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Invasive Species *Echinochloa colona* Reduces Abundance and Diversity of Resident Plant Communities in Tropical Wetland

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Abstract

Although the relationship between invasive alien species (IAS) and plant community structure has attracted considerable interest, the impacts of IAS on abundance and diversity of resident plant communities in species rich-ecosystems, such as tropical wetlands are poorly understood. Consequently, this has impeded development of improved management strategies and successful restoration of invaded tropical wetlands. Therefore, data on vegetation were collected from 60 plots of 20 × 50 m to study the impacts of alien invasive grass *Echinochloa colona* (L.) Link abundance on plant community abundance, richness, evenness and diversity of resident plant species within grasslands of the Kilombero Valley wetland, Tanzania. Moreover, the impacts of abundance of *E. colona* on plant functional groups (*i.e.* graminoids, forbs and shrubs) richness were also explored. Generalized linear models showed that community richness, evenness, diversity and abundance of resident species were negatively related to the *E. colona* abundance. There was a negative relationship between richness of graminoids and shrubs and the abundance of *E. colona*. Similarly, the abundance of graminoids, forbs and shrubs is related negatively to the abundance of *E. colona*. Given that most of the community and functional group attributes of resident plants is related negatively to *E. colona* abundance, improved management strategies should be developed to minimize the abundance and further spread of *E. colona* to restore and conserve wetland biodiversity.

Keywords

Native Species, Evenness, Richness, Diversity, Functional Groups, Resident Species

1. Introduction

Plant invasion is increasingly causing ecosystems degradation with large negative impacts on ecological functions and biodiversity in natural and agroecosystems. There is therefore a pressing need to understand the impacts of invasive alien species (IAS) on resident plant communities and monitor their spread [1] as the extent of biological invasions grows rapidly across the globe and native species extinctions increase. Such an understanding would facilitate development of improved mitigation strategies to restore and halt biodiversity loss particularly in high rate plant invasion ecosystems such as wetlands [2]. Once established, invasive plants compete with resident species for resources such as light, moisture, nutrient and space, and progressively increase their abundance and colonization of disturbed and new habitats [3]. Moreover, invasive species may achieve dominance in invaded landscapes that ultimately displace native plant species and decrease local plant species diversity [4] [5]. It is also known that invasive species inhibits native species seedling establishment and growth and alters ecosystem processes and physical resources of the recipient community [6] with serious negative consequences on ecosystems goods and services plant communities provide. The impacts of invasive species on resident plant communities however, do not necessarily allow generalization since the effects depend on the biological traits of the invading species and characteristics of invaded resident communities [7] [8]. Thus, for best restoration strategies, studies focusing on the impacts of invasive species on abundance and diversity of resident plant communities in areas where the invader is highly abundant and impacts community structure are important. Surprisingly studies measuring community level impacts of plant invasions are rather scarce in tropical regions, and particularly in Africa [9]. This study therefore contributes to filling the existing knowledge gap on the relationship between IAS and resident plant communities in species-rich tropical ecosystems which are overall little studied in regards to biological invasions [4].

Among the ecosystems, wetlands have steady moisture, experience natural and human disturbance, and are sinks of nutrients, inorganic sediments and organic carbons and are therefore more susceptible to plant invasion perhaps than any other ecosystem [2]. At Kilombero Valley wetland in Tanzania (study area), suppression of native plant species might be a result of dominance of the alien invading grass species *Echinochloa colona* (L.) Link as supported by [10]. It is reported that *E. colona* invades agricultural landscapes, pastures and seasonally flooded habitats and has a large potential to change composition of resident species and other community attributes [11] [12]. It is not yet clear however why species like *E. colona* are such successful invaders in many areas. Previous studies have investigated the economic loss in crop yields (due to the weed) and control of *E. colona* but none have tested its relationship with the abundance, richness, evenness and diversity of resident communities and plant functional groups. It is known that resident plant species responds differently to invaders whereby some are excluded easily than others. Species or functional groups with high biomass increase community resistance to invasions [13] [14]. Thus, understanding the relationship between the abundance and diversity of resident communities and plant functional groups and the abundance of IAS facilitates early detection of potential invasions, preparation of optimal control strategies and minimizes impacts to the biodiversity. The overall objective of this study was therefore to examine the impacts of invasive weed *E. colona* on community structure of resident plant species and assess if these impacts differ among plant functional groups in the tropical wetland. Specifically this study addresses the following questions: 1) Does *E. colona* abundance decreases the abundance, richness, evenness and diversity of other resident plant species in a community? and 2) Are the impacts of *E. colona* abundance on the species abundance and richness varies among graminoid, forb and shrub plant functional groups?

2. Materials and Methods

2.1. Study Site

The study was carried out in the Kilombero Valley wetland in Morogoro region, Tanzania (8˚32'0"S, 36˚29'0"E; **Figure 1**). Kilombero wetland covers an area of 7967 km^2 and because of its ecological and biodiversity importance it was declared a Ramsar site in 2002. It is one of the largest low altitude inland freshwater wetland in East Africa. Kilombero is a sub-humid area with mean annual temperature of 26˚C and mean annual rainfall of 1600 mm [15]. The area experiences bimodal rainfall with short rains common between December and February and long rains from March to May. Kilombero River which flows in the SW-NE direction dissects the Valley into two administrative districts of Kilombero and Ulanga. The Kilombero area has fertile clay soils which are inundated during wet season and crack open during dry season (July-October).

Kilombero wetland hosts around 350 plant species including indigenous species of *Paspalum scrobiculatum, Digitaria velutina, Hygrophila auriculata* and *Chamaecrista mimosoides*. Eight plant communities namely low lying valley grasslands, tall grasslands, papyrus swamps, marginal grasslands, marginal woodlands, combretaceous wooded grasslands and miombo woodland are recorded in the valley [15]. This study focuses on the marginal grasslands ecosystem with a relatively large area with significant proportion (33%, 115 species) of plant species including the alien weed species *E. colona* [14]. This allows testing the potential impacts of alien grass species e.g. *E. colona* on the resident plant communities and functional groups.

The wetland accommodates 75% of the world's remaining puku antelopes (*Kobus vardonii*), a near threatened species [16]. The wetland is also recognized internationally as an important bird area supporting more than 300 bird species including 3 endemic species. The Kilombero Game Controlled Area (KGCA), with high concentration of large mammals like elephants (*Loxodonta africana*), hippopotamus (*Hippopotamus amphibious*), buffalos (*Syncerus caffer*), common

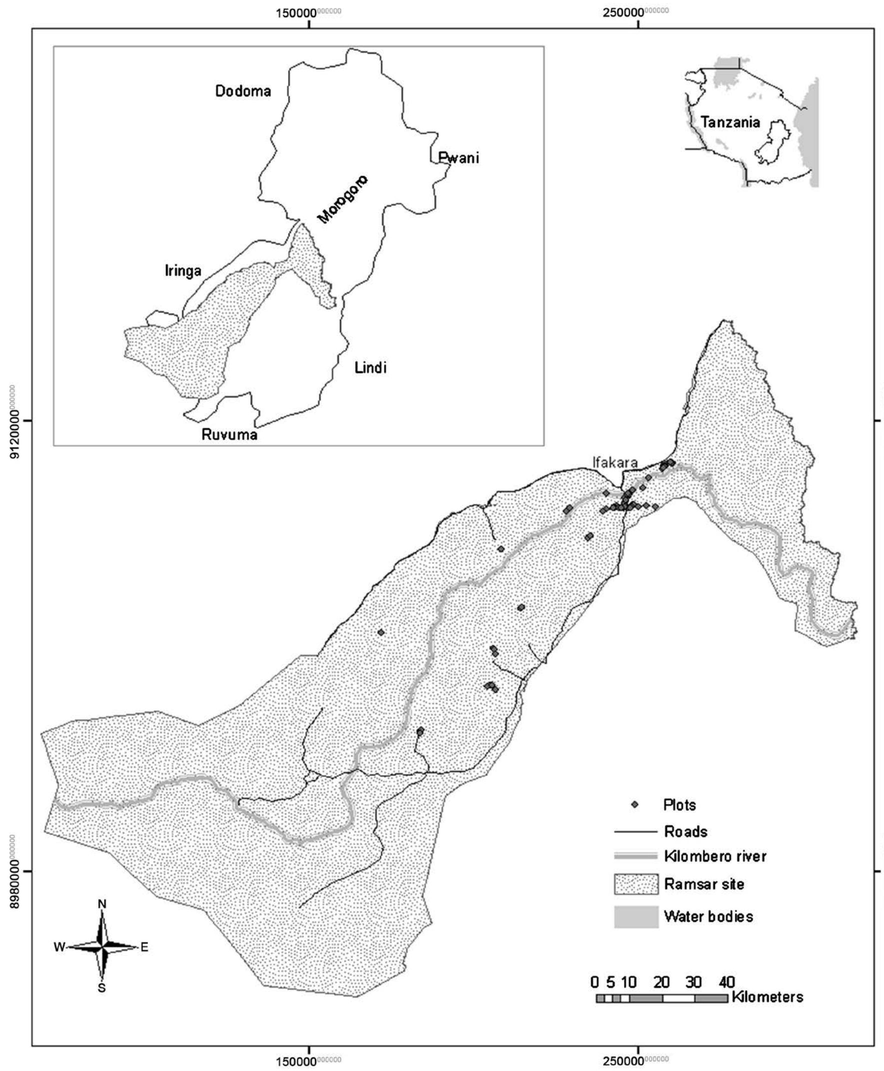

Figure 1. Location of the study area: Morogoro region of southern-central Tanzania with Kilombero Valley Floodplain wetland (top left), and the location of 60 study plots on the north-eastern side of the floodplain (down).

zebra (*Equus quagga*) and lions (*Panthera leo*), is located in the interior part of the Valley [15].

2.2. Study Species

Echinochloa colona (Junglerice) is an invading weed tufted C_4 annual grass native to India. It is a cosmopolitan species widely distributed in the tropics and subtropics. It is thought to be introduced together with the seeds of rice in many parts of the world. It is often abundant on fertile and heavy textured soils, stream sides, rangelands and pastures, and on seasonally flooded landscapes [17]. It is a host of diseases such as tungro and rice yellow dwarf. It is documented that light is an important factor for seed germination and the species responds to nutrients additions [18]. It produces abundant small seeds with a short dormancy period and the seeds may be viable up to 3 years. It grows very rapidly, has competitive potential and is resistant against several herbicides. *E. colona* is propagated by seeds but can as well regenerate vegetatively through nodes [12]. In some areas it flowers throughout the year and it has a wide range of adaptations to environmental conditions and ecological niches. Thus, all these traits make it a successful invader of disturbed habitats in agroecosystems and semi-natural environments [17]. The overall cover of *E. colona* in the Kilombero marginal grasslands is reported to be 20% [14].

2.3. Data Collection

Sixty (20 × 50 m) plots were randomly selected and surveyed to investigate the impacts of *E. colona* abundance on community species richness, evenness, diversity and abundance, and abundance and richness of graminoids, forbs and shrubs between February and March 2010. The plots were positioned within the north-eastern side of the Valley where the Valley forms mostly a peneplain (**Figure 1**). In this area, there are patches of rice farms which were avoided during the vegetation survey. The shortest distance between plots was 450 m to minimize the dependence of data. In each plot, 20 (50 × 50 cm) quadrats were randomly located and species identities and abundance were recorded using the point intercept method [19]. The abundance of each species was estimated by recording the number of contacts each species made with the pin. All contacts with the pin were recorded even if the same individual was in contact with the pin more than once [20]. The abundance of other resident species was enumerated and *E. colona* abundance data was collected following the same procedure. Abundance was estimated for *E. colona* against counting ramet individuals because the grassland vegetation had abundant cover and the fact that *E. colona* develops ramets altogether made it difficult to estimate in the field. Plant species were grouped into graminoid, forb and shrub functional groups. Plant species were identified in the field and those that could not be identified therein were identified at the Arusha National Herbarium of Tanzania where all voucher specimens are deposited.

2.4. Data Analysis

To establish the impacts of *E. colona* on community abundance, richness, evenness and diversity vegetation data from 20 quadrats were summed to obtain data for plots (n = 60). Similar approach was employed to assess the impacts of *E. colona* on richness and abundance of graminoid, forb and shrub functional groups. Thus, community abundance was the sum of abundances of individual species in 20 quadrats. Species richness (S), Shannon-Wiener diversity index (H'), evenness (E) and abundance were computed for each plot. To determine community species richness number of all species present in a plot was added. The Shannon diversity index was computed with *BiodiversityR* package following [21] and evenness as $E = H'/\ln S$ where S is the number of species in the plot [22]. It was not possible to compute evenness and diversity indices for all functional groups as shrub group had few individuals. Consequently, only species richness and abundance for functional groups were calculated. Functional group richness was the sum of different plant species recorded in each group (*i.e.* graminoid, forb and shrub) per plot. Similarly, functional group abundance was obtained by adding the abundances of individual species in respective groups per plot. Scatter plots were used to explore data trends for all dependent and independent variables before the actual analyses. Data for *E. colona* abundance was removed from data matrices before computation of functional group and community structure indices (*i.e.* abundance, richness, evenness and diversity). Generalized linear models (GLMs) were then used to examine the relationship between community species richness, evenness, Shannon diversity, total abundance, and the species richness and abundance of graminoid, forb and shrub functional groups, and *E. colona* abundance [23]. Because our response data sets had both count (e.g. number of shrub species) and continuous data (e.g. diversity of graminoid species), we ran GLMs with logarithmic link function and Poisson distribution for count data, and used GLMs with identity link function and normal distribution of errors for continuous data [23]. We used standard diagnostic plots to validate all final models. All the statistical analyses were done using R [24].

3. Results

There was a negative relationship between most community and plant functional group responses and the abundance of *E. colona*.

Plant community diversity, richness, evenness and abundance were negatively related to the *E. colona* abundance (**Table 1**; **Figures 2(a)-(d)**). Species richness of graminoids and shrubs related negatively to the abundance of *E. colona* (**Table 2**; **Figure 3(a)**, **Figure 3(b)**). The abundance of graminoids, forbs and shrubs were related negatively to the abundance of *E. colona* in the Kilombero wetland (**Table 2**; **Figures 3(c)-(e)**). There were no relationships between forbs richness and the abundance of *E. colona* (**Table 2**).

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4. Discussion

Impacts of *E. colona* on resident plant communities and functional groups.

The results of this study show that most of plant community attributes (*i.e.*

Table 1. The effects of *Echinochloa colona* abundance on community structure of resident plants at Kilombero wetland, Morogoro, Tanzania.

Effects	Estimate	Std. Error	*t*-value	*P*-value
Plant species richness	−0.016	0.002	−8.635	<0.001
Plant species evenness	−0.019	0.007	−2.814	0.005
Shannon diversity	−0.014	0.0036	−4.061	<0.001
Total abundance of species	−0.057	0.022	−75.89	<0.001

Table 2. The effect of *Echinochloa colona* abundance on the abundance and richness of plant functional groups of resident plants at Kilombero wetland, Morogoro, Tanzania.

Effects	Estimate	Std. Error	*t*-value	*P*-value
Functional group richness				
Graminoids	−0.02	0.002	−9.465	<0.001
Forbs	0.001	0.004	0.13	0.896
Shrubs	−0.013	0.006	−2.01	0.044
Abundance of plant functional groups				
Graminoids	−0.044	0.001	−60.97	<0.001
Forbs	−0.007	0.002	−3.401	0.001
Shrubs	−0.022	0.004	−6.138	<0.001

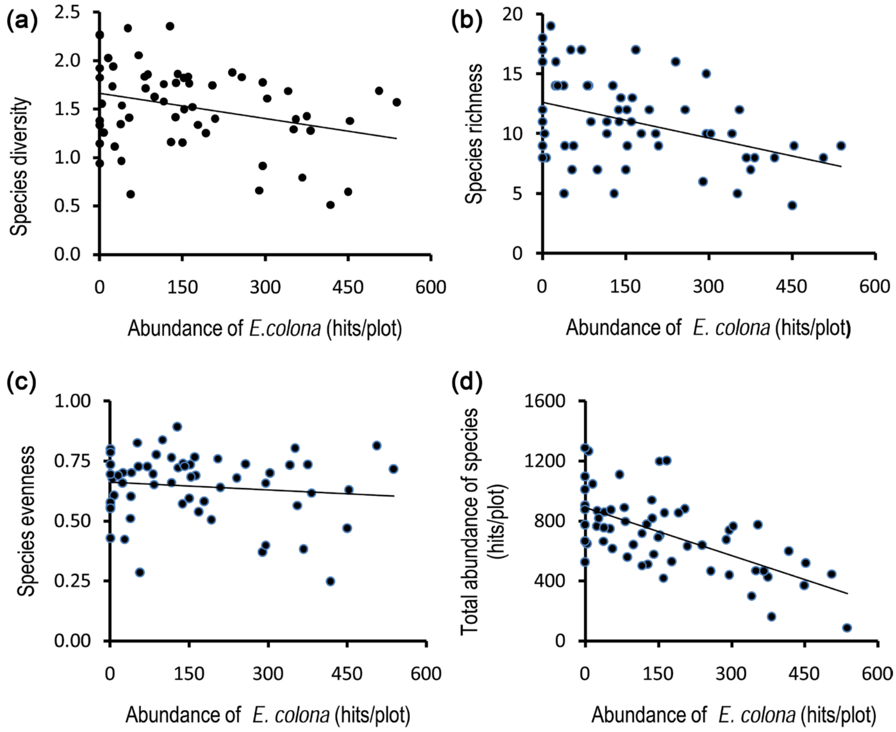

Figure 2. The relationship of resident plant community structure and the abundance of *E. colona* at the Kilombero wetland, Morogoro, Tanzania.

community richness, evenness, diversity and abundance) were negatively related to the abundance of *E. colona* at Kilombero wetland. The study also shows that there was a negative relationship between species richness of graminoids and shrubs and abundance of graminoids, forbs and shrubs, and *E. colona* abundance. The negative relationship between community and functional group attributes and *E. colona* abundance support the widespread evidence that alien species invasion exert significant negative impacts on resident plant communities [25]. The negative relationship between community (richness, evenness, diversity and abundance) and functional group (richness of graminoids and shrubs and abundance

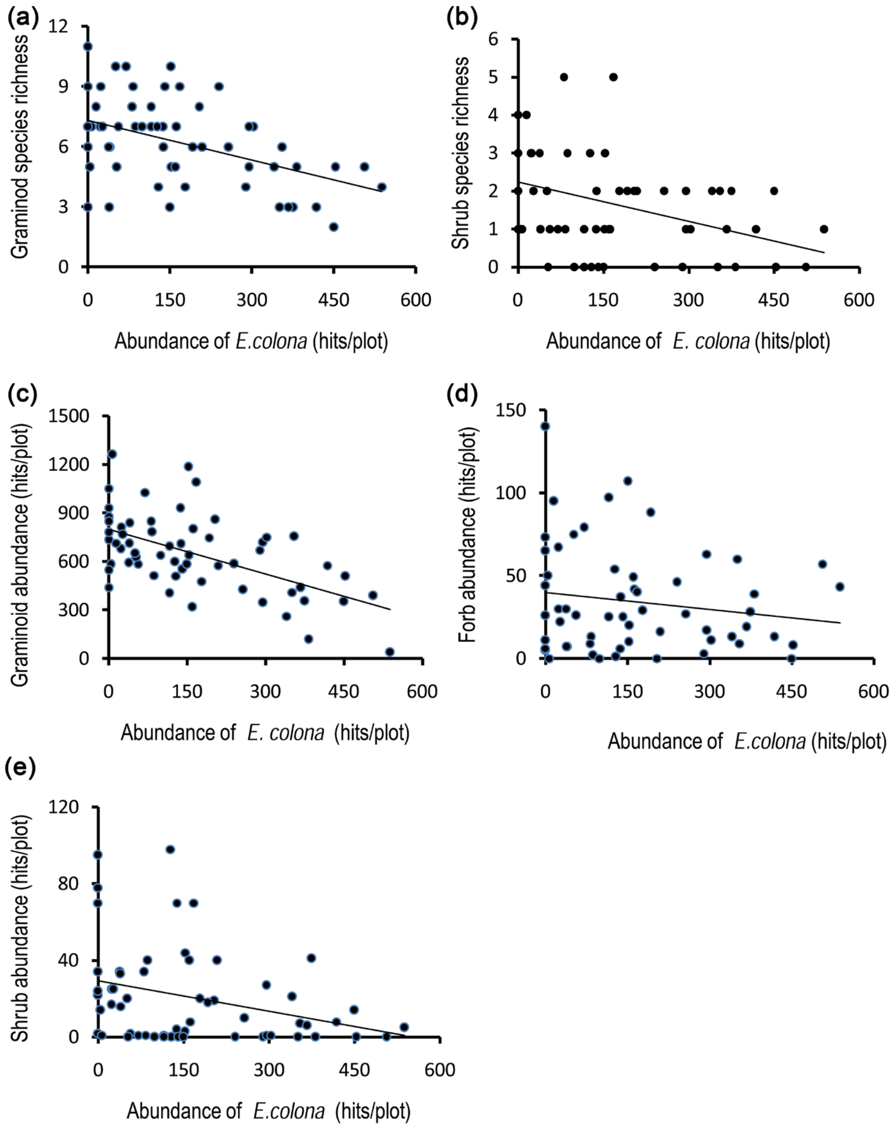

Figure 3. The relationship of plant functional groups of resident communities and the abundance of *E. colona* at the Kilombero wetland, Morogoro, Tanzania. Only significant ($P < 0.05$) variables from GLM multiple regressions are shown.

of graminoids, forbs and shrubs), and *E. colona* abundance represents an often general relationship between an invader and resident plant communities. Other studies have reported similar results and point out that the negative impacts associated with high abundance of introduced species on native community biodiversity is through reductions in colonization rates of native species [6] [26]. At Kilombero *E. colona* is reported to be dominant with an overall cover of 20% at the marginal grasslands [14]. Therefore, it is likely that *E. colona* slows down the rate of colonization of native species through occupying open niches which consequently reduces plant community richness, evenness, diversity and abundance and richness of graminoids and shrubs and abundance of graminoids, forbs and shrubs [10].

It has been pointed out that many invasive species e.g. *E. colona* are either opportunists or generalists [2]. In semi natural habitats like those of Kilombero there are high chances that the abundance of resident species is reduced (because of disturbance) thereby enhancing the ability of *E. colona* to utilize available resources more efficiently than other resident species [10] and shift the weed-resident species competition in the weed favour [27].

Another plausible explanation for the negative relationship between community richness, evenness, diversity and abundance and richness of graminoids and shrubs and abundance of graminoids, forbs and shrubs, and *E. colona* abundance could be that the invader poses intense competition for environmental resources (*i.e.* light, space, moisture and nutrients) to the resident plant species. This explanation is supported well by an experimental study which demonstrated that *E. colona* responds to light and nutrient additions suggesting clearly that it indeed exerts intense competition for environmental resources to the resident species [18]. It is documented that *E. colona* is a highly competitive noxious weed species and results into loss in crop yield and growth following its infestation in agroecosystems [12]. It has the tendency of increasing growth rates and accumulates high dry matter at early stages which promotes competitive abilities and ensures maximum photosynthate turnover [28]. Thus, *E. colona* reduces crop yields in agroecosystems and cause pasture loss in natural landscapes [17].

It is widely known that invasive species inhibit native species seedling establishment and growth and alter ecosystem processes and physical resources of the recipient community [6], through for example release of phytochemicals. Likewise, *E. colona* can interfere with the development of other resident plant species using specific secondary metabolites known as allelochemicals. Through these allelochemicals *E. colona* is able to inhibit the vegetative and reproductive growth of other resident species. Using an experiment it was demonstrated that the extract and bioassays of *E. colona* inhibited roots and shoot growth of rice [29]. In another study investigating the interactive nature of *E. colona* decomposing leachates on the germination and seedling growth of agronomic crops it was revealed that germination was reduced by 90% while seedling shoot and root by 43% and 100%, respectively [30]. Similarly at Kilombero, it could be that reduction in community richness, evenness, diversity and abundance and richness of graminoids and shrubs and abundance of graminoids, forbs and shrubs is caused partly by allelopathic interference of *E. colona*.

Although this study indeed found that community richness, evenness, diversity and abundance and richness of graminoids and shrubs and abundance of graminoids, forbs and shrubs related negatively to *E. colona* abundance, these results should be interpreted with caution since this study is observational. In ecology, observational studies have been challenged since they do not necessarily provide conclusive evidences of cause-effect relationships [31]. It is also possible that the negative relationships observed between plant community and functional group attributes and *E. colona* abundance might have been coincidental or caused by other co-varying factors including land use history and disturbance at Kilombero. Therefore, a strict conclusion about cause-effect relationships cannot be made unless confirmation experiments are carefully done. Nevertheless, observational studies provide useful information and significant steps for developing hypothesis for confirmation through experimental testing. Overall, this study therefore adds valuable information on the impacts of invasive species on tropical wetland ecosystems and provides relationships that validate and support existing empirical studies [10].

5. Conclusion

This study was set with the objective of understanding the impacts of invasive species *E. colona* on community abundance, richness, evenness and diversity and assessing whether these impacts vary among graminoid, forb and shrub plant functional group richness and abundance. The results show that community richness, evenness, diversity and abundance and richness of graminoids and shrubs and abundance of graminoids, forbs and shrubs decreased with increase in abundance of *E. colona*. In this study three mechanisms (*i.e.* open niche occupation, intense competition and allelopathic interference) are suggested to be responsible and are the major roots for the impacts of *E. colona* on resident plant community and functional group structure in Kilombero. *E. colona* is dominant and widespread and impacts negatively many habitats with negative consequences on functions and structure of plant communities. Invasive species are known to change native species abundance, richness, evenness and diversity and are economic and environmental concern to most protected areas worldwide. Kilombero wetland is a Ramsar site of international importance that supports high, rare and unique biodiversity thus improved restoration and management strategies should be developed sooner than later to counteract the spread and further impacts of *E. colona*. If the current situation is left unchecked with effective management interventions there is a danger that the study system might lose its value and functions thus jeopardizing biodiversity and livelihoods that depend on wetland ecosystem goods and services. The findings of this study together with other available information on the nature and impacts of *E. colona* should facilitate development of improved management and restoration strategies to minimize the abundance and further spread of *E. colona* to restore and conserve wetland biodiversity.

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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