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Floristic Inventory of Invasive Alien Aquatic Plants Found in Some Congolese Rivers, Kinshasa, Democratic Republic of the Congo

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Authors' contributions

This work was carried out in collaboration among all authors. Authors HKM and FLL designed the study and wrote the protocol. Authors MTM, ABK and GNB performed the identification of species and wrote the first draft of the manuscript. Authors MTM, HKM, ABK and FLL managed the analyses of the study. Author GNB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aim: To identify invasive aquatic alien plant species found in the Pool Malebo and some rivers in Kinshasa city, their behavior as well as their socio-economic impacts.
Study Design: The study used a combination of purposive sampling and simple random sampling in order to select different sites where samples were collected.
Place and Duration of Study: This study was carried out in different rivers (Pool Malebo system (Kinkole, Kingabwa), and N'sele, Funa and Lukaya rivers) of Kinshasa city in Democratic Republic of the Congo. The Pool Malebo is located along the Congo River. This was conducted between March and October 2013.
Methodology: The collection was performed after a direct observation. The location of collection depended on sites, at Kingabwa and Kinkole, we collected invasive species in the middle of the Congo river and to achieve that, we used canoe. While at N'sele, Lukaya and Funa rivers, samples

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were collected at the edges. The collection took place in the morning between 7 and 11 am. Recorded species were classified either alien species or invasive alien species according to the status in the study region. The identification of collected species was carried out according to APG III. Seeing the way these species invade the environment and how they disturb the ecology of rivers, the physico-chemical characteristics of waters were measured between 7:00 and 11:00 am with the appropriate electronic probe for each parameter. For each parameter, the comparison between the sites was carried out using the ANOVA test with XLSTAT 2013 software.

Results: Out of 151 specimens collected, 35 species have been identified of which 19 species as alien were identified and 4 proved to be invasive alien species, namely: *Eichhornia crassipes, Echinochloa pyramidalis, Ludwigia peploides* and *Pistia stratiotes*. These invasive species are used by farmers as livestock feed and also as green manure for different agricultural and farming activities, As to the physico-chemical characteristics, no significant differences were observed for the temperature and the turbidity in various sites while the pH and conductivity, there was a highly significant difference between different sites. The hydrology of these rivers is seriously disturbed due to the presence of these invasive alien species. These species constitute a serious threat in the erosion of aquatic biodiversity in the removal of native species in the formation of floating monospecific dense mats as observed.

Conclusion: The invasion of alien species is a consequence of human activities and a concern, which affects all sectors of the society. It constitutes a true challenge for ecologists, economists, social scientists, agricultural engineers, environmentalists and other in order to develop and implement strong risk analysis frameworks and environmental impact assessments.

Keywords: Alien species; invasive; socio-economic impacts; Kinshasa; Democratic Republic of the Congo.

1. INTRODUCTION

The equilibrium of nature (biological diversity) is provided either by different species of animals or plants along within their respective ecosystems. Once this equilibrium is broken, consequences are global and life becomes difficult [1,2]. So, it is beyond our scope to determine which species are essential or redundant to the functioning of a given ecosystem and which ones would flourish in a changing world [3-5]. Once a new species is placed into a new ecosystem, most of the time its impact is not observed directly but later its environmental impact can be observed i.e. it takes long enough to realize the environmental impacts of exotic (alien) species invading a new ecological habitat [6]. Invasive species are a current focus of interest of ecologists, botanists, biological conservationists and natural resources managers due to their rapid spread, threat to biodiversity and damage to ecosystems [7].

Invasive alien species are species that are non-native (or alien) to the ecosystem under consideration and of which introduction causes or is likely to cause economic or environmental harm or harm to human health. They are generally coming from another ecological habitat [7-9]. These alien species might be a plant, an animal, a fish, a microorganism which has been introduced in a specific area as a result from human activities, outside of its natural habitat [10-13]. In a specific way, an alien species is a species moved outside of its native range (introduced deliberate or by inadvertence). They are also called exotic species, introduced or non-indigenous [14]. In fact, most cases of invasiveness can be linked to the intended or unintended consequences of economic activities and therefore economic applications are essential to understand the problem and provide more accurate and comprehensive assessments of the benefits and costs of control alternatives to increase the effectiveness and efficiency of public funding [7]. However, invasive species are increasingly recognized as having important impacts on landscapes, ecosystems and levels of biodiversity [15].

Different pathways through which invasive alien species can be introduced or spread are intentional (deliberate), unintentional (accidental) introductions, and authorized/unauthorized introductions. These ways are rivers, navigation, aquarium, pet trade, horticulture, aquaculture, commerce, tourism, illegal entry of species with goods and by various modes of transport (air, water, railways and roads) [16,17]. The history is rich in information and examples of disasters caused by intentional introductions, such as the Nile perch, which resulted in the extinction of more than two hundred fish species. Lessons from the past can help us to avoid repeating such mistakes. Unfortunately, these harmful practices continue such as the continuous implantation of the gambusie, the international trade of the

ornamental seed plants and pets [11]. Ahimbisibwe, [7] asserts that invasive species are a major environmental and ecological problem as well as a serious threat to trade. Quarantine against introduction of such invasive species is necessary to protect plant, environmental, human and animal health. However, the enforcement of quarantine and control of such invasive species are very expensive to both country of introduction and country of origin. The extent to which an invasion might cause a damage would depend on how and to what degree the indigenous biotic community is disrupted [18]. These biological invasions as an uncertain process comprise four different stages, which are: the introduction, the establishment, the naturalization and the spread [19]. Global progress has been insufficient for the reduction of their spread. Various international conventions and global, regional, and national policies as well as programmes directed towards the prevention, control or the eradication of invasive alien species. However, efforts to mitigate their impacts are insufficient as well [20]. Furthermore, species invasions are likely to increase on a par with climate change along with the international trade. With the climate change issue, these invasive species would inevitably provoke changes in biodiversity and in the ecosystem services that it provides [9].

It is in this frame that this study was conducted, and it focused on the identification and behavioral study of alien species invading rivers in Kinshasa city, which is an urban area. Unlike, urban areas are characterized by intense stress levels related to pollution sewage, nutrients, toxic chemicals, heat and biological pathogens (including invasive species). With the increasing urbanization, natural areas are being fragmented quickly [21].

This study is a contribution to the 10-year Strategic Plan for Biodiversity 2011-2020 to the Aichi Targets [12]. This prompted us to study invasive alien aquatic plants in the Pool Malebo system, which includes exotic plants such as water hyacinth (*Eichhornia crassipes* Mart, Solms). Originally from South America, *E. crassipes* (Mart. Solms), a pantropical hydrophyte belonging to the Pontederiaceae family, is one of the world's weeds. The beautiful purple and purple flowers make it an ornamental plant very popular for ponds. Today, it is present in more than 50 countries in the world. The water hyacinth grows very quickly, with populations known to have doubled in less than 12 days [12]. Infestations of watercourses by this weed block access routes and navigation of water thus limiting the maritime traffic, swimming and fishing. Water hyacinth also prevents light and oxygen from entering the water and reaching submerged plants. Its shade encumbers native aquatic plants and severely reduces the biological diversity of aquatic ecosystems. Currently it is ranked among the 100 most invasive alien species in the world [22]. Its accidental invasion in the edges of the Congo River dates back to the years 1954 and led the Belgian colonial administration to promulgate on May 4, 1955 an order prohibiting the possession, cultivation, multiplication, sale and transport of this plant considered, since, as invasive.

The aim of this study was to identify invasive aquatic alien plant species found in the Pool Malebo and some rivers in Kinshasa city, their behavior as well as their socio-economic impacts. Henceforth, the Pool Malebo system (Kinkole, Kingabwa), and N'sele, Funa and Lukaya rivers were selected as sampling sites for this study.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Kinshasa city (Fig. 1) more precisely in the Pool Malebo system of which Kinkole and Kingabwa sites, and N'sele, Funa and Lukaya rivers (Fig. 1).

This city with its low-altitude climate is characterized by a hot and humid tropical climate of AW_4 type according to Köppen's classification. There is an alternation of two seasons: A dry season from June to September and a rainy season from September to May [23].

2.2 Study Design and Sample Collection

The study used a combination of purposive sampling and simple random sampling procedure in order to select different sites where samples were collected. All the study sites were located in Kinshasa city and these chosen habitats were invaded by alien species. The Pool Malebo sites (Kingabwa and Kinkole) as well as N'sele river while Funa and Lukaya rivers were located at the eastern and western part of Kinshasa city respectively. The collection was performed after a direct observation. The location of collection depended on sites, at Kingabwa and Kinkole, we collected invasive species in the middle of the Congo river and to achieve that, we used canoe. While at N'sele, Lukaya and Funa, samples were collected

in the morning between 7 and 11 am. Recorded species were classified either alien species or invasive alien species according to the status in the study region. These species named "invasive" are species that cause any apparent damage or may pose threats to native species, aquatic ecosystem and to the economy. The sampling effort was of 151 specimens collected for the targeted sites for this research. The study period was performed between March and October, 2013.

2.3 Methods Used

The identification of different species in the field was performed using specific identification keys (precisely Phylogenetic classification APG III) [24], while specimens which were difficult to identify in the field were brought to the herbarium of INERA, located at the department of Biology, Faculty of Sciences, University of Kinshasa.

The foliar types were: (Aphyle (Aph), Leptophyle (Lepto), Nanophyle (Nano), Microphyle (Micro), Mesophyle (Meso), Macrophyle (Macro) and Megaphyle (Mega)). The biological types were: (Mesophanerophytes (MsPh), Microphanerophytes (McPh), Nanophanerophytes (NPh), Climbing Phanerophytes (Phgr), Erect Chamephytes (Chd), Climbing Chamephytes (Chgr), Prostrate Chamehytes, Rampant Chamephytes, Cespitous Chamephytes (Chces), Cespitous Hemicryptophytes (Hces)), Bulbous Geophytes (Gb), Tuberous Geophytes (Gt), Rhizomatous Geophytes (Grh), Cespitous Therophytes (Thces), Erect Therophytes (Thd), Prostrate Therophytes (Thpr), Climbing Therophytes (Thgr) and Pelophytes (Pelo). The phytogeographic distribution was (Afro-tropical (AT), Cosmopolitan (Cosmo), Paleotropical (Paleo), Pantropical (Pan), Afro-malgache (Am), Guineo-Congolian (Gc). The study of phytogeographic distribution was inspired by the chorological divisions recognized for tropical Africa. The diaspore types (DT) was: (Pterochores (Ptero), Pogonochores (Pogo), Sclerochores (Sclero), Desmochores (Desmo), Sarcochores (Sarco), Ballochores (Ballo), Barochores (Baro) and Pleo)).

2.4 Hydrological Parameters

They constitute elements of which manifestation conditions and influences, to varying degrees affect the wetland macrophytes. From an ecological point of view, the analyzed parameters were the temperature (°C), the pH, the turbidity, and the electrical conductivity, which has been measured (at 25°C) in micro-Siemens by cm (µS / cm). These physico-chemical parameters were measured between 7:00 and 11:00 am using HANNA HI98130 electronic probe brand. The turbidity was measured in ppm using a multi-parameter probe (HANNA HI 98130). It reflects the quantity of dissolved solids in the water.

2.5 Data Analysis

For each parameter, the comparison between the sites was performed using the ANOVA test. The threshold of significance chosen was 0.05. With each significant difference, the variance analysis was accompanied by a multiple pairwise comparison (LSD test). The data analysis was performed using the XLSTAT 2013 software.

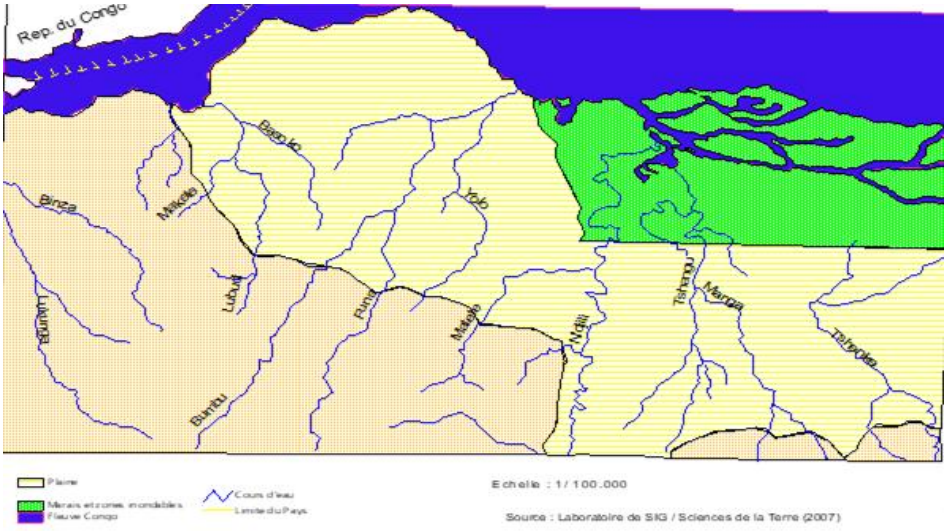


Fig. 1. Hydrography of Kinshasa city

3. RESULTS

3.1 Floristic Inventory of Alien Aquatic Plant Species

Table 1 presents an inventory of invasive alien aquatic species collected in Kinshasa City Rivers.

As observed in this table, the floristic inventory showed the presence of 35 species out of 151 specimens collected of which 4 Pteridophytes and 31 Angiosperms, distributed into 15 families and 12 orders. The classification of Angiosperms was performed according to the phylogenetic classification APG III, and the Pteridophytes classification was according to Cronquist (1968). It should be noted that Poaceae was the most representative family with 9 species, followed by the Cyperaceae with 5 species and Asteraceae as well as Onagraceae have 3 species each. Other families identified have either 2 species or are monospecific.

Table 2 describes the statistics of the large taxonomic units.

Table 1. Floristic inventory of invasive alien species collected in Kinshasa

Species classification	FT	BT	DT	PD
Clade Angiosperms				
1. Asterales				
a. Asteraceae				
Ageratum conyzoides L.	Micro	Thd	Pogo	Pan
Eclipta alba L.	Nano	Chpr	Scleo	Pan
Struchiums paraganophora (L) O. Ktze	Micro	Thp	Sclero	Aa
Clade: Rosidae / Malvidae				
2. Myrtales				
a. Onagraceae				
Ludwigia abyssinica A. Rich	Micro	Chd	Sclero	Am
Ludwigia leptocarpa (Nutt) Hara	Micro	Chd	Sclero	Aa
Ludwigia peploides (Kunth) Raven	Micro	Hd	Sclero	Pan
b. Melastomataceae				
Thollonu dissotis (Cogn)	Micro	Chd	Sarco	At
Dissotis rotundifolia (Sm) Triana	Micro	Chpr	Sclero	At
Clade: Fabidae				
3. Malpighiales				
a. Euphorbiaceae				
Alchornea cordifolia (Schum & Thonn)	Meso	Msph	Sarco	At
Clade: Lamidea				
4. Solanales				
a. Convolvulaceae				
Ipomoea aquatica Forsk	Meso	Hdfl	Ptero	Pan
Clade: True dicotyledonous core				
5. Caryophyllales				
a. Amaranthaceae				
Althernanthera tenella L	Nano	Chpr	Sclero	Pan
Clade: Angiosperms				
6. Nymphaeale				
a. Nymphaeaceae				
Nymphaea lotus L**.**	Macro	Hd	Pleo	Pal
Nymphaea maculate Schum &Thonn	Macro	Hd	Pleo	At
Clade: Angiosperm				
7. Commelinales				
a. Commelinaceae				
Commelina diffusa Burm. F	Micro	Chrp	Sclero	Pan
b. Pontederiaceae				
Eichhornea crassipes (Mart) Solms	Meso	Hd	Sclero	Pan
8. Alismatales				
a. Araceae				
Pistia stratiotes L.	Micro	Hd	Pleo	Pan
Colocasia esculenta (L) Schott	Macro	Gt	Sarco	Pan

Species classification	FT	BT	DT	PD
9. Poales				
a. Cyperaceae				
Cyperus alternifolius L.	Micro	Grh	Sclero	Pan
Cyperus latifolius Poir	Meso	Grh	Sclero	Pal
Cyperus papyrus L.	Aph	Grh	Sclero	GC
Rhynchospora corymbosa (L) Butt	Micro	Grh	Sclero	Pan
Fuirena umbellata Rott b	Micro	Grh	Sclero	Pan
b. Poaceae				
Leersia hexandra (Sw)	Micro	Grh	Pleo	Pan
Echinochloa pyramidalis (Lam)	Meso	Grh	Sclero	Pan
Echinochloa stagnina (Retz) P. Beauv	Micro	Grh	Sclero	Pan
Echinochloa colona (L) Link	Micro	Thc	Sclero	Pan
Jardinea congoensis (Hack) Franch	Meso	Hc	Sclero	At
Loudetia phragmitoides C. Hubb	Meso	Hces	Desmo	Am
Vossia cuspidata B**.**	Meso	Grh	Sclero	At
Oryza barsthie A. Chev	Meso	Thd	Sclero	Pan
Phragmites mauritianus Kunth	Meso	Hc	Sclero	At
Phyllum: Pteridophyta / Filicopsida				
10. Blechnales				
a. Thelypteridaceae				
Cyclosurus gongylodes (Schkuhr) Link	Meso			
11. Selaginellales				
a. Selaginellaceae				
Selaginella myosorus L**.**	Micro	Grh	Sclero	Gc
Clade: Hydropteride				
a. Salviniaceae				
Salvinia molesta D.S. Mitchell	Micro	Hd	Pleo	Gc
Salvinia nymphellula L.	Nano	Hd	Pleo	Gc

From the Table 2, it emerged that there was a predominance of the Angiosperm clade with Commelidae having 17 species grouped into 5 families and 3 orders; followed by the Malvidae clade which has 5 species in 2 families and 1 order and that of Campanulidae with 4 species grouped into 1 family and 1 order.

The floristic list of the exotic species found among these species is presented in the Table 3.

As observed in the indicated table, out of the 35 plant species found in different study sites, 19 species were found to be alien. Among these 19 alien species, four species were identified as invasive in the environment. These aquatic invasive alien species are the following: *Eichhornia crassipes* (Mart) Solms, *Echinochloa pyramidalis* (Lam) Hitch & Clase, *Pistia stratiotes* L. and *Ludwigia peploides* (Kunth) Raven. It should be noted that these invasive species are used as fodders for cows and pigs and also as green manure, The distribution of these four species is presented in Fig. 2. The below photos present the behavior of some invasive alien species identified in different sites.

3.2 Hydrological Parameters

Seeing the way these species invade the environment and how they disturb the ecology of rivers, we thought of determining some physico-chemical characteristics of these rivers in order to know if these alien species disturb or not. Figures below show means and standard deviations of various parameters taken from the sites surveyed in the environment where the invasive alien species are found. The means represented by the same letter do not differ significantly between them (critical F for ddl1 = 4 and ddl 2 = 20 is 2,866).

Fig. 4 shows the pace of temperature in the different sites.

At the 5% probability level, the analysis of the variance did not reveal any significant difference between the different sites (F = 1.162, p = 0.357).

Fig. 5 presents the pH collected in different study sites.

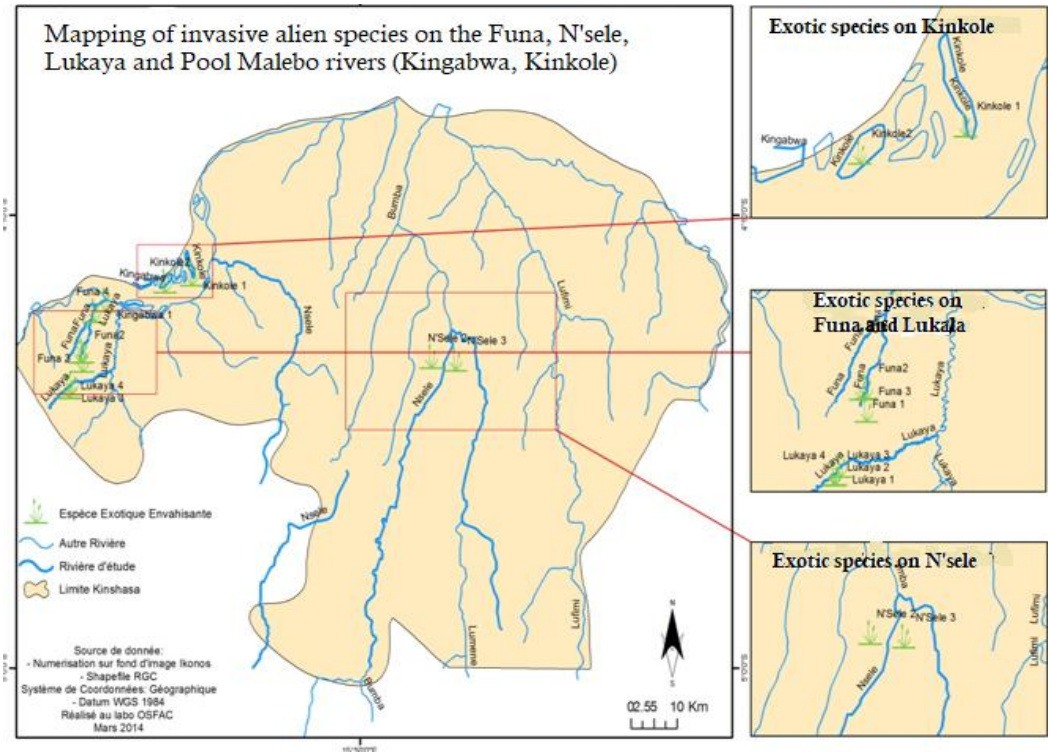


Fig. 2. Spatial distribution of invasive alien plants in different study sites

Table 2. Statistics of large taxonomic units

Clade	Families	Orders	Species
Angiosperms, Monocotyledones, Commelinids,	5	3	17
True Angiosperms, Dicotyledons, Asteridae, campanulidae	1	1	4
True Angiosperms, Real Dicotyledons, Rosids, Malvidea	2	1	5
Angiosperms, Real Dicotyledons, Fabidae,	1	1	1
Angiosperms, Real Dicotyledons, Real Dicotyledonous Nucleus	1	1	1
Angiosperms,	1	1	2
Angiosperms, Real Dicotyledones, Lamidae	1	1	1
Pteridophyta	3	3	4
Total	**15**	**12**	**35**

With respect to pH, the analysis indicates that the sites are highly differentiated (F = 7.442, p = 0.001, LSD = 0.58).

Fig. 6 describes the turbidity status (ppm).

The analysis does not indicate a significant difference between the sites in terms of turbidity (F = 2.560, p = 0.070).

Fig. 7 shows the conductivity situation (µS / cm).

With respect to conductivity, the analysis indicates that the sites differentiate very highly (F = 17.785, p <0.0001, LSD = 7.99).

4. DISCUSSION

Invasive species are a current focus of interest of ecologists, biological conservationists as well as natural resources managers due to their rapid spread, threat to biodiversity and damage to ecosystems. They are the most significant drivers of environmental change worldwide and have been implicated in the endangerment of specific species, degradation of aquatic and terrestrial environments, which alter the biogeochemical cycles [7,18]. Invasion of ecological systems by non-indigenous species has gained recognition as a growing global problem and therefore the control of such

species is indeed an international and frequently global public good [7]. They also play a major economic impact on agriculture, social instability, human health and the value of natural environment [7]. They place constraints on the conservation of biodiversity, sustainable development as well as the economic growth [18].

The study on the identification of aquatic invasive alien plants in the hydrographic network of Kinshasa city precisely in the Pool Malebo (Kinkole and Kingabwa), as well as in the N'sele, Funa, and Lukaya rivers, listed 19 aquatic alien species of which 4 were invasive to the environment. CBD [13] reported that the inventory of flora in Côte d'Ivoire gives 3 853 plant species of which 240 species (6.2%) were alien and 20 species (8.3%) were invasive species. For invasive alien plant species, their study counted 10 species in the Côte d'Ivoire network, namely: *Eichhornia crassipes, Echinochloa pyramidalis, Pistia stratiotes, Salvinia molesta, Nelumbo nucifera, Typha australis, Polygonum lanigenum var africanum, Bacopa crenata, Hydrolea glabra* and *Paspalum vaginatum*. In DRC, studies on inventories of invasive flora are poorly documented and fragmented. In this work, the focus was on the inventory and distribution of invasive aquatic alien plants to contribute to the Aichi Targets of the Nagoya Protocol on the Preservation of Biodiversity. The findings of this study showed that out of the 35 plant species collected in general, 19 species were alien, but only 4 of which exhibited the invasive behavior. As in Côte d'Ivoire, *E. crassipes, P. stratiotes* and *E. pyramidalis* were also collected in our different study sites. However, *Ludwigia peploid* species found in Kinshasa has not been reported in Côte d'Ivoire. In a study on the vegetation of La Funa in Kinshasa, *E. crassipes* and *L. peploid* species were not harvested in Funa i.e. these species were absent [25].

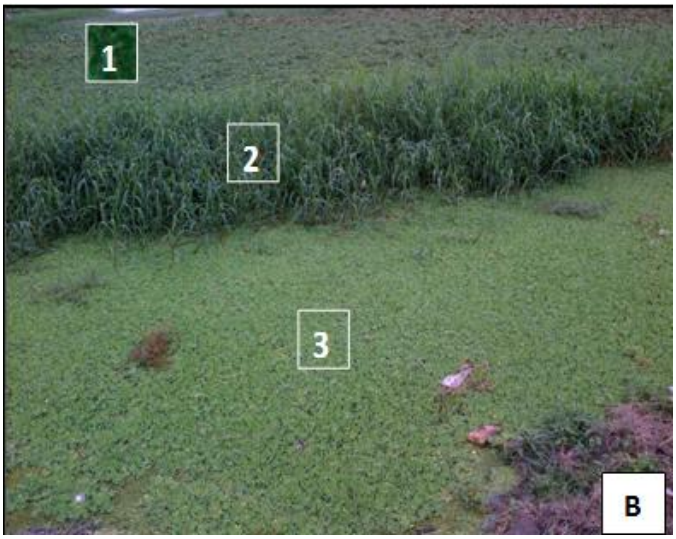
Regarding the socio-economic impacts of these species, Reaser et al. [18] arose the point of the changes, which come with globalization. This latter has brought social and economic benefits to many people, but it has also presented new challenges of which invasive alien species are among the most significant. At no time in history has the rate of biological invasion or the diversity and volume of these invaders been so high and the consequences so great. On the other side, Mack et al. [26] report that the damages, which are caused by invasive species and their causes are much explained by economic activities. Though newly colonized alien species may spend decades present with low abundances and minimum ecological impact, once they are in the invasive phase, they can rapidly induce changes in the abundance and distribution of native species, causing local extinctions and large shifts in the community structure.

Table 3. Exotic aquatic plants found in the different sites

N°	Alien species	PD
1.	*Ageratum conyzoïdes* L	Pan
2.	*Althernanthera tenea* L	Pan
3.	*Commelina diffusa* Burm.F	Pan
4.	*Colocasia esculenta*(L) Schott	Pan
5.	*Cyperus alternifolius* L	Pan
6.	*Cyperus latifolius* Poir	Pal
7.	*Echinochloa pyramidalis* (Lam) Hitch & Chase	Pan
8.	*E. stagnina* (Retz) P.Beauv	Pan
9.	*E.colona* (L) Link	Pan
10.	*Eichhornia crassipes* (Mart) Solms	Pan
11.	*Eclipta alba* L	Pan
12.	*Fuirena umbellata* Rott.b	Pan
13.	*Leersia hexandra* Sw	Pan
14.	*Pistia stratiotes* L	Pan
15.	*Rhynchospora corymbosa* (L) Butt	Pan
16.	*Ipomoea aquatica* Forsk	Pan
17.	*Oryza barsthie* A.Chev	Pan
18.	*Nymphaea lotus* L	Pal
19.	*Ludwigia peploides* (Kunth) Raven	Pan

Legend: PD: Phytogeographic distribution, Pan: Pan-tropical


1
2
A


1
2
3
B


1
2
3
C

Fig. 3. Some invasive alien species photos captured at different sites (Photo Mukendi, 2013)
A. Eichhornia crassipes invade the aquatic environment by forming a monospecific mat.
B. (1) Eichhornia crassipes, (2) Echinochloa pyramidalis, (3) Pistia stratiotes
C. (1) Echinochloa pyramidalis, (2) Pistia stratiotes, (3) Colocasia esculanta
D. Invasion of Eichhornia crassipes in Lukaya river, E. Echinochloa pyramidalis in Lukaya river

However, it is also recognized that invasive alien species also alter the magnitude and stability of ecosystem functioning, and delivery of supporting, provisioning, regulating and recreational/cultural ecosystem services [19]. The costs of the impacts are then measured as the difference in the value of ecosystem services with and without the invader under study. In the US, Environmental and economic costs associated with non-indigenous invasive species tough it is not the case for many countries [27].

In Benin for instance, the water hyacinth became the worst aquatic plant. The population calls it "Togble" which means "the country is in ruins" where 2 aquatic invasive alien species were reported namely *E. crassipes* and *P. stratiotes* [10]. Actions are being taken to control the invasion of water hyacinth in Benin, including biological control conducted by the International Institute of Tropical Agriculture (IITA) and the Directorate of Fisheries from the release of the following biological agents*: Neochetina eichhorniae, Neochetina bruchi, Niphograpta albiguttalis* and *Eccritotarsus catarinensis.*

Among the socio-economic impacts of the water hyacinth in Benin, we can pinpoint: The construction of water hyacinth parks for the release of biological agents, the death of the water hyacinth in Lake Nokoné in the dry season, the drop in yield in the fish-growing farms called "Acadja", the blocking of fishing activities, as the use of fishing gear becomes difficult. In Burkina Faso, the analysis of the water bodies sampled at the level of aquatic ecosystems made it possible to classify them in two groups, from the point of view of their colonization by macro-

phytocenosis: the plans for water free of vegetation macrophytes or very weakly colonized by vegetation. These can be subdivided into three subgroups: (i) Colonization by graminaceous species of forage, sedges, legumes and various Nymphaeaceae; (ii) Colonization by prolific species, in particular Ceratophyllum and (iii) The colonization by *Eichhornia crassipes, Typha australis, Azolla africana*, interests plans and watercourses prospected (7%).

The study of the impacts of invasive alien plants also refers to the concept of "disturbance" classically defined as a change in the conditions of a population or a community, generated by an external agent, often man. The authors clarify this definition by equating a disturbance with a change in an environmental factor of a biological system that interferes with its normal state [28]. Other impacts may be on fisheries, agriculture, ornamentals, infrastructure, tourism, human health, animal health, governance and costs. Environmental consequences translate into socio-economic impacts when they influence the ability of ecosystems to provide goods and services for humanity. Some species have direct effects across a variety of ecological features and socio-economic sectors [18].

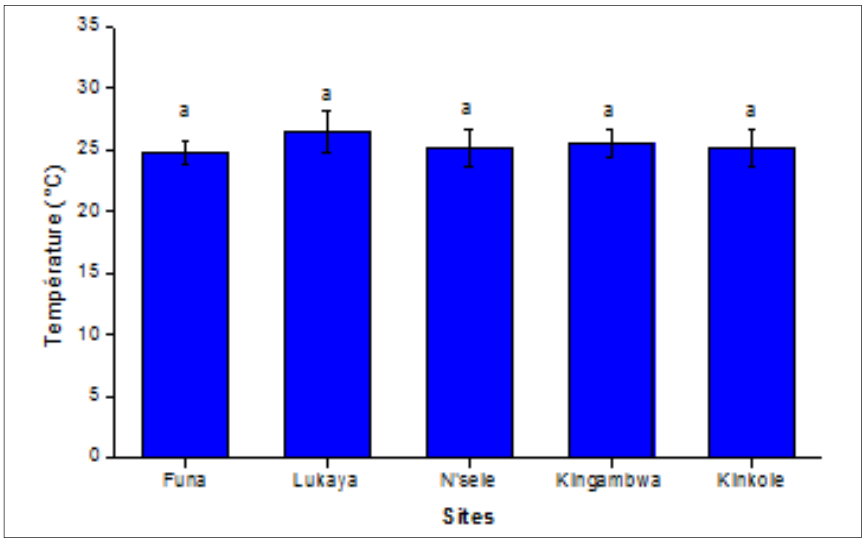


Fig. 4. Water temperature

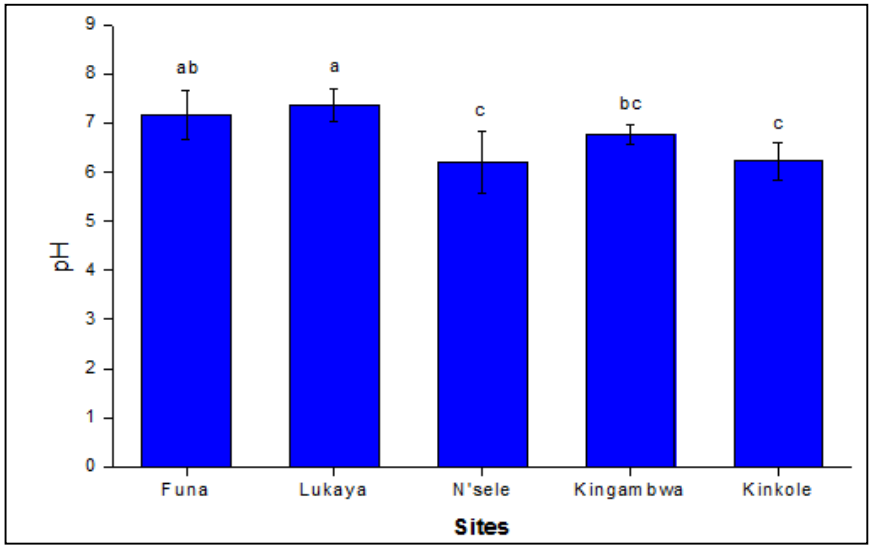


Fig. 5. Variation of pH

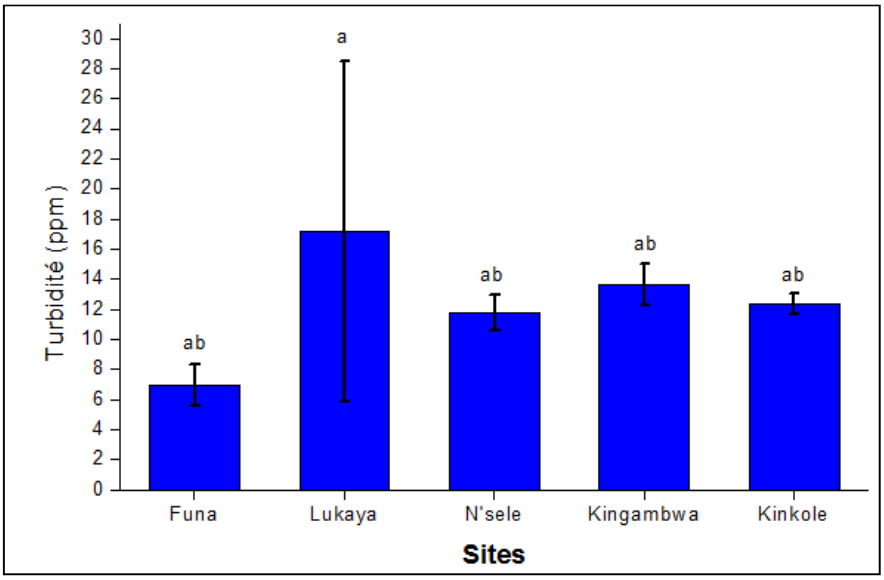


Fig. 6. Variation of turbidity

Moreover, invasive alien species may alter hydrology, nutrient accumulation and cycling, and carbon sequestration on grasslands [7]. This invasive aquatic vegetation can change ecosystem functions such as physical structure, community composition, biogeochemical cycling and hydrology [29]. These invasive aquatic weeds reduce water velocity substantially, impact water quality as well as provide habitat for non-native fish predators [29]. The observation of the hydrological parameters showed that there are no significant differences for the temperature in the different sites. For the pH, the analysis indicated that the sites are highly significant, the analysis does not indicate a significant difference between the sites for turbidity. Meanwhile, the conductivity indicated that the sites differ in a very highly significant way.

In South Africa, several alien aquatic plant species are important invaders of rivers and water bodies, and these are namely *E. crassipes*, *Pistia stratiotes*, *Salvinia molesta*, *Myriophyllum aquaticum* and *Azolla filiculoides* have become

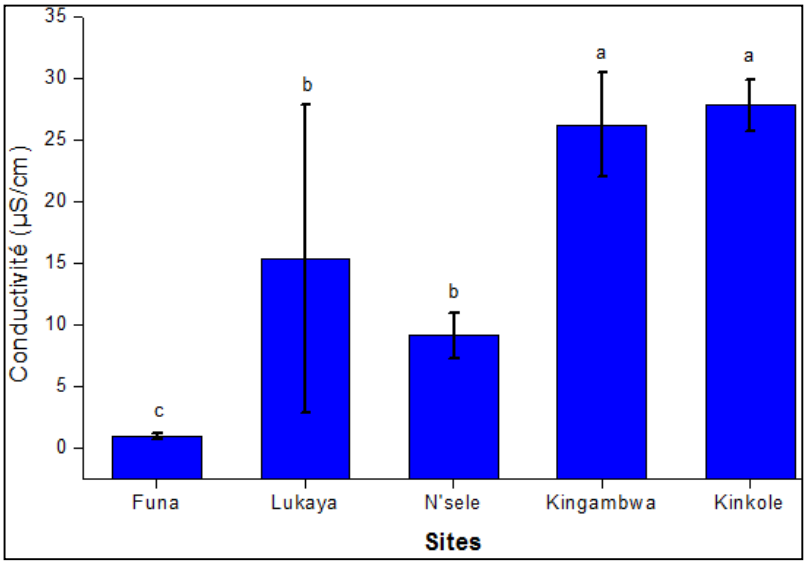


Fig. 7. Variation in conductivity

relatively widespread, forming dense mats in nutrient-rich aquatic ecosystems as floating weeds. This invasion is associated with a range of impacts on water quality. They can impede water flow and inhibit the diffusion of air into water, resulting in lower concentrations of dissolved oxygen [30]. Anyway, the author did not relate it to any physico-chemical characteristics of water [30]. As can be seen, the present study has just shown that the knowledge of ecological factors is essential for the wetland development, the fight against alien species that threaten native or local species, the consequences of which are either the disappearance of native species, the modification of the environment, or by various socio-economic impacts.

Although the prevention, eradication and control of invasive alien species in different ecosystems present scientific, political and ethical challenges. This issue can be substantially reduced through concerted action. There is a need to inform different stakeholders of this crucial situation and motivate them to address it so that sustainable solutions might be found. Scientifically-based information and effective tools need to be provided to policy makers and resource managers so that well-informed decisions can be taken. Thus, management strategies, which can be made available to the decision-maker along the invasion chain, which is prevention – early detection – rapid response and lastly the eradication, control as well as the adaptation. Furthermore, cooperative programs and NGOs need to be forged among governments as well as other institutions to enable the problem to be addressed in a strategic, holistic and timely manner.

5. CONCLUSION

The invasion of alien species is a consequence of human activities and an issue, which affects all sectors of society. It is a challenge for ecologists, economists, social scientists, agricultural engineers and other to develop as well to implement strong risk analysis frameworks and environmental impact assessments.

The study on the floristic inventory of aquatic invasive alien plants in Kinshasa is part of the work on wetland vegetation in general, and that of the city of Kinshasa in particular. This study is of high relevance to a country where the vegetal cover is more and more affected the introduction of alien species, which disturb the flowing of rivers. The present study has just shown that knowledge of ecological factors is essential for wetland development, the fight against alien species that threaten native species, the consequences of which are either the disappearance of native species, the modification of the environment, or serious socio-economic impacts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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