Distribution Patterns of Invasive Alien Species along An Elevation and Rainfall Gradient in Kenya and Uganda

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Abstract: ***Alien species distribution and population may be affected by topography and climate change. In this study we aimed to examine the effects of elevation and rainfall on invasive alien species diversity, richness and evenness in both terrestrial and aquatic habitats in Kenya and Uganda, through large scale elevation and rainfall gradient field investigation. We carried out survey in 82 regions which had an elevation that ranged from 855-4062m. We established 3 experimental plots in each region giving a total of 246 plots. In each plot we recorded species name, abundance, GPS coordinates, elevation and rainfall. We measured species diversity (Shannon and Simpson indices); species richness (Patrick index) and species evenness (Pielou index). We found that elevation and rainfall affected the invasive alien species diversity, richness and uniformity. The highest diversity, richness and uniformity was found at mid elevation (1500-2500m) and rainfall (1000-1500mm) and decreased at both lower and higher elevation and rainfall gradients. These results suggest that climate change may affect invasive alien plant species diversity in high elevation areas in Kenya and Uganda, which should be considered in the future management of plant invasions.***

Keywords: Invasive plant species, Elevation, Rainfall, Species diversity indices, Biodiversity

1. Introduction

Due to the rapid development of economic globalization and improvement in transport [1-3], invasive alien species are proving to be a major threat to sustainable development [1, 4]. According to Millennium Ecosystem Assessment, through the trends in species introduction and modeling predictions, invasion by alien species will continue to be on the rise and this can be attributed to global environmental changes that include climate change, changes in land use and disturbances[5]

The East African region has been facing major threats from invasion by invasive alien species. In Kenya and Uganda they pose a huge threat to the native biodiversity, ecosystem functioning, agriculture, forestry, aquaculture, landscape and real estate values and they also pose major health hazards as they act as allergens or disease vectors [5-8]. They also alter the habitats in which they have been naturalized, modifying the structure, composition and habitat quality of the native plant communities [6, 7]. Invasive alien species are also able to create disturbances that lead to changes in ecosystem processes and resources [9-11]. Previous studies found 26 invasive alien plant species in Kenya and 22 invasive alien plant species in Uganda (CAB International, 2012).

Altitude (elevation) may affect invasive alien plant distribution and population, as it plays a role in influencing species diversity, richness and dispersion behavior[12]. Studies have shown that species diversity, evenness and richness tend to decrease with an increase in altitude [5, 13, 14] and as species richness decreases species dominance increases [15]. The decrease in species diversity with increase in elevation can be attributed to an increase in harsh climatic conditions [6, 16] which include low temperatures, low air pressure and an increase in solar radiation [14, 17]. With increase in temperature there is a shift in species range especially into higher latitudes and altitudes, as species migrate from adjacent regions [18]. Stresses caused by changes in precipitation and other climatic variables in ecosystems found in higher elevations also tend to favor their vulnerability to invasion by invasive alien plant species [19]. Mid altitude is found to favor the highest species richness, diversity and evenness [18, 20] and this is attributed to optimum humidity [19] and high productivity that promotes optimal combination resource availability [20, 21].

Precipitation also has an effect on invasive alien species diversity, evenness and richness [20, 22-24]. Precipitation affects seed germination, seedling growth, survival and phenology and hence in turn affects species diversity, productivity and richness [25-29]. Precipitation has been found to show positive correlation at the mid precipitation level and it tends to show negative correlation at low and high precipitation levels [25-30]. It is not only the quantity of rainfall that affect invasive alien species diversity, evenness and richness, but also the temporal patterns of precipitation at a given area also play a part [25, 27-29].

In this study we conducted large scale field surveys to examine the effects of elevation and rainfall on alien species diversity, richness and uniformity across an elevation and rainfall gradient in Kenya and Uganda. In the survey we chose some key sites because these sites hold major biodiversity hotspots in the regions, with the high increase in naturalization patterns of different invasive alien species. The survey can assist us to evaluate the effects of the invasive alien plant species on native species biodiversity. In the study we specifically address the following questions: (1) does elevation and rainfall affect invasive alien species diversity, richness and evenness; (2) whether there are differences in the diversity, richness and uniformity of alien plant species between sites in Kenya and Uganda?

2. Materials and Methods

Site Selection

The study was carried out in Kenya and Uganda. Kenya lies between latitudes 5°N and 5°S and longitudes 34°E and 42°E and Uganda lies between 4°N and 2°S and longitude 29°E and 38°E (Fig.1) we set up our experimental plots at an elevation gradient that ranged from 855m to 4062m and annual rainfall gradient that ranged from 616-1820mm(www.en.climate-data.org, 2016). The field survey was carried out in 82 regions within the two countries from July to September 2015. In each region we established 3 experimental plots and each experimental plot was more than 2km apart. We sampled in a total of 246 experimental plots in the 82 regions. We selected our study regions to encompass different regions in Kenya and Uganda. In each region we then set up 3 experimental plots which were randomly selected and the experimental plots in each region were more than 2KM apart and each measured at 500 × 2M. The plots covered both terrestrial and aquatic habitats and spanned tropical and warm and temperate climatic zones. The study areas were being used for various activities which included Agriculture, construction, foot paths and damp sites

Vegetation Sampling and Data Collection

In each study plot we recorded species name and number of individuals for each species. We also recorded longitude, latitude and elevation for every plot using a handheld GPS receiver (HOLUX m241). We also recorded the average rainfall, average temperature and climate for the respective regions (www.en.climate-data.org, 2016). We counted the number of invasive alien species and took pictures of the invasive alien species in each study plot from an elevation of 855m to 4062m.The identification of species was done in the field by taxonomists from Wuhan Botanical Garden, Chinese Academy of Sciences with aid of invasive alien species list produced by Centre for Agriculture and Bioscience international. The unknown plant species were identified using ‘ Field Guide to Common Trees and Shrubs of East Africa’, ‘ Guide to the Naturalized and Invasive Plants of East Africa’ and Kenya Trees, Shrubs and Lianas’. We used the species number that we obtained calculate diversity indices that we used for our data analysis.

Data Analysis

We placed our data in Excel (Microsoft Office Excel 2007) where we sorted our data and cleaned it up. We added then divided figures from the 3 repetitions in each region to obtain the average for each region. To measure the patterns of species diversity we employed α species diversity indices (Pruchniewicz and Zolnierz, 2014; Zhang et al, 2015)

Simpson diversity index: $\lambda = 1 - \sum P_i^2$
Shannon diversity index: $H = - \sum P_i \ln P_i$
Pielou evenness index: $E = (- \sum P_i \ln P_i)/\ln S$
Patrick richness index: $R = S$

To examine the effects of elevation and rainfall on invasive alien species diversity, evenness and richness we performed a series of regression using SPSS 20.0 software (SPSS Inc, Chicago, USA). We used linear regression model to perform the regression test. We carried out a ‘one-way ANOVA and ‘multiple comparisons’ to examine the differences in species diversity indices along the elevation gradient and climatic variables. We also did Pearson’s correlation to understand whether there is an association between the variables.

3. Results

Species identified in sites in Kenya and Uganda.

A total of 42 invasive alien plant species were found during the study. In Kenya we identified 36 (Table1) invasive alien plant species that extended across 19 families and of these 19 were herbs, 12 were shrubs and 5 were medium to large trees. Solanaceae and Fabaceae had the highest number of representatives followed by Asteraceae. A majority of the species that we came across had their native range in South America.

In Uganda we identified 29 (Table2) invasive alien plant species that extended across 16 families and of these 14 were herbs, 12 were shrubs and 3 were trees. Asteraceae and Fabaceae had the highest number of representatives followed by Solanaceae.

During the study *Solanum spp* appeared most frequently (63/82) followed by *Parthenium spp*
(60/82), *Lantana spp* (50/82), *Rubus niveus* (43/82), *Bidens pilosa* (39/82), *Datura spp* (36/82), *Tagetes minuta* (33/82)

Species Diversity Indices along Elevation Gradient

Species evenness (Pielou index) varied across the elevation gradient ($F_{10,70}=3.101$, $P=0.005$). Evenness was highest at mid elevation (1000-2500m) compared to higher elevations (>2500m). Species diversity (Shannon and Simpson indices) differed across the elevation gradient. Shannon index ($F_{10,70}=3.542$, $P=0.005$) and Simpson index ($F_{10,70}=3.895$, $P=0.005$). Species diversity was greatest in mid elevation and dropped significantly at lower and higher elevations.

Species Diversity Indices along Rainfall Gradient

Species richness (Patrick index) varied across the rainfall gradient ($F_{10,70}=2.981$, $P=0.005$). Species richness was greatest at rainfall gradient (1000-1500mm) and dropped at both lower and higher rainfall gradients. Species diversity (Shannon and Simpson indices) differed across the rainfall gradient. Shannon index ($F_{10,\ 69}=2.792$, $P=0.003$) and Simpson index ($F_{10,70}=2.397$, $P=0.005$). The greatest species diversity was found at mid rainfall gradient and dropped at lower and higher rainfall gradient <1000mm and >1500mm respectively.

Regression analysis showed the optimal fitting relationship between our variables and Shannon index ($F_{5,75}$ $=6.522$,

$P=0.005$, $R^2=0.325$), Simpson index ($F_{5,75}=6.414$, $P=0.005$, $R^2=0.307$).and Pielou evenness index ($F_{5,75}=3.133$, $P=0.003$, $R^2=0.217$). The relationship showed a drop in the diversity indices at both high and low elevation and rainfall gradient levels and the peak relationship was at mid elevation and rainfall gradient levels.(Figs 2 and 3)

The correlation analysis showed the optimal fitting association between elevation and Shannon index $r\ (81) = -0.439$, $P=0.005$, Shannon index and rainfall $r\ (81) = -0.246$, $P=0.003$, Simpson index and elevation $r\ (81) = -0.277$, $P = 0.024$, Pielou evenness index and rainfall $r\ (81) = -0.261$, $P=0.033$, Pielou evenness index and elevation $r\ (81) = -0.307$, $P = 0.005$. The association was a linear negative association with the peak association being at the mid elevation and rainfall gradient levels. Patrick index did not show a linear association as they had an $r\ (81) = -0.166$, $p = 0.302$.

4. Discussion

In this study, we showed that there was a variation in the diversity of invasive alien plant species across an elevation and rainfall gradient in Kenya and Uganda. We found the highest indices of diversity, richness and evenness (Shannon, Simpson, Patrick and Pielou indices) at middle class elevation and rainfall gradients. We found the greatest diversity, richness and uniformity between the elevation of 1000-2500m and rainfall of 1000-1500mm. Low diversity, richness and uniformity were found at both low and high elevation and rainfall gradients.

The low levels of invasive alien plant species diversity, richness and uniformity/ evenness at high elevations could be attributed to ecophysiological constrains that include reduced growing season, low temperatures and low ecosystem productivity [21, 26, 31, 32]. The highest diversity, richness and evenness was at mid elevation and these high levels of diversity, richness and evenness at the mid elevation can be due to optimum humidity conditions and high productivity that is attributed to optimal combination resource availability [5, 26, 30, 32]. We could also attribute the peak at mid elevation due to overlapping habitats and resources. With increasing elevation there are also environmental factors that contribute to differentiation of alien species diversity, richness and uniformity and they include temperatures decrease, air pressure decrease and solar radiation increase, all which occur with increase in elevation [19, 33, 34].

Due to high levels of adaptability invasive alien plant species are able to have high cover in their naturalized environments leading to them dominating the environment and hence suppress the native species [35, 36]. This increases their impacts on species diversity, richness and evenness [21, 23, 33, 37]. The level of disturbance at mid elevation can also be a contributing factor to the high levels of invasive alien species diversity, richness and uniformity and this can be attributed to human activity and human mediated transport [33, 38].

Our results indicate that the changes in annual rainfall had an effect on invasive alien plant species diversity, evenness and richness. We found that the highest invasive alien plant species diversity, evenness and richness were found at mid rainfall levels. With the effects of climate change being evident, regions are experiencing changes in temperature and rainfall and in turn species are affected by the magnitude and pattern of climate variation [26, 32]. The changes in annual rainfall amounts have been found to favor the introduction and naturalization of invasive alien plant species that are altering the structure and function of the native ecosystems [25, 27, 28]. We found that mid rainfall amounts favors high levels of invasibility due to the abundant supply of water and it's just adequate to avoid flooding and to prevent drought [25, 27]. Rainfall is found to influence the spread of invasive alien plant species due to the effects on soil moisture availability [25, 27]. The high levels of adaptability of invasive alien plant species, allows them to be able to out compete the native species and in turn they repress and exclude them leading to changes in the ecosystem which leads to loss of biodiversity.

The increase in proliferation of invasive alien plant species in Kenya and Uganda, especially at mid elevation levels that experience maximum human and natural mediated disturbance is putting a heavy strain on the development and environmental objectives of the countries [38], since they lead to the disruption of ecological integrity of the regions by outcompeting the native species and degrading ecosystem services [39]. Also control and eradication of these invasive alien plants are taking away resources that would be better used to solve more pressing issues such as access to better health care and education. However, the diversity and richness of the invasive alien plants may continue to be on the rise, especially if there is no proper eradication, control or prevention mechanisms that have been put in place [40].

In summary the study shows that altitude and climatic variables, in our case rainfall, have effect on species diversity, richness and evenness in Kenya and Uganda, with a negative correlation between elevation, rainfall and diversity indices. There is need for further studies to clearly evaluate the impacts of the range shift of invasive alien plant species and to come up with methods to mitigate or control this range shift, if there will be any hope of saving the already diminishing biodiversity that is already under threat from human activities and population increase. These studies will provide clear incite on methods to evaluate the current patterns of invasion and in turn predict their future effects in the introduced and naturalized environments. There is also need for further studies as to why there is an increase in diversity, richness and uniformity of invasive alien plant species in undisturbed areas, when previously they only targeted exogenously disturbed areas [41, 42]. These studies will play a crucial role in aiding the host countries to come up with proper mechanisms for control and eradication and also come up with legislations to prevent future introductions.

5. Acknowledgements

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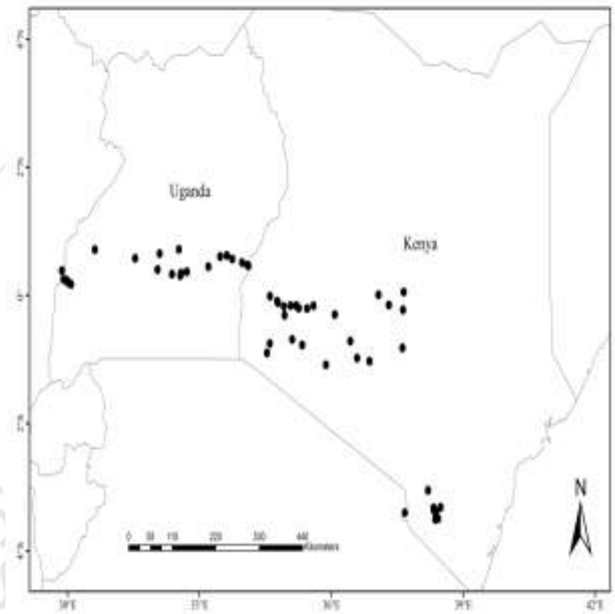
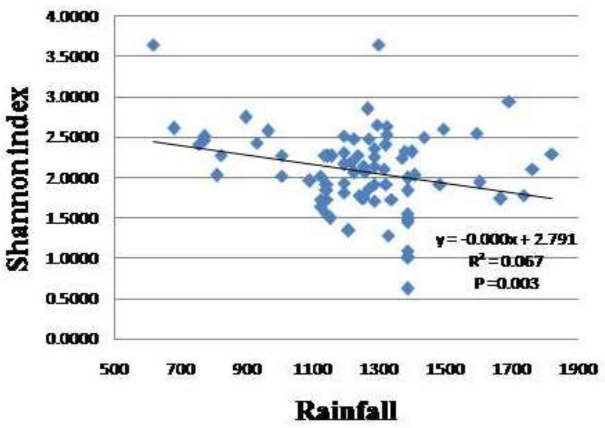
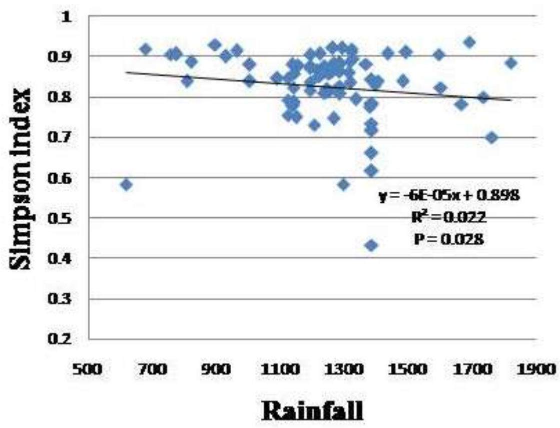


Figure 1: Sampling plots distribution of alien plants in Kenya and Uganda. The black dots represent the location of our plots.





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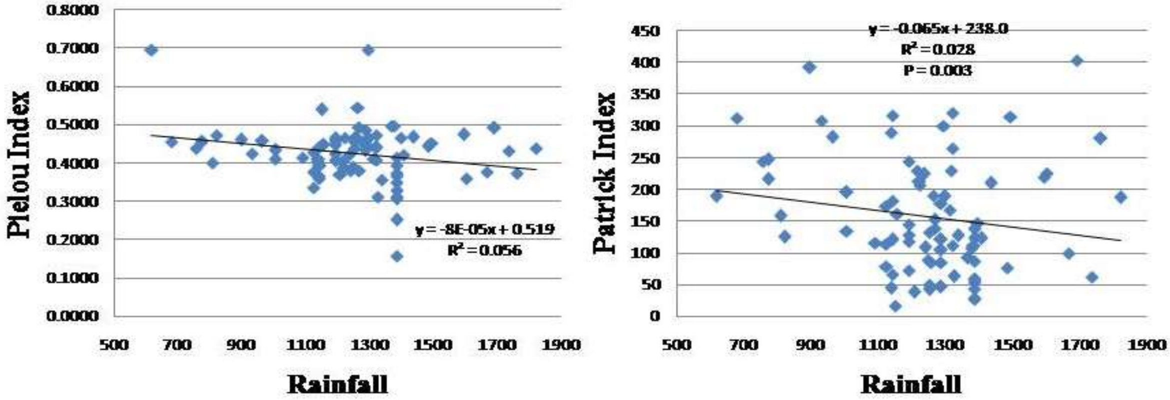

Figure 2: Regression analysis between rainfall and species diversity, evenness and richness indices of alien plant species in Kenya and Uganda

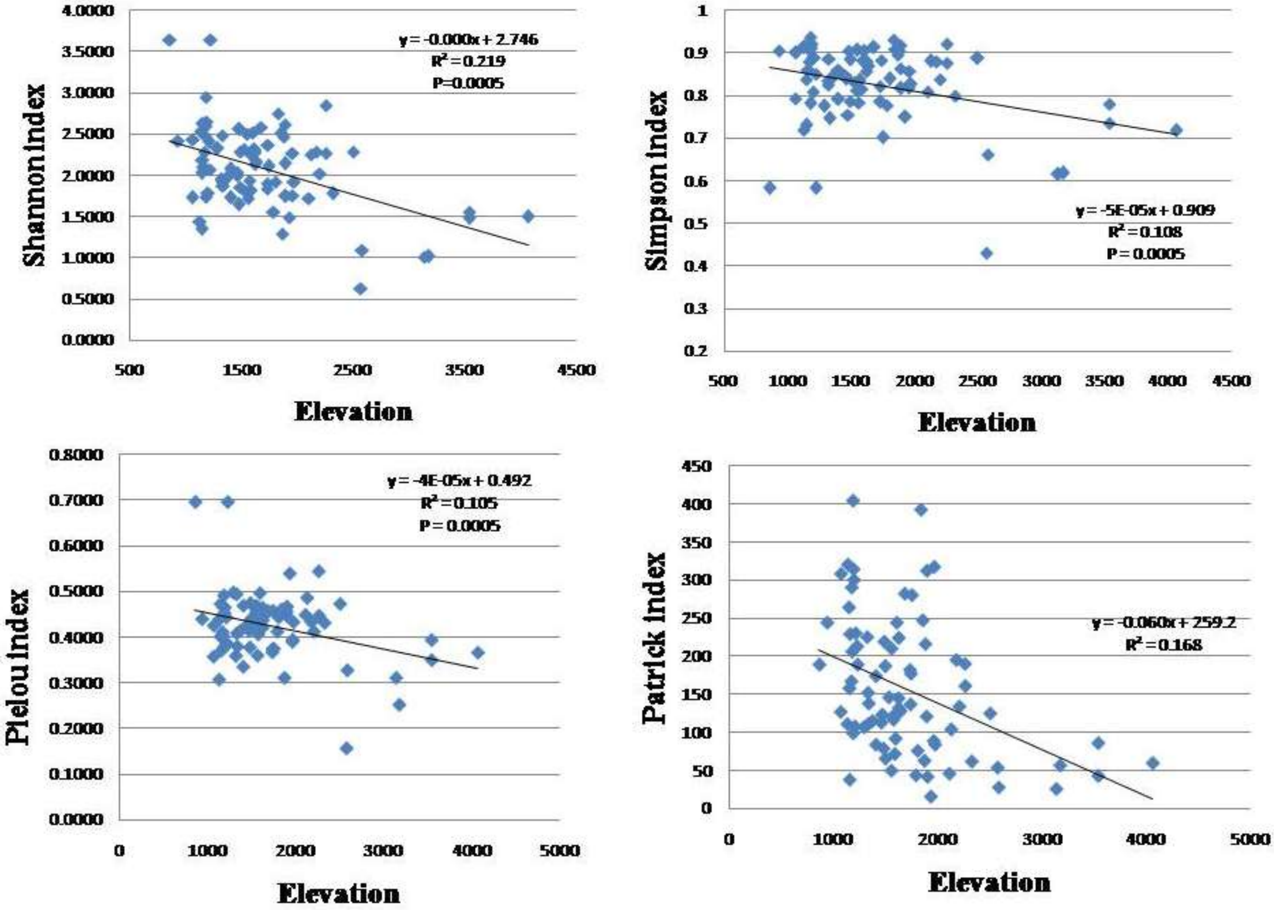

Figure 3: Regression analysis between elevation and species diversity, evenness and richness indices of invasive alien plant species in Kenya and Uganda

Table 1: Invasive alien plant species in Kenya

Species Name	*Author*	*common name*	*Family*	*description*
Acacia mearnsii	De Wild, 1925	black wattle	Fabaceae	large shrub or small tree
Acanthospermum hispidum	D.C, 1836	bristly starbur	Asteraceae	annual herb
Agave americana	L. 1753	American aloe	Asparagaceae	
Allium vineale	L. 1753	wild garlic	Amaryllidaceae	herb
Azadirachta indica	A. Juss	neem tree	Meliaceae	medium to large tree
Bidens pilosa	L. 1753	blackjack	Asteraceae	erect annual herb
Caesalpinia decapetala	(Roth) Alston	Mysore thorn	Fabaceae	robust and sprawling shrub or climber
Cyperus rotundus	L. 1753	purple nutsedge	Cyperaceae	perennial sedge
Datura metel	L. 1753	devil's trumpet	Solanaceae	perrennial herb
Datura stramonium	L. 1753	jimsonweed	Solanaceae	annual herb
Desmodium uncinatum	(Jacq.) DC.	Spanish tick clover	Fabaceae	perrenial legume
Eichhornia crassipes	(Mart.) Solms	water hyacinth	Pontederiaceae	Perennial aquatic herb
Eucalyptus	L'her. 1789		Myrtaceae	medium-sized to tall tree
Fraxinus pennysylvanica	Marshall		Oleaceae	deciduous tree

Hydrocotyle ranunculoides	L.f.	water pennywort	Apiaceae	aquatic herb
Lantana camara	L. 1753	lantana	Verbenaceae	perennial shrub
Lantana trifolia	L. 1753	lantana	Verbenaceae	perennial shrub
Mimosa pigra	L. 1753	catclaw mimosa	Mimosoideae	thorny shrub
mimosa pudica	L. 1753	sensitive plant	Fabaceae	sprawling shrub
Murdannia nudiflora	L. 1753	doveweed	Commelinaceae	annual or perennial herb
Nicotiana glauca	Graham	mustard tree	Solanaceae	shrub or small tree
Opuntia ficus indica	(L.) Mill.	prickly pear	Cactaceae	perennial succulent tree
Parthenium hysterophorus	L. 1753	Parthenium weed	Asteraceae	herbaceous plant
Passiflora edulis	Sims, 1818	passion fruit	Passifloraceae	herbaceous perennial climber
Physalis peruviana	L. 1753	cape gooseberry	Solanaceae	herbaceous plant
Prosopis juliflora	(Sw.) DC	Mesquite	Fabaceae	shrub/ tree
Physalis angulata	L. 1753	wild gooseberry	Solanaceae	herbaceous shrub
Psidium guajava	L. 1753	guava	Myrtaceae	shrub or small tree
Ricinus communis	L. 1753	castor oil plant	Euphorbiaceae	perrenial shrub
Rubus niveus	Thunb. 1813	hill raspberry	rosaceae	shrub
Salvinia molesta	D. Mitch	kariba weed	Salviniaceae	heterosporous herbs
Senna spectabilis	(DC.) Irwin & Barneby		Fabaceae	tree
Setaria verticillata	(L.) P. Beauv.	bristly foxtail	Poaceae	annual grass
Solanum mauritianum	Scop.	tree tobacco	Solanaceae	shrub or small tree
Solanum nigrum	L. 1753	black nightshade	Solanaceae	annual or sometimes biennial herb
Tagetes Minuta	L. 1753	stinking Roger	Asteraceae	woody annual herb
Tithonia diversifolia	(Hemsl.) A. Gray		Asteraceae	woody shrub
Verbena brasiliensis	Vell.		Verbenaceae	herb

Table 1: Invasive alien plant species in Uganda

Species Name	Author	common name	Family	description
Acanthospermum hispidum	D.C, 1836	bristly starbur	Asteraceae	annual herb
Agave americana	L. 1753	American aloe	Asparagaceae	
broussonetia papyrifera	(L.) vent.	paper mulberry	Moraceae	deciduous shrub/ tree
Bidens pilosa	L. 1753	blackjack	Asteraceae	erect annual herb
Caesalpinia decapetala	(Roth) Alston	Mysore thorn	Fabaceae	robust and sprawling shrub or climber
Cymbopogon nardus	(L.) Rendle	Citronella grass	Poaceae	perrenial grass
Datura stramonium	L. 1753	jimsonweed	Solanaceae	annual herb
Desmodium uncinatum	(Jacq.) DC.	Spanish tick clover	Fabaceae	perrenial legume
Eichhornia crassipes	(Mart.) Solms	water hyacinth	Pontederiaceae	Perennial aquatic herb
Hydrocotyle ranunculoides	L.f.	water pennywort	Apiaceae	aquatic herb
Lantana camara	L. 1753	lantana	Verbenaceae	perennial shrub
Lantana trifolia	L. 1753		Verbenaceae	perennial shrub
Mimosa pigra	L. 1753	catclaw mimosa	Mimosoideae	thorny shrub
mimosa pudica	L. 1753	sensitive plant	Fabaceae	sprawling shrub
Murdannia nudiflora	L. 1753	doveweed	Commelinaceae	annual or perennial herb
Opuntia ficus indica	(.) Mill.	prickly pear	Cactaceae	perennial succulent tree
Parthenium hysterophorus	L. 1753	Parthenium weed	Asteraceae	herbaceous plant
Passiflora edulis	Sis, 1818	passion fruit	Passifloraceae	herbaceous perennial climber
Physalis peruviana	L. 1753	wild gooseberry	Solanaceae	herbaceous shrub
Prosopis juliflora	(Sw.) DC	Mesquite	Fabaceae	shrub/ tree
Psidium guajava	L. 1753	guava	Myrtaceae	shrub or small tree
Rubus niveus	Thunb. 1813	hill raspberry	rosaceae	shrub
Senna spectabilis	(DC.) Irwin & Barneby		Fabaceae	tree
Setaria verticillata	(L.) P. Beauv.	bristly foxtail	Poaceae	annual grass
Solanum mauritianum	Scop.	tree tobacco	Solanaceae	shrub or small tree
Tagetes Minuta	L. 1753	stinking Roger	Asteraceae	woody annual herb
Tithonia diversifolia	(Hemsl.) A. Gray		Asteraceae	woody shrub
Verbena brasiliensis	Vell.		Verbenaceae	herb

Author Profile

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