explains the dominance of a particular species over others at the sites and the evenness index is concerned with the spread of individual species within the sites (Peet, 1974).

2.3 Statistical analyses

We used a rarefaction and extrapolation analysis to estimate the species richness of each invaded and non-invaded site because of the presence of individual species that were less than 10 in number (Chao *et al.*, 2014). This was done by

employing 100 bootstrap replicates of the abundance data of all the species. Significant differences in species richness between invaded and non-invaded sites were determined using the confidence intervals of the curves (Rahmad & Akomolafe, 2018). Online software called iNEXT was used to achieve this (Chao, Ma, & Hsieh, 2016). PAST software version 3.19 was used to quantify the diversity indices of each site. We also used one-way ANOVA with pairwise permutation to determine significance differences in all of the diversity indices between invaded and non-invaded sites.

3. Results

A total of 1634 individual plants belonging to 9 different species including the invader *P. afra* were observed at the invaded sites while a total of 1032 individuals belonging to 14 different species were observed at the non-invaded sites (Table 1). *P. afra* had the highest relative frequency at the invaded sites (87.18%) while *Calopogonium mucunoides* had the highest relative frequency at the non-invaded sites (21.15%). The species that were common to both the invaded and non-invaded sites included *Calopogonium mucunoides*, *Sida cordifolia*, and *Urena lobata*. *Oryza sativa* was observed to have the lowest relative frequency (0.21%) at the invaded sites while *Mangifera indica* had the lowest relative frequency (0.36%) at the non-invaded sites.

The Sorensen similarity coefficient of both invaded and non-invaded sites was calculated to be 26.09%. The rarefied and extrapolated species richness, Shannon index, and Simpson index of the non-invaded sites were significantly higher than the invaded sites since there was no overlap in

Table 1. Checklist of plants identified and their relative frequencies at both the invaded and non-invaded sites.

S/N	Species name	Family name	Invaded sites		Non-invaded sites	
			Presence/Absence	Relative frequency (%)	Presence/Absence	Relative frequency (%)
1	<i>Calopogonium mucunoides</i> Desv.	Fabaceae	√	1.93	√	21.15
2	<i>Chromolaena odorata</i> (L.) King & H. Rob.	Asteraceae	X	0	√	0.37
3	<i>Pneumatopteris afra</i> (Christ.) Holtum	Thelypteridaceae	√	87.18	X	0
4	<i>Cynodon dactylon</i> (L.) Pers.	Poaceae	X	0	√	1.03
5	<i>Elaeis guineensis</i> Jacq.	Arecaceae	X	0	√	0.73
6	<i>Heterotis rotundifolia</i> (Sm.) Jacq.	Melastomataceae	√	1.79	X	0
7	<i>Ipomoea triloba</i> L.	Convolvulaceae	X	0	√	10.74
8	<i>Mangifera indica</i> L.	Anacardiaceae	X	0	√	0.36
9	<i>Melochia corchorifolia</i> L.	Sterculiaceae	√	1.46	X	0
10	<i>Mimosa pudica</i> L.	Mimosaceae	X	0	√	15.92
11	<i>Oryza barthii</i> A. Chev.	Poaceae	√	1.32	X	0
12	<i>Oryza sativa</i> L.	Poaceae	√	0.21	X	0
13	<i>Panicum subalbidum</i> Kunth	Poaceae	X	0	√	8.74
14	<i>Pennisetum pedicellatum</i> Trin.	Poaceae	X	0	√	8.76
15	<i>Pennisetum polystachion</i> (L.) Schult.	Poaceae	X	0	√	3.08
16	<i>Rhynchospora corymbosa</i> (L.) Britton	Cyperaceae	√	3.59	X	0
17	<i>Sesame alatum</i> Thonn.	Pedaliaceae	X	0	√	11.72
18	<i>Sida acuta</i> Burm.F.	Malvaceae	X	0	√	9.52
19	<i>Sida cordifolia</i> L.	Malvaceae	√	0.29	√	0.75
20	<i>Urena lobata</i> L.	Malvaceae	√	2.32	√	7.02

KEY: √ means Present, X means Absent

their confidence intervals (Figures 2–4). In the same vein, the one-way ANOVA with pairwise permutation test revealed that all of the diversity indices quantified for the non-invaded sites were significantly higher than the invaded sites (Table 2). More importantly, the Shannon diversity index of the non-invaded sites (2.252) was significantly different from the invaded sites (0.618). In the same vein, the species evenness index of the non-invaded sites (0.679) was significantly higher than the invaded sites (0.206).

4. Discussion

According to Santoro *et al.* (2012), any community with the same species that occupies more than 10% of the total sampled plots/quadrants is described as an invaded community. Therefore, it can be deduced that *P. afra* has invaded the wetlands studied since it occupied 100% of all the quadrants. The reverse was the case for the non-invaded sites because none of the species occupied more than 10% of the sampled quadrants. Unlike the invaded sites where *P. afra* dominated, none of the plant species at non-invaded sites exhibited strong dominance over others. This is an indication of a more even distribution of plant species at the non-invaded sites than the invaded sites and it was evidenced by the higher evenness index observed at the non-invaded sites. Also, the sampling of plants at these study sites was very sufficient due to the asymptote level reached by the rarefied-extrapolated curves for species richness, Shannon index, and Simpson index (Rahmad & Akomolafe, 2018). The Sorenson similarity index showed the percentage similarity in terms of the same species of plants common to both the invaded and non-invaded wetlands. The lower percentage recorded in this study

showed that the two categories of wetlands did not share many species in common.

Although some of the plants identified at the non-invaded sites, that included *Chromolaena odorata*, *Sida acuta*, and *Urena lobata*, have been reported by several authors to be widespread and aggressive invasive plants (Awan, Chauhan, & Cruz, 2014; Naidoo & Naidoo, 2018; Oseni *et al.*, 2018; Shao *et al.*, 2018; Shrestha *et al.*, 2018; Thapa *et al.*, 2016), they did not exhibit any traces of dominance in these wetlands. The lower species diversity of the invaded sites compared with the non-invaded sites was also an indicator for the level of threats posed on the wetlands by *P. afra*. This

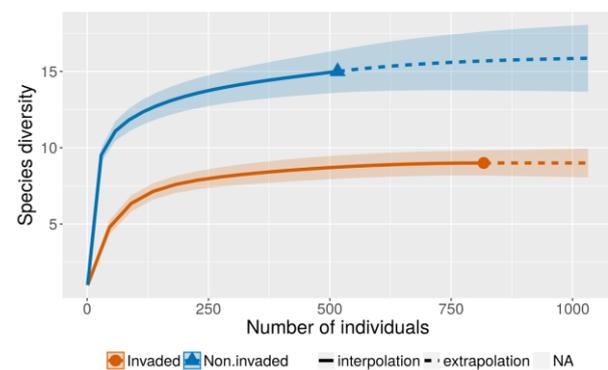


Figure 2. Sample-sized based rarefaction and extrapolation curve for species richness of the invaded and non-invaded sites. Reference samples are indicated by solid shapes, rarefaction by solid lines, and extrapolation by dashed lines.

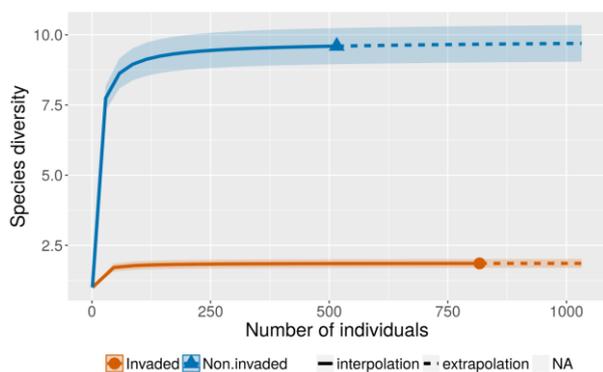


Figure 3. Sample-sized based rarefaction and extrapolation curve for Shannon diversity of the invaded and non-invaded sites. Reference samples are indicated by solid shapes, rarefaction by solid lines, and extrapolation by dashed lines.

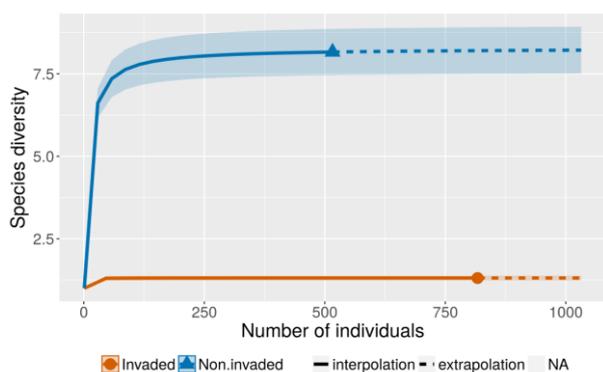


Figure 4. Sample-sized based rarefaction and extrapolation curve for Simpson diversity of the invaded and non-invaded sites. Reference samples are indicated by solid shapes, rarefaction by solid lines, and extrapolation by dashed lines.

Table 2. Comparison of different analyses of community characteristics of the invaded and non-invaded sites.

Community characteristics	Invaded sites	Non-invaded sites
Observed species richness*	9 ^a	14 ^b
Rarefied and extrapolated species richness**	9 ^a	16 ^b
Evenness index*	0.206 ^a	0.679 ^b
Margalef index*	1.193 ^a	2.082 ^b
Shannon index*	0.618 ^a	2.252 ^b
Simpson index*	0.237 ^a	0.877 ^b

Values with different superscripts across the rows are significantly different ($P \leq 0.05$).

*Significant differences were determined by one-way ANOVA with pairwise permutation test in PAST 3.19.

**Significance differences were determined by the confidence interval.

means that the non-invaded sites were richer in terms of number of species and were more diverse than the invaded sites. This threat could be the result of limited recruitments and growth of other plants through competition for resources

or allelopathy by *P. afra*, thus accounting for reduced diversity.

Our observation in this work can be compared with a similar study by Morón *et al.* (2009) on sites invaded by *Solidago canadensis* and *Solidago gigantea* (goldenrods). They observed that plant diversity and richness of the non-invaded sites were significantly higher than the ones invaded by these goldenrods. The invaded sites were therefore described as being threatened by goldenrod invasion. The same was observed at the sites invaded by *Lantana camara* in some wet forests of south-east Australia where non-invaded sites had higher species diversity, richness, and compositions (Gooden *et al.*, 2009). Similarly a significant reduction in plant community richness and diversity, that occurred in some forests invaded by *Acer platanoides* but not in the non-invaded counterparts in western Montana, USA, was reported by Reinhart, Greene, and Callaway (2005). The invasion of this plant was apparently associated with the change in the community structure and loss of native plant diversity. The lower diversity indices observed at the invaded sites as a result of the invasion of *P. afra* agrees with the earlier hypothesis that invasive plants do have a negative influence on plant diversities of invaded communities compared with non-invaded communities at smaller scales (Wang *et al.*, 2018b). Our observation in this study, however, contradicts the reports of Wang *et al.* (2018a) on Canadian goldenrod which stated that its invasion success did not affect the plant diversity of the communities invaded compared with the non-invaded communities. This was attributed to the likelihood of higher intraspecific competition among individuals of this goldenrod which shared the same resources, thereby leading to stability in the community diversity (Stanley Harpole & Tilman, 2006).

5. Conclusions

This study of the comparative assessment of plant diversities of wetlands invaded by *P. afra* and non-invaded wetlands clearly showed that the invaded wetlands were more threatened than the non-invaded wetlands. This is due to high plant density and reduction in the plant species richness and diversities of these invaded sites compared with the non-invaded sites. All of the diversity indices helped us to understand the nature of the communities with reference to the impacts of invasion. The massive growth of *P. afra* on the wetlands, which amounts to higher plant density, will increase the rate of secondary succession of the wetlands into terrestrial habitats. The invasion of *P. afra* will eventually adversely affect the local communities who depend on the water from these wetlands for domestic, commercial, and agricultural activities. It is therefore necessary to implement measures to control this invasive tropical fern to save these wetlands and others from further invasion consequences.

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