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Floristic Inventory of Invasive Alien Aquatic Plants Found in Molondo, Mipongo and Japan Islands of the Pool Malebo in Congo River, in the Democratic Republic of the Congo

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Authors' contributions

This work was carried out in collaboration among all authors. Author FLL designed the study and wrote the protocol. Authors MTM and HKM wrote the first draft of the manuscript. Authors MTM, HKM 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 make a floristic inventory and identify invasive aquatic alien plant species found in the Pool Malebo and their behavior along with their impacts on their habitat.
Study Design: A combination of reasoned sampling and simple random sampling to select different sites from which samples of the riparian flora were collected.
Site and Duration of the Study: This study was carried out in three different islands as follow: Molondo, Mipongo and Japon islands in the Pool Malebo located in Kinkole, Kinshasa in the Democratic Republic of the Congo. This study was conducted in August 2020.
Methodology: The sample collection was carried out after direct observation. Using a motorized canoe, we docked on islands for sample collection as well as in the swampy areas of the Kinkole Islands. We also collected invasive species in the middle of the Congo River. The recorded species

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were classified either as alien species or as invasive alien species depending on the status in the study region. The botanical classification of species was performed according to APG III. Environmental impacts were also considered.
Results: Among the collected specimens, 12 species were recognized as exotic and 2 species were found to be invasive alien species, of which *Echinochloa pyramidalis* and *Eichhornia crassipes*. These species pose a serious threat from the erosion of aquatic biodiversity and may form a monospecific mat and eliminate native or autochthonous species from the aquatic or riparian flora.
Conclusion: The invasion of alien species is a consequence of human activities and a concern, as they affect all sectors of the society. The invasion of these species presents a challenge for environmentalists, economists, social scientists, agricultural engineers, and others. Henceforth, the need to develop and implement robust risk analysis frameworks and environmental impact assessments.

Keywords: Invasive alien plants; environmental impacts; pool malebo; Kinshasa; DR Congo.

1. INTRODUCTION

Biodiversity refers to the variety of genes, species and ecosystems that can be found in the environment. It contributes to many constituents of human well-being, including security, basic materials for a good life, health, good social relations and freedom of choice and actions [1]. According to the Millenium Ecosystem Assessment (MEA) Report, the most important direct drivers of biodiversity loss and ecosystem service changes are: habitat change (such as land use changes, physical modification of rivers or water withdrawal from rivers, loss of coral reefs, and damage to sea floors resulting from trawling); climate change; invasive alien species; overexploitation; and pollution [1].

Invasive alien species are considered as the second cause of biodiversity loss (as one of the most important threats to the global ecosystem), here seen as a decline in biodiversity just after their habitat being destroyed and fragmented [2]. The term “invasive alien species” has been defined by the International Union for Conservation of Nature and Natural Resources as “an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity [2,3].

Species and ecosystems constitute the biological diversity of the earth, and are so important that their loss and degradation handicap nature [2]. Species other than ours have a right to exist and a place in the world. We are unable to determine which species are essential or redundant for the functioning of a given ecosystem and which will flourish in a changing world [4]. When a new species is introduced into an ecosystem, often the impact is not immediately apparent, it will take a fairly long period of time (5 years or 10 years) to realize its environmental impacts. They are the five most important drivers affecting nature, and the fourth most important direct-driver of species extinctions, and this invasion can be exceedingly difficult to reverse [3].

The eradication of invasive plant species already established over a large area is rarely possible [4]. Strategies to prevent new introductions and spread of alien invasive plants are considered more effective [5]. Thus, understanding and predicting the invasive success of plants is one of the major concerns of invasive plant ecology. Unfortunately, in many parts of the world, the magnitude of this problem has not been sufficiently documented [6].

The socio-environmental impacts associated with plant invasions are increasingly recognized around the world and are expected to increase dramatically due to climate change or land use [7-9]. Invasive alien species have a lot of negative impacts at the ecological, economic and social levels [10] and pertaining to whose local people have a good knowledge of these species [11-12]. Local people assess the impact of invasive plants based on how their socio-economic needs are influenced by these species [10,13]. In Africa, several invasive plant species are used by local populations who have the knowledge to manage these plants and offer them benefits for their daily routine life namely firewood, food, medicine, or forage, etc. [14]. Depending on the uses made of it, the better knowledge and management of invasive plants could help improve the living conditions of its local people such as the case in the Democratic Republic of the Congo (DRC). Despite much work on plant invasions in recent decades,

persistent gaps in scientific knowledge continue to hamper the ability to predict the successful establishment and spread of invasive plants. The aim of this study was to inventory and identify invasive aquatic alien plant species found in different islands namely Molongo, Mopongo and Japan of the Pool Malebo and their behavior as well as their socio-economic impacts.

2. MATERIALS AND METHODS

2.1 Study Area

The Pool Malebo, formerly called Stanley Pool, is the terminal part of the middle course of the Congo River [15]. It stands at an average elevation of 272 m and ranges from 4 ° 05 to 4 ° 20 'South latitude and 15 ° 19' to 15 ° 19 'to 15 ° 32' East longitude. It is the widening of the Congo River located on the border between DRC (Kinshasa city) and the Republic of Congo (Brazzaville City) [16]. The mapping of prospecting sites of the Pool Malebo in the Congo river (Mipongo, Molondo and Japan), where the floristic inventory survey was carried out is presented in the Fig. 1.

The Pool Malebo refers to the palm trees (*Borassus aethiopum* Mart, Syn. *Borassus flabelifere*), locally called Malebo, which abundantly displays the banks and islands of Pool Malebo as well as the alluvial plain of Kinshasa. Pool Malebo is dotted with numerous islets and temporary sandbanks [16]; Mbamou Island, which covers an area of approximately 180 km^2, occupies the center. It is entirely part of the Republic of Congo and forms, in its eastern limit, the border with DRC [16].

2.2 Biological Material

The field work carried out in August 2020 was summarized in the floristic inventory at the Pool Malebo at the sites of Molondo, Mipongo and Japan islands, and plant species collected constituted the biological material.

2.3 Methods

2.3.1 Floristic study

In the field, the identification of species was performed with specific identification keys namely APG III [17]. Species, which seemed to be unidentifiable due to the lack of flowers and fruits, those species were brought to the Laboratory of Systematic Botany and Plant Ecology, located in the Department of Biology, University of Kinshasa for further taxonomic investigations on specimens already identified *in situ*. Or by using a suitable identification by comparison with the dead floristic collection kept at the Herbarium of the University of Kinshasa and the National Institute for Agricultural Study and Research (INERA) for unidentified specimens in the field.

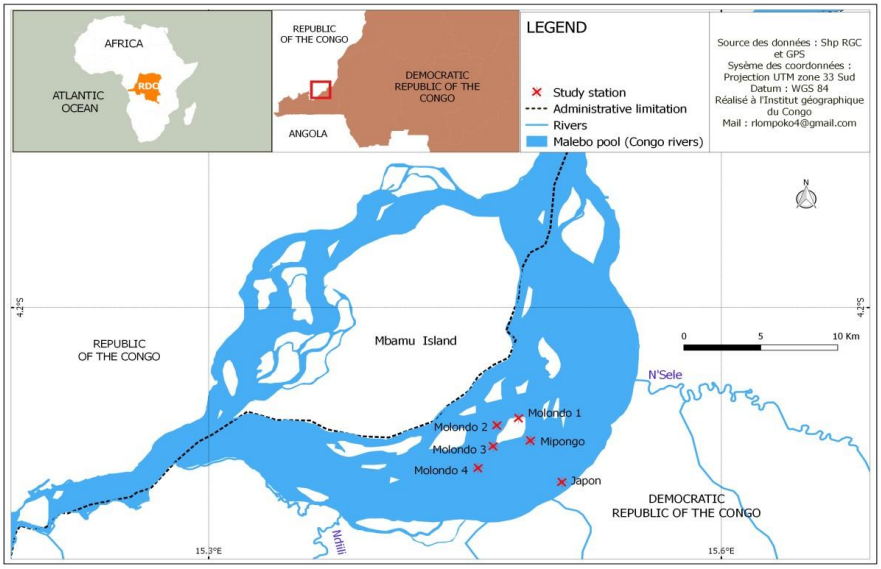

Fig. 1. The map of Pool Malebo indicating different study sites

2.3.2 Ecological study

2.3.2.1 Biological types

The biological types are morphological arrangements by which plants show their adaptation to the environment in which they live. For Mandango [18], phytogeographiers are unanimous in affirming that biological forms explain the physiognomic and ecological organization of the vegetation of a territory or a region.

The classification of biological types is inspired by Raunkiaer as adapted to tropical regions by Lebrun [19] and taken up by Schnel [20], taking into account the behavior of species to protect their buds or their young shoots during bad weather season. The following biological types that have been recognized in the flora of these islands are named below.

Mesophanerophytes (MsPh), Microphanero-phytes (McPh), Nanophanerophytes (NPh), Climbing Phanerophytes (Phgr), Erect Chamephytes (Chd), Climbing Chamephytes (Chgr), Chamehytes, Rampant Chamephytes, Cespitous Chamephytes (Chces), Cespitous Hemicryptophytes (Hces), Bulbous Geophytes (Gb), Tuberous Geophytes (Gt), Rhizomatous Geophytes (Grh), Cespitous Therophytes (Thces), Erect Therophytes (Thd), ProstrateTherophytes (Thpr), Climbing Therophytes (Thgr)and Pelophytes (Pelo).

2.3.2.2 Phytogeographic Types (PT)

The study of phytogeographic distribution is inspired by the chorological divisions recognized for tropical Africa by the following authors: Lebrun [21], Mullenders [22]; Evrard, [23]; Aubreville, [24]; White [25] and Denys [26]. The phytogeographic distribution types considered were: Afro-tropical (AT), Cosmopolitain (Cosmo), Paleotropical (Paleo), Pantropical (Pan), Afro-malgache (Am), Guineo Central (Gc) and Congolian (C).

2.3.2.3 Diaspore Types (DT)

Diaspores are organs capable of regenerating through various modes of dissemination, corresponding to plant individuals. Based on the categorization of the morphological types of diaspores as defined by Dansereau and Lems in Lejoly and Mandango [27].

The different types of diaspores recognized in the inventoried sites were the following: Pterochores (Ptero), Pogonochores (Pogo), Sclerochores (Sclero), Desmochores (Desmo), Sarcochores (Sarco), Ballochores (Ballo), Barochores (Baro) and Pleochores (Pleo).

2.3.2.4 Biological spectra

Biological spectra reflect the respective importance of biological types in the flora of a territory or within a plant community. A distinction is made between the raw spectrum and the weighted or real spectrum.

(i) Raw spectrum (RS)

The raw spectrum is determined by the number of species identified in each group in accordance with the eco-morphological criterion considered. The results obtained being expressed as a percentage according to the following formula:

$$R.S. = \frac{Number\ of\ species\ of\ considered\ group}{Total\ number\ of\ species\ of\ all\ groups}\ x\ 100$$

(ii) Chorological study

The study of phytogeographic distribution (PD) is inspired by the chorological divisions recognized for tropical Africa by the following authors: Lebrun [21], Mulumbu [22]; Evrard, [23]; Aubreville, [24]; White [25] and Denys, [26].

(iii) Species with very wide distribution

Cosmopolitan species (Cosm): plants found both in tropical and temperate zones of the world. Pantropical species (Pan): plants observed in all tropical regions of the globe. Afro-American species (Aa): plants found in Africa and tropical America. Paleotropical species (Pal): plants distributed in the tropics and subtropics of the old world (Africa, Asia). Afro-Malagasy species (Am): species from regions of tropical Africa and the island of Madagascar.

(iv) Species of the Guinean base element

These are plants distributed in the Guinean - Congolian region (region of African forests).
This element consists of:

- Guinean - Congolese species (GC): plants found in all regions of the African equatorial forest (region from Guinea to Congo);
- Guinean species (G): plants of which distribution covers all of West Africa;
- Congolese species (C): endemic species in the Congo Basin.

3. RESULTS

3.1 Floristic Inventory of Aquatic Plants

Table 1 presents an inventory of invasive alien aquatic species collected in Kinshasa City precisely in different islands of the Pool Malebo.

As observed these species are classified into clades, orders and families in accordance either with the phylogenetic classification system APG III [17] or with the classification of Cronquist [28].

This table indicates the presence of 19 species including 2 Pteridophytes and 17 Angiosperms, divided into 15 families and 12 orders.

The Table 2 gives both the survey of the presence or absence of the aquatic plants collected in the 3 islands and determines their aquatic habitats (water, bank of the river and Marsh).

Among of these 19 aquatic plants, 10 plants prefer marshed habitats (*Aeschinomene fluitans, Aechinomum sensitiva, Colocasia esculenta, Cyperus papyrus, Gisekia pharnaceiodes, Ipomoea aquatica, Leersia hexandra, Ludwigia abyssinica, L. leptocarpa, Selaginella myosorus*). While 5 other plants prefer water environment (*Echinochloa pyramidalis, Eichhornia crassipes, Nymphaea lotus, Pistia satriotes, Salvinia molesta*) and the 4 last plants are riparian (*Alternathera sessilis, Commelina diffusa, Oldenlandia affinis, Polygonum lanigerum*).

3.2 Study of Ecological Spectra

3.2.1 Raw spectra of biological types

The spectrum of biological types is given in Fig. 2.

Table 1. Inventory of invasive alien species collected in different islands of the Pool Malebo

Phylogenetic classification	BT	DT	PT
Clade Angiosperms Clade			
Rosidae/Malvidae			
O.1.Myrtales			
F1. Onagraceae	Chd	Sclero	GC
Es1. Ludwigia abyssica A. Rich.	Chd	Sclero	
Es2.Ludwigia leptocarpa (Nutt) Hara Clade :			Aa
True dicotyledonous core			
O.2.Caryophyllales	Ch	Sarco	
F2. Amaranthaceae			Pan
ES3. Alternanthera sessilis (L.) DC.			
Clade : Lamidea	Hd	Ptero	
O.4.Solanales			Pan
F3.Convolvulaceae	Hd	Pleo	
Es4. Ipomoea aquatica			Pal
ForskClade : Angiosperms			
O.5Nymphaeales	Chgr	Sclero	
F4 Nymphaeaceae *Es5.*	Hd	Sclero	Pan
Nymphaea lotus LClade :			Pan
Angiosperm			
O. 6.Commelinales	Hd	Pleo	
F5 Commelinaceae	Gt	Sarco	Pan Pan
Es6. Commelina diffusa Burm.F			
F6. Pontederiaceae			
Es7.Eichhornia crassipes (Mart.)	Grh	Sclero	
Solms			C
Alismatales	Grh	Sclero	Pan
F7. Araceae	Grh	Pleo	Pan
Es8. Pistia stratiotes L			
Es9. Colocasia esculenta (L) Schott			
Poales			
F8. Cyperaceae			

Phylogenetic classification	BT	DT	PT
Es10. Cyperus papyrus L.	Ch	Sclero	Pan
F9 Poaceae		Sclero	
Es11. Echinochloa pyramidalis(Lam.)	Th		Pal
Es12. Leersia hexandra (Sw)			
Clade : Tracheophytes Clade			
:Angiosperms			
Clade : Eudicots		Ballo	
Caryophyllales	NPh		AT
F10Polygonaceae		Ballo	
Es13. Polygonum lanigerum	NPh		Am
O.10.Caryophyllales			
F11Gisekiaceae			
Es14.Gisekia pharnaceiodes L.			
Clade : Angiospermes			
Clade : Dicotylédones vraies	Th	Sclero	
Clade : Noyau des dicotylédonesvraies			
Clade :Rosidées			Pan
Clade :Fabidées			
O.11. Fabales F12			
Fabaceae			
Es15.Aeschynomene fluitans L. peter			
Es16. Aechinomum sensitiva Swartz			
Clade : Asteridées			
Clade :Lamidées			
O.12.Gentianales			
F13 .Rubiaceae			
Es17. Oldenlandia affinis (Roem.&Schult.).			
Phyllum : Pteridophyta/ Filicopsida			
Selaginellales			
F14Selaginellaceae			
Es18. Selaginella myosurus L	Grh	Pleo Pleo	Gc Gc
Hydropteridales	Hd		
F15Salviniaceae			
Es19. Salvinia molesta D.S.Mitchell			

Table 2. Comparison of the vegetation in different study sites

Family / species	Molondo	Mipongo	Japan	Habitats
Onagraceae				
1. *Ludwigia abyssinica* A. Rich.	+	+	+	R
2. *Ludwigia leptocarpa* (Nutt.) H. Hara	+	+	-	R
. Amaranthaceae				
3. *Alternanthera sessilis* (L.) DC.	+	+	+	R
.Convolvulaceae				
4. *Ipomoea aquatica* Forssk	+	+	+	M
Nymphaeaceae				
5. *Nymphaea lotus* L.	+	-	-	W
Commelinaceae				
6. *Commelina diffusa* Burm. F	+	+	+	M
Pontederiaceae				
7. *Eichhornia crassipes* (Mart.)Solms	+	+	+	W
Araceae				
8. *Pistia stratiotes* L.	+	+	+	W
9. *Colocasia esculenta* (L.) Schott	+	-	-	M
Cyperaceae				

Family / species	Molondo	Mipongo	Japan	Habitats
10. *Cyperus papyrus*L.	-	-	+	M
Poaceae				
11. *Echinochloa pyramidalis*(Lam.)	+	+	+	W
12. *Leersia hexandra* (Sw)	+	-	-	M
Polygonaceae				
13. *Polygonum lanigerum*R. Br.	+	+	+	M
Gisekiaceae				
14. *Gisekia pharnaceiodes* L.	-	+	+	M
Fabaceae				
15. *Aeschynomene fluitans* L. Peter	+	-	-	M
16. *Aechinomum sensitiva* Swartz	-	+	+	M
Rubiaceae				
17.*Oldenlandia affinis*(Roem.&Schult.).	-	+	-	R
Selaginellaceae				
18. *Selaginella myosurus* (Sw.) Alston	+	-	-	M
Salviniaceae				
19. *Salvinia molesta* D.S.Mitchell	+	+	+	W
Total of species per site	15	13	12	

Legend: presence: +; absence: -; W: water; R: Riparian; M: Marsh

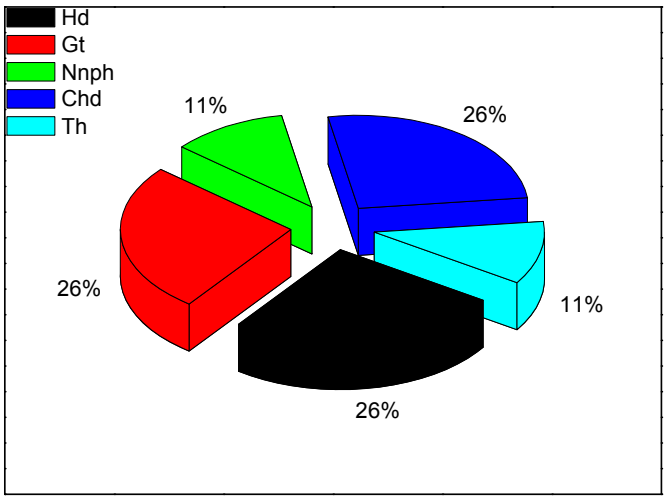

Fig. 2. Raw spectrum of biological types

It was observed that there is a strong dominance of Chamephytes (Chd), Geophytes (Gt) and Hydrophytes (Hd) with respectively 26%, followed by Nanophanerophytes (Nnph) and Therophytes (Th) with a low representation (11%).

Fig. 3 gives the chorological distribution of different inventoried taxa.

It is noted a strong dominance of Pantropical species (53%), Guinean-Congolian species (16%) and Paleotropics (11%). The other phytochories are weakly represented with 5% respectively.

The raw spectrum of the type distribution of the diaspores of the species listed is given in Fig. 5.

Fig. 4 shows a clear predominance of sclerochoric species (47.5%), followed by Pleochores (27.3%), while sarcochores and ballochores respectively represent only 11.1%. The remaining represent a low percentage of the flora studied.

The Table 3 represents the list of the most invasive alien species on the three sites in general.

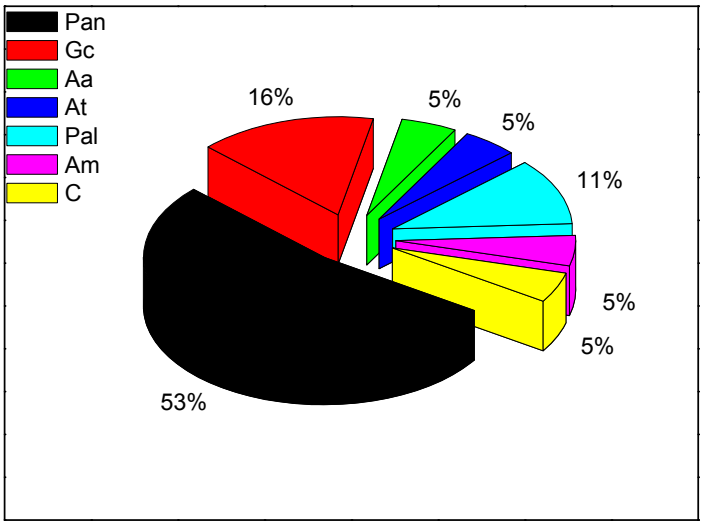

Fig. 3. Raw spectrum of distribution types of phytochories

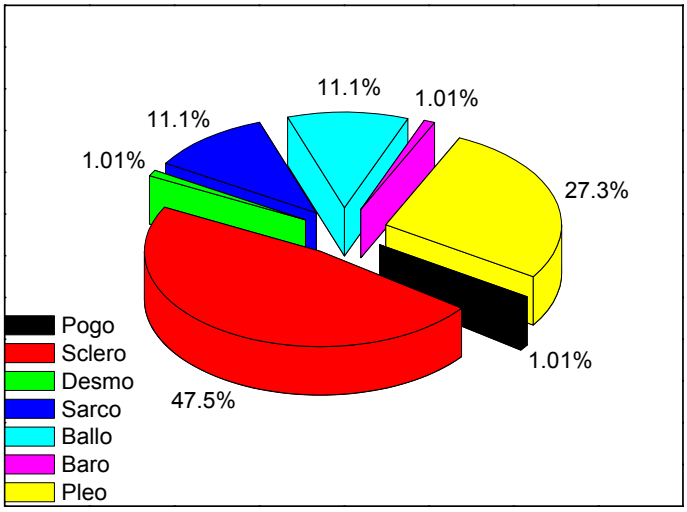

Fig. 4. Raw spectrum of diaspore types

Table 3. Exotic species listed after the inventory

Family / species	DP
Amaranthaceae	
1 .*Alternanthera sessilis* (L)DC	Pan
Convolvulaceae	
2. *Ipomoea aquatica* Forsk	Pan
Nymphaeaceae	
3. *Nymphaea lotus* L	Pan
Commelinaceae	
4. *Commelina diffusa* Burm.F	Pan
Pontederiaceae	
5. *Eichhornia crassipes* (Mart) Solms	Pan
Araceae	
6. *Pistia stratiotes* L.	Pan

Family / species	DP
7. *Colocasia esculenta* (L.) Schott	Pan
Poaceae	
8. *Echinochloa pyramidalis*(Lam)	Pan
9. *Leersia hexandra* (Sw)	Pan
Polygonaceae	
10. *Polygonum lanigerum* R. Br.	Pan
Gisekiaceae	
11. *Gysekia pharnaceiodes* L.	Pan
Rubiaceae	
12. *Oldenlandia affinis* (Roem.&Schult.).	Pan

Legend: D.P = phytogeographic distribution; Pan : Pantropical.

Table 4. Invasive alien species found at the three study sites

Invasive alien species	Observation
1 .*Echhornia crassipes*(Mart) Solms	The most alien invasive floating plant of the Pool Malebo. Always in association with E*chinochloa pyramidalis*
2. *Echinochloa pyramidalis* (Lam)	Floating plant always in association with *Eichhornia crassipes* also invasive.

Photo A. Floating aquatic association of *Eichhornia crassipes* (2) and *Echinochloa pyramidalis* (1) at the Mipongo island / Nsele Kinkole (Source: Mukendi, 2020)

Photo B. Floating *Echinochloa pyramidalis* meadow at the Molondo island / Nsele district (Source: Mukendi, 2020)

Photo C. Floating aquatic association of *Echinochloa pyramidalis* (1) *and Ipomoea aquatica* (2) at the Molondo island / Nsele District (Source: Mukendi, 2020)

Photo D. Floating heterospecific aquatic association made of *Eichhornia crassipes*, *Echinochloa pyramidalis,* at the Japan island / Nsele District (Source: Mukendi, 2020)

The ecological spectrum indicates that the pantropical phytogeographic type is the most abundant among all the plants collected in the Pool Malebo islands.

The Table 4 represents only the invasive alien species found at the three islands of the Pool Malebo.

Photos (A, B, C etc.) illustrating aquatic invasive plants associations in three islands of the Pool Malebo.

In view of the configuration and floristic composition of the various plant associations identified (photos A, B, C and D), as well as their sizes, it would be quite possible that in several places in the Pool Malebo, in particular, and in the Congo River, in general, a diversity of plant associations, both floating and fixed, could form, differentiate and agglomerate over several hundred meters or even kilometers, or even hectares, to the point of making traffic, fishing, and river transport difficult or even impossible.

In addition, living plant colonies (monospecific or heterospecific) and their detritus could also be the basis for the formation of several islands, plant associations, and disrupt the movement of various wastes dumped into the Congo River via its tributaries as well as running water and aquatic plants at the level of the Pool Malebo and the Congo River.

4. DISCUSSION

Invasive species may be generally described as biotic agents that occupy new environments or

habitats and cause harm to the habitats or human interests. They include all categories of life such as land plants (trees, shrubs, herbs, grass), aquatic plants, insects, molluscs, birds, fungi, reptiles, amphibians, crustaceans, and microorganisms. Invasive species are introduced intentionally or unintentionally to new environments. Invasive species are recognized as a major threat to the world's biodiversity [29].

The floristic study of invasive alien aquatic plants in Kinshasa is part of the work relating to the achievement of the Aichi targets, Objectives 9 and 19 of the Nagoya 2010 protocol [30]. The present study is a research project involving a territory of which the vegetation cover is increasingly being impacted by hydrological and anthropogenic parameters by the introduction of exotic species. Furthermore, the anthropogenic fishing, market gardening and rice cultivation activities on the banks of the Congo River sometimes lead to allochthon species being introduced into the aquatic environment of the islands of this great river. The inventory of the flora prospected indicated the presence of 19 species in general, including 2 Pteridophytes and 17 Angiosperms, divided into 19 families, 14 orders.

The study of invasive aquatic exotic plants in the hydrographic network of Kinshasa city, at Pool Malebo, in the three islands (Molondo, Mipongo and Japan), at Kinkole, identifies 19 plant species including 12 exotic species and 2 invasive alien species. These results show that the aquatic flora of Kinshasa is polluted with the presence of many exotic species. This is explained by the fact that aquatic environments are often open, and it was observed that hydrochory is one of the most effective modes of diaspore dispersal. This finding is consistent with our previous study [30]. The report of the Convention of Biological Diversity (CDB) showed that the floristic inventory of Côte d'Ivoire invasive plant species provided 3 853 plant species, of which 240 species (6.2%) were exotic or introduced and out of these species, 20 were invasive alien species. In DRC, studies on inventories of invasive flora are poorly documented and fragmented. Thus, there is a need of conducting studies in the different sites along the Congo River, of which findings would help to implement policies and strategies, which may help for the management, and control of these invasive alien species, which impact negatively the aquatic ecosystem and lives of the surrounding population. The 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 [31].

Concerning the socio-economic and environmental impacts, many studies arose the point of changes that come with the globalization. These species form a dense monospecific mat on the surface of water, which prevent light to reach the bottom of the river, and destroy the habitat of native species. The socio-economic aspect of these species brought several benefits to local people but they present more challenges [30]. 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 [30].

5. CONCLUSION

The present study revealed the presence of 12 exotic plants, 2 of which are invasive in environment: *Eichhornia crassipes* and *Echinochloa pyramidalis*. These two species deserve increased surveillance, as they pose major challenges for the navigability of rivers, and the invasion of fishing sites, sometimes completely modifying the spawning areas of fish.

Species recorded in Kinshasa highlighted the existence of a disturbed flora dominated by species with a very wide distribution, which, over time, have supplanted those of the Guinean base element of which disappearance in the prospected perimeter confirms the explicit anthropogenic activities.

The Congo Basin is very large, and the Congo River has several tributaries likely to be colonized by aquatic species. It is therefore recommended to widen the prospecting field in order to identify and list the exotic and / or invasive aquatic species of the Congo's aquatic flora.

This study will be long-term, but it deserves to be undertaken before the aquatic ecosystems are sufficiently degraded, with the risk of losing many aquatic species in our country. Botanists, biodiversity defenders and policy-makers are therefore invited to become aware of this aspect of the problem, and to take appropriate

measures to manage the protection of the local aquatic flora, and avoid the invasion by exotic species of the aforementioned flora.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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