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A REVIEW ON GLOBAL FERNS INVASIONS: MECHANISMS, MANAGEMENT AND CONTROL

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ABSTRACT

There has been paucity of information and inadequate studies on the invasive potentials of ferns as most invasive ecological studies have so far focused on higher plants across the continents. This paper therefore, reviews ferns invasions, mechanisms of invasions and management of invasive ferns that have been reported in literatures. We searched four databases including Jstor, Science direct, Willey online library and Scopus for relevant literature between 1990 – 2018. A total of seventy articles reporting ferns invasions in various countries in six continents were harvested. Eighteen ferns reported to be invasive across the world include Lygodium microphyllum, Lygodium japonicum, Azolla pinnata, Pteridium arachnoideum, Dennstaedtia punctilobula, Thelypteris noveboracensis, Pityrogramma calomelanos, Azolla filiculoides, Acrostichum spp, Asplenium adiantum-nigrum, Dryopteris carthusiana, Dryopteris intermedia, Polystichum acrostichoides, Cyclosorus afer, Sphaeropteris cooperi, Angiopteris evecta, Salvinia molesta and Pteridium aquilinum. Most of these ferns were reported to have invaded parts of North America than other continents. Prevalent mechanisms of invasion for these ferns include their polyploidy nature, ability to disperse spores for long distance, allelopathy, adaptation to disturbed areas and unfavourable environmental conditions. It was suggested that using biological approaches which enable ecological succession and ecosystem restoration is preferable to other methods of controlling these invasive ferns.

Keyword: control, *Cyclosorus*, ecology, ferns, invasion, *Pteridium*

INTRODUCTION

Plants invasions are regarded as global issues that negatively influence biodiversity and ecosystem function (Mooney and Hobbs, 2000; Lugo, 2004; Lockwood *et al.*, 2007). They are naturally stimulated, but can also be triggered by various anthropogenic activities (Mack, 2005). Researches on plant invasions so far have been community-based and the subsequent effects on the structure and productivity of ecosystem, changes in biodiversity and other ecosystem-related factors (Mooney and Hobbs, 2000; Sutherst, 2000). Very little focus has been paid to the understanding of human-environment interactions in plant invasions (Schneider, 2004). Integrated approaches that engage ecological, human, remote sensing and other scientific methods are necessary for a robust understanding of mechanisms of plant invasions (Rindfuss *et al.*, 2004). Recently, researches have revealed the combining influences of climate change and human disturbances on successful plant invasion (Mooney and Hobbs, 2000; Crowl *et al.*, 2008).

Fern invasion has not gained massive publicity over the years and their effects on the environment cannot be overlooked. Though there have been extensive studies on their horticultural uses, medicinal values, evolution and taxonomy, yet their ecology is mostly ignored (Watkins, 2011). More attention has been given to angiosperm invasion ecology by researchers in most developing and developed nations. The reason for this could be due to paucity of sufficient recent literatures on fern ecology.

Ferns have been described as having the ability to invade nutrient-deficient soils (particularly low nitrogen and calcium) thereby restoring its fertility (Mehltreter *et al.*, 2010). They are also very tolerant to environmental stresses than expected and do play significant roles in the ecological revitalization of disturbed soils (Watkins, 2011).

The study of dynamics of invasions of some ferns have been linked to several components of the human-environment system such as: socio-economic assessment; spatial landscape assessment and environmental factors assessment. Proper analyses of these components have been used to develop models which explains fern invasions and predictions of their spread in certain regions of the world. These needed to be assessed as a whole entity than isolating the components (Schneider, 2004).

Ferns

Ferns (Pteridophytes) originated from the ancient tropical habitats and have now colonized different types of environment across the world (Sharpe *et al.*, 2010). They belong to the group of plants called cryptogams due to their hidden reproductive systems. They are also referred to as seedless vascular plants (Umi-Kalsom, 2010).

Ferns serve important functions in ecosystem processes as they are now vital components of the biodiversity, flora and natural habitats of many regions of the world (Kamrul-Haque *et al.*, 2016). Despite that they have been found abundantly in most tropical, sub-tropical and other regions of the world, their survival has been greatly threatened by several environmental factors such as moisture availability and habitat destruction in which most of them are about to go into extinction (Dixit, 2000). Due to these threats and evoliutionary processes, some ferns have been able to develop very strange adaptive strategies which have now lead to their invasiveness in many favourable and unconducive environments. Though, these ferns have been excluded from most plant invasion studies by ecologists today (Kamrul-Haque *et al.*, 2016). There is then a need for a review of the ferns reported so far as being invasive across the world, hence this study.

Descriptions of Specific Invasive Ferns

Here are some of the ferns that have invaded various countries in the world. A comprehensive list of the invasive ferns as classified under each continent is provided in table 1.

***Angiopteris evecta* (Forst.) Hoffm (The Oriental vessel fern)**

Angiopteris evecta (Plate 1) has been listed among invasive ferns in regions such as Costa Rica, Jamaica and Hawaii (all in North America) where it has disrupted the native biodiversities (Christenhusz and Toivonen, 2008).

Plate 1: *Angiopteris evecta* growing (A) growing on the forest floor (B) as ornamental plant

Table 1: Checklist of some invasive ferns in different continents

Continent	Country	Invasive Ferns	Source
Africa	Cameroon	*Pityrogramma calomelanos*	Wardlaw (1962)
	Nigeria	*Cyclosorus afer*	Akomolafe *et al.* (2017)
	South Africa	*Azolla filiculoides*	McConnachie *et al.* (2003)
Asia	Malaysia	*Acrostichum spp.*	Jawa and Srivastava (1989)
	Iran	*Azolla filiculoides*	Roghayeh *et al*. (2012)
Australia	Australia	*Pteridium aquilinum*	
	New Zealand	*Pteridium aquilinum*	Marrs *et al.* (2000)
Europe	Britain	*Pteridium aquilinum*	Marrs and Watt (2006)
	Poland	*Azolla filiculloides*	Myśliwy and Szlauer-Łukaszewska (2017)
	Italy	*Salvinia molesta*	Giardini (2004)
North America	Mexico	*Pteridium aquilinum*	Schneider and Fernando (2010)
	USA	*Pteridium aquilinum*; *Lygodium microphyllum; Lygodium japonicum; Pteridium arachnoideum*; *Azolla pinnata, Dennstaedtia punctilobula; Thelypteris noveboracensis, Asplenium adiantum-nigrum; Dryopteris carthusiana; Dryopteris intermedia; Polystichum acrostichoides*	Hill (1996); Lott *et al.* (2003); Flinn (2006); Madeira *et al.* (2013); Ranker (2016)
	Canada	*Pteridium aquilinum*	Schneider (2006)
	Costa Rica	*Angiopteris evecta*	Christenhusz and Toivonen (2008)
	Jamaica	*Angiopteris evecta*	Christenhusz and Toivonen (2008)
South America	Brazil	*Pteridium arachnoideum*	Miatto *et al.* (2011)

***Azolla filiculoides* Lam. (Red water fern)**

Azolla filiculoides (Plate 2), an aquatic fern native to South America has been reported by McConnachie *et al.* (2003) to have invaded aquatic ecosystems in Iran, South Africa and most African countries. This fern often forms very thick mats on most slow-moving water bodies thereby causing economic losses to natives who rely on those waters (McConnachie *et al.*, 2003).

Plate 2: *Azolla filiculoides* growing inside water

***Dennstaedtia punctilobula* (Michx.) T. Moore (Hayscented fern)**

Hayscented fern (Plate 3), a native to USA and Canada has strong interference with the survivorship and regeneration of forests in some parts of USA, North America (Hill, 1996). Tree seedlings hardly survive under the canopies of this fern. Therefore, it has been described as an aggressive invasive fern due to its rapid spread (Hill and Silander, 2001). This fern was also found colonizing forests and roadsides in New England (Hammen, 1993).

Plate 3: *Dennstaedtia punctilobula* (A) at close range (B) as an invasive fern

***Dryopteris carthusiana* (Villars) Fuchs and *Dryopteris intermedia* (Muhl.) Gray**

These ferns were reported by Singleton *et al.* (2001) to have invaded upland forests in some parts of USA, North America (Plate 4). The spores have the capacity to travel over a long distance through the wind. The two ferns species though have similar spore dispersal attribute, are distributed differently in primary and secondary forests in USA (Linn, 2006).

Plate 4: (A) *Dryopteris carthusiana* (B) *Dryopteris intermedia*

***Lygodium microphyllum* (Cav.) R.Br. (Old World climbing fern)**

This fern has been reported by Kurumatani *et al.* (2001) to have swallowed up about 39,000 acres of South Central Florida's pinelands (North America), cypress swamps and Everglades tree islands (Plate 5). The fern is known for its thick and strong vines which cover native plants and alter natural processes such as free flow of streams. Consequently, *Lygodium* eradicates understory

vegetation and some established trees by preventing them from receiving enough sunlight (Randall, 1998). This fern can reproduce through several means such as intra and inter-gametophytic selfing. Its spores have high germination rate. Likewise, the high transition rate of gametophyte to sporophyte is responsible for rapid colonization of this fern in South Florida (Lott *et al.*, 2003).

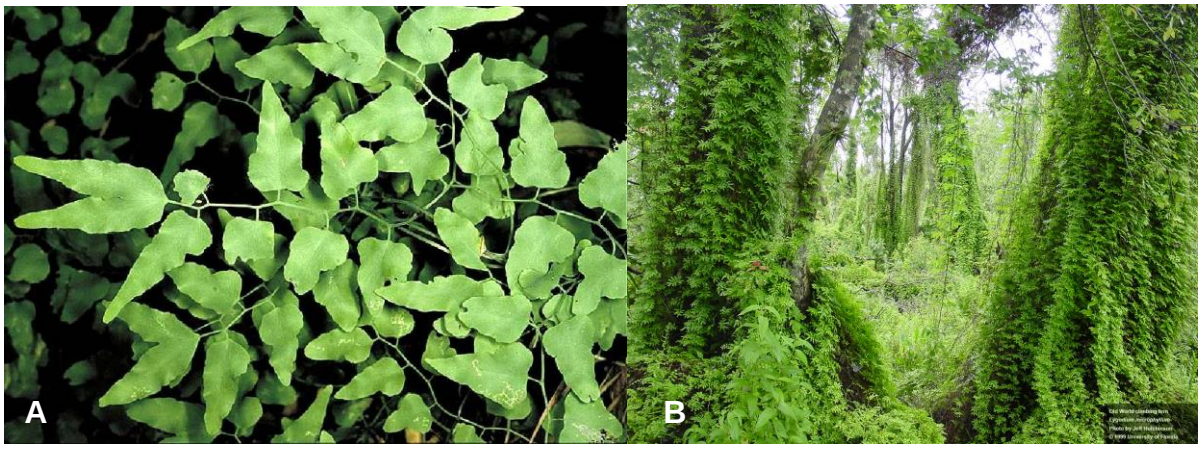

Plate 5: *Lygodium microphyllum* (A) growing as climber in the forest (B) invading trees

***Pityrogramma calomelanos* L.**

Pityrogramma calomelanos (Plate 6) has been identified as a troublesome plant invading most oil palm plantations that were established in Cameroon (Africa). The invasion of the fern was as a result of application of arsenical herbicide on a leguminous weed *Pueraria phaseoloides* in order to establish oil palm. The fern therefore took over and became very difficult to control. The fern mainly undergoes sexual reproduction in the wet season, but has the potential to survive long period of dryness in most rocky and sandy areas (Wardlaw, 1962).

Plate 6: *Pityrogramma calomelanos* showing its whitish leaflets

***Polystichum acrostichoides* (Michaux) Schott (Christmas fern)**

Polystichum acrostichoides (Plate 7), a native of North America, has been regarded as an invasive fern species across primary forests in Central New York, USA. This fern is usually green throughout the year and is found in varieties of habitats such as woodlands, shady forests, banks of streams and slopes (Linn, 2006).

Plate 7: *Polystichum acrostichoides* growing on forest floor

***Pteridium aquilinum* (L.) Kuhn (Bracken fern)**

Bracken fern (Plate 8), a native of the Britain has been regarded as one of the most successful invasive plant species in that it occurs all over the world except in extremely dry regions (Taylor, 1990; Marrs and Watt, 2006). Its invasion is economically relevant due to the loss of productive agricultural land and interference with forest regeneration. This fern has become very difficult to control due to its stubborn underground rhizome. This gives it the ability to colonize most habitats, even in highly human-disturbed areas, thereby creating problems for agriculturists (Der *et al.*, 2009; Roos *et al.*, 2011). The invasive success of bracken fern in tropical regions has been attributed to its mechanism of spore dispersion in which they are spread all through the year (Schneider, 2004). This fern also has the potential of resisting diseases and releasing allelopathic substances limiting the growth of neighboring plants (Marrs *et al.*, 2000; Alonso-Amelot and Avendano, 2002). Furthermore, its ability to adapt to broad range of environmental conditions and disasters such as fires made it a successful invader (Page, 1986). This fern has successfully invaded Southern Yucata for decades and the areas invaded have outgrown cultivated areas (Schneider, 2006). Its invasion in most regrowth forests has been aided by frequent fires and land clearance for farming. Therefore, its potential to get out of control thereby forming monospecific colonies which threatens native biodiversity makes it best described as invasive fern species (Schneider and Fernando, 2010).

Plate 8: *Pteridium aquilinum* [A] at close range, [B] as invasive on forest floor

***Pteridium arachnoideum* (Kaulf.) Maxon. (neotropical bracken fern)**

Pteridium arachnoideum (Plate 9) was identified as a potential invasive fern in the Brazilian Cerrado, South America where it was predicted to change the vegetation structure of the area. The areas invaded by this fern was found to have lower diversities and densities thereby indicating its threat on the future biodiversity of this area (Miatto *et al.*, 2011).

Plate 9: *Pteridium arachnoideum*

***Salvinia molesta* D.S. Mitchell**

Salvinia molesta (Plate 10), a native of Brazil is an aggressive invasive fern species in Italy. It has spread to virtually most tropical regions of the world. *S. molesta*, usually grows to the extent of covering water surfaces within a short period of time (Giardini, 2004).

Plate 10: *Salvinia molesta* growing on water surface

***Sphaeropteris cooperi* (W.J. Hooker ex. Mueller) Tryon (Australian tree fern)**

Sphaeropteris cooperi (Plate 11) has displaced native plants and other ferns in some rainforests in Hawaiian (North America) for many years ago. This evergreen fern is characterized by the ability to produce fast growing croziers which enable it to spread rapidly than native plants (Chau *et al.*, 2013).

Plate 11: *Sphaeropteris cooperi*

***Thelypteris noveboracensis* (L.) Nieuwl (New York fern)**

New York fern (Plate 12) is another well-known fern species in USA for its ability to disturb the regeneration of forests vegetations (Hill and Silander, 2001). This fern is very abundant, occupying the understory of secondary forests in Connecticut, USA.

Plate 12: *Thelypteris noveboracensis* growing as invader

Mechanisms of Successful Fern Invasion

The successful invasion of most ferns has been attributed to their roles in the transformation of soil ecosystem particularly in Nitrogen uptake. They can meet their nitrogen needs regardless of the amount present in the soil. This gives them the competitive advantage over other native plants (Werkman and Callaghan, 2002). Previous studies have shown that ferns such as *Pteridium aquilinum* may stimulate Nitrogen turnover and the accumulation of mineralizable Nitrogen and NH_4^+ in belowground compared to other plants (Marrs *et al.*, 1992). The rhizome of bracken fern is so much endowed with carbohydrate reserves which enhance its rapid growth from the buds. This is also responsible for

its fast regrowth after long unfavorable seasons and disturbances (Pakeman and Marrs, 1993).

Also, ferns such as *Lygodium* can successfully invade new colonies due to features like high spore count, continuous spore production, dispersal ability, and rapid growth (Lott *et al.*, 2003). Their spores have the potential to germinate in different environmental conditions (Call *et al.*, 2007). For Hayscented fern, its invasion comes after colonization through spores and rapid spread through rhizomes in the areas (Groninger and McCormick, 1991). It has the intrinsic ability to spread by either repeated branching or linear growth of the already established rhizome in the soil (Hill 1996). This perennating habit enables the rapid production of new canopies in early growing season and this gives it competitive advantage over other nearby plants (Hill and Silander, 2001).
The successful invasion of some ferns in Hawaii has been attributed to the polyploidy nature of such ferns. This is explained by their ability to produce new fernlets through gametophytic selfing (Sessa *et al.*, 2016). This is an added advantage of ferns over other plants because a single spore can produce new population of ferns. Therefore, higher rates of formation of sporophytes could be a striking reason for the rapid colonization and distribution of ferns species (Linn, 2006). Furthermore, invasive ferns have been reported by Jatoba *et al.* (2016) to have various secondary metabolites which enable them to exalt allelopathic effects on neighboring plants thereby colonizing the habitats. These allelochemicals may be present in their fresh fronds, leaflets liters or in the soil. For instance, proanthocyanidin selligueain A was isolated from the fresh fronds of *Pteridium arachnoideum* and found to limit the growth of some specific species such as *Sesamum indicum* (Jatoba *et al.*, 2016).

Adverse effects of Fern Invasion

i. Invasive ferns could extremely disrupt native plant communities by changing vegetation structure and composition in the areas invaded (Brandt and Black, 2001).
ii. Some of them pose serious threats to the life of animals that are entangled in their mats (Darby and McKercher, 2002).
iii. Bracken fern, for instance, has caused several problems in most parts of the world where it has invaded. Some of them include direct loss of grazing land.
iv. It also acts as a reservoir for sheep ticks, causing problems for farmers and managers of grouse moors.
v. It has led to severe loss of biodiversity which are more valuable to conservationists (Lawton *et al.*, 1988).
vi. Invasive ferns do alter the soil physicochemical characteristics and nutrients availability to other plants (DeLuca *et al.*, 2012).
vii. They also contribute to forest fires due to the large amount of leaflet litters they produce (Adie *et al.*, 2011).
viii. These ferns have been reported to affect forest seed banks after invasion success thereby preventing restoration of the environment (Ghorbani *et al.*, 2006).

Management and Control of Invasive Ferns

Characteristics such as adaptability to long dry seasons, resistance to fire, disease resistance, herbivory resistance, and continuous spore dispersal have been suggested as factors responsible for the difficulty encountered in the control and management of fern invasions (Schneider, 2004). This is probably because invasive ferns are mostly perennial and evergreen which make them to be able to resist most means of controlling them. Also, there could be some genetic resistances developed by these invasive ferns through evolutionary processes in resisting disease and herbivore attacks. Some control measures have been suggested by researchers over the years which include the underlisted:

i. The spread of these ferns can be prevented by removing them manually or mechanically through using heavy equipment before the start of the dry season when spore dispersal normally occurs (Pakeman and Marrs, 2003; Ghorbani *et al.*, 2006).
ii. They may also be sprayed with suitable chemicals early in the dry season so as to eradicate the fernlets (young embryonic ferns)

which were formed in the rainy period (Stewart *et al.*, 2008; Bohn *et al.*, 2011).

iii. The gametophytes of old world climbing fern were discovered to be very susceptible to metsulfuron methyl chemical when treated with about 423 mgL^{-1} of it (Hutchinson and Langeland, 2013).

These methods are not viable in most rural areas due to the high financial implications and time consumption (Ghorbani *et al.*, 2006). Also, use of these mechanical and chemical methods usually results in reinvasion of the controlled species or new invasive plants after a period (Kettenring and Adams, 2011). Such occurrence has been documented in the United Kingdom where bracken fern reinvaded some sites after control measures were implemented (Pakeman *et al.*, 2000). Therefore, methods which employ natural succession and other ecological dynamics are encouraged to ensure long-term and effective control (Pakeman *et al.*, 2002). Some of them are listed below:

i. Slocum *et al.*, (2006) suggested that areas invaded by Bracken fern could be restored by the re-establishment of pioneer native species in such areas.
ii. Using Balsa (*Ochroma pyramidale*), a native tree with rapid growth has proved effective in the initial control of Bracken fern in most part of USA due to its ability to shade out light from the reach of the fern (Hiral, 2004; Douterlungne *et al.*, 2010).
iii. Consequently, this has promoted the regeneration of forests (Kleijn, 2003; Cusack and Montagnini, 2004; Hooper *et al.*, 2005).
iv. The use of mite *Floracarus perrepae* has been suggested for the control of *Lygodium microphyllum* in Florida.
v. Based on field surveys and preliminary laboratory examinations, this mite has demonstrated greatest potential for biological control of the fern (Goolsby *et al.*, 2003).
vi. The frond-feeding weevil *Stenopelmus rufinasus* was employed for the control of *Azolla filiculoides* in South Africa. This weevil was able to drastically reduce the spread of the fern to a level where it was no longer a national menace within three years (McConnachie *et al.*, 2003).

CONCLUSION

It is now evident that there is a lot of gaps in the study of fern invasion ecology as most researches have focused on angiosperms invasions. Most of the countries particularly in Africa, Asia, South America and Europe do not have adequate documentation on the likely spread of ferns as invasive plants. Invasive ferns may be very virulent in their spread if not detected early and controlled. Among the ferns reported as invasive, none could be regarded as the most noxious because the invasive ability of each of them differs with the geographical locations and habitats. Therefore, there is need for earlier detection of invasive potentials of ferns. More researches should be encouraged on invasive ecology of ferns and their managements using biological processes in native vegetations across the world so as to save the biodiversity.

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