Original Research Article

Localization and distribution of invasive exotic aquatic plants and associated plants in Pool Malebo: The Case Study of *Eichhornia crassipes* and *Echinocloa pyramidalis*

Abstract

Objective: To locate and identify the two invasive alien plants and their distribution in the Malebo pool and related plant species found in the Malebo pool and their behaviors and impacts.

Methodology: The study used a combination of purposive sampling and simple random sampling to select different sites for sampling. The research was conducted on three different Malebo pool islands: Molondo, Mipongo, and Japan at the Malebo pool in Kinkole (Malebo Pool system) and the Malebo Kingabwa pool in Kinshasa, Democratic Republic of the Congo. Pool Malebo stretches along the Congo River. This study was conducted in August 2020. The collection was carried out after direct observation. The place of harvest depends on the sites. Using a motorized canoe, we landed on islands to collect samples, as well as in the marshy areas of the Kinkole Islands and on the bank of the Malebo Kingabwa pool. We also located and identified invasive species sought after in the middle of the Congo River and on the shore of the Malebo Pool. Recorded species were classified according to their status in the study area. The botanical classification of the species was made according to APG III. Ecological impacts were also taken into account.

Results: Among the specimens collected, 19 species were identified, including 2 study species, including *Echinochloa pyramidalis* and *Eichhornia crassipes*, located on the four prospected sites. These species pose a serious threat to the erosion of aquatic biodiversity. These species form a mono-specific carpet and eliminate native or autochthonous species of aquatic or riparian flora.

Conclusions and suggestions: The invasion of alien species is a consequence of human activities and a concern, as it affects all sectors of society. Controlling invasive alien species is a challenge for ecologists, economists, social scientists, agricultural engineers, and others. This work is a recommendation of the Aichi objectives of the Nagoya protocol.

Keywords: Invasive alien plants, environmental impacts, Malebo pool, Kinshasa city, the Democratic Republic of the Congo

1. Introduction

The accidental invasion of *Eichhornia crassipes* in the Congo River reaches dates back to 1954, prompting the Belgian Colonial Administration to issue an ordinance on May 4, 1955, prohibiting the possession, cultivation, multiplication, sale, and transport of this plant, which has since been considered invasive [1]. *E. crassipes* is regarded as one of the world's most invasive aquatic plants. Beautiful and large purple flowers and violets make it a very popular ornamental plant for ponds. Today, it is present in more than 50 countries on five continents. *E. crassipes* also prevent light and oxygen from entering the water and reaching submerged plants. The shading and covering of native aquatic plants seriously reduce the biological diversity of aquatic ecosystems [2]. It preferentially colonizes the fresh waters of the lower courses of the Mainland Rivers [3].

Invasive alien species are considered the second cause of erosion, here considered as the regression of biodiversity just after the destruction and fragmentation of habitats. Socio-environmental impacts associated with plant invasions are increasingly recognized worldwide and are projected to increase significantly due to climate or land-use change [4-7]. Apart from their negative or positive impacts on biodiversity [8, 9], invasive plants also have positive economic, social, and ecological contributions [10], of which local populations are well aware. Local people assess the impact of invasive plants based on how their socio-economic needs are influenced by these species [11, 12]. In Africa, local people who also know to manage these plants use several invasive plant species. Depending on the uses made of them, better knowledge and management of invasive plants could contribute to improving the living conditions of populations (7). Species and ecosystems constitute the biological diversity of the earth and are so important that their loss and degradation handicap nature. 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 to the functioning of a given ecosystem and which will thrive in a changing world. Species and ecosystems comprise the earth's biological diversity and are so important that their loss and degradation harm nature. 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 to the functioning of a given ecosystem and which will thrive in a changing world.

2. Materials and Methods

2.1. Study environment

The Malebo Pool, formerly called Stanley Pool, (Figure 1), is the terminal part of the middle course of the Congo River [14]. It is located at an average altitude of 272 m and extends 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 at the border between the Democratic Republic of Congo (city of Kinshasa) and the Republic of Congo (City of Brazzaville). The word "pool" is an English term meaning "swimming pool" or "lake". This term is used in the Congo to designate the vast expanse of water between Kinshasa and Brazzaville [15].

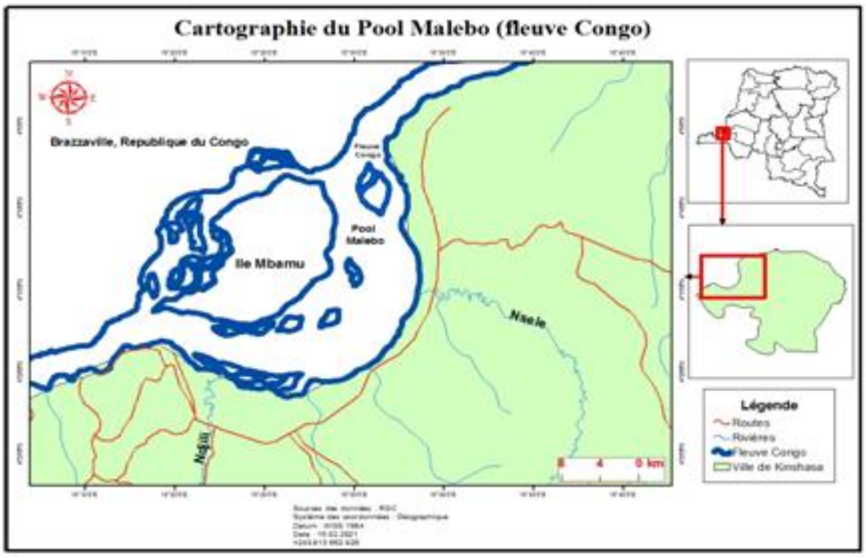

Figure 1: Localization of Kinshasa City and Pool Malebo

The Malebo Pool refers to the ronier palms (*Borassus aethiopum* Mart, Syn. *Borassus flabelifere*), locally called Malebo, which abundantly feature the shores and islands of Pool Malebo as well as the alluvial plain of Kinshasa. The Malebo Pool is dotted with numerous islets and temporary sandbanks [16]; Mbamou Island, whose area is approximately 180 km2, occupies the center. It is entirely part of the Republic of Congo and forms, at its eastern limit, the border with the Democratic Republic of the Congo.

The Malebo Pool regions have an equatorial to tropical climate [17]. Two major seasons characterize the climate of this region: three dry months from June to August and nine rainy months from September to May, with a short dry season between January and February. The heaviest rainfall occurs in November, December and March. July is the driest month. The city of Kinshasa, which is located in the low altitude climate, is characterized by a hot and humid tropical climate belonging to the AW4 type according to the Köppen classification [18]. There is an alternation of two seasons: a dry season from June to September and a rainy season from September to the end of May.

2.2. Methods

2.2.1. Flora study

The identification of the plants in the field was done by us; those whose identification was hardly possible on the spot-because the samples present were either botanically sterile (absence of flower and fruit) or absent in the identification keys in our possession-were brought back to the laboratory and to the herbarium. The samples of collected plants were identified by comparison with the herbarium floristic collection of the University of Kinshasa.

2.2.2. Ecological studies

i. Biological types (BT)

plants show their adaptation to the environment in which they live [19]. For [20], phytogeographers are unanimous in asserting that biological forms explain the physiognomic and ecological organization of the vegetation of a territory or region. The classification of biological types is inspired by Raunkiaer as adapted to tropical regions by Lebrun [21-23] and taken up by Schnell [24], taking into account the behavior of species to protect their buds or their young shoots during the bad season. The following types have been recognized in the flora of these rivers:

- *Phanerophytes (Ph)*

The diversification of biological types has made it possible to distinguish the following subdivisions:

ü Mesophanerophytes (MsPh) are trees whose renovation organs are located between 10 and 30m above the ground,

ü Microphanerophytes (McPh): shrubs whose buds are located in the space between 2 and 10 m above the ground,

ü Nanophanerophytes (NPh): sub-shrubs and bushes whose young shoots are observed at a height of less than 2 m,

ü Climbing phanerophytes (Phgr) are the twining lianas that climb to the top of trees by various means of attachment.

Chamaephytes (Ch). It is :

ü Erect chamaephytes (Chd): sub-woody plants whose aerial axis is erect or upright.

ü Climbing chamephytes (Chgr): these are under-woody plants whose herbaceous part wraps around support.

ü Prostrate chamephytes (Chpr) are sub-woody plants with a branched aerial axis that remains on the ground at the level of its base.

ü Creeping chamaephytes (Chrp) are under-woody plants with a stem lying on the ground that emits adventitious roots at the nodes.

ü Cespitose chamaephytes (Chces): sub-woody plants with numerous stems emerging from the base.

Hemicryptophytes (Hc) & Hemicryptophytes cespitose (Hces)

Geophytes (G): Bulbous geophytes (BG): plants whose renovation organs are bulbs. Tuberous geophytes (Gt) are plants whose perennial organs consist of tubers. Rhizomatous geophytes (Grh): plants whose renovation organs are represented by rhizomes (underground stems).

The Therophytes (Th)

These are Cespitose Therophytes (Thces): grasses forming radical or axial tufts. Erect therophytes (Thd): plants with an aerial vegetative apparatus formed by an erect or erect stem. Prostrate therophytes (Thpr) are herbaceous plants whose stem is half-lying at their base. Climbing therophytes (Thgr) are laniform annual plants that climb.

Hydrophytes (Hd)

Types of Diaspores (TD) Anemochorous plants

The dissemination of plants is ensured by the wind. The types of diaspores recognized in this category are: pterochores (Ptero): diaspores with aliform appendages disseminated over short distances; Pogonochores (Pogo): diaspores with feathery or silky appendages like fruits and seeds with pappus, stipitate or sessile with a slight tuft of hairs at the end; Sclerochores (Sclero): non-fleshy diaspores are relatively light and likely to be transported by the wind over long distances.

Zoochores plants

Plants are disseminated by animals, including humans. Their diaspores are represented by desmochores (Desmo).

Autochorous plants

They are Ballochores (Ballo) and Barochores (Baro).

Hydrochoric plants

We have recognized the pleochores (Pléo) 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.

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 are expressed as a percentage according to the following formula:

RS= [Number of species from considered group/total number of species in all groups] x 100

1.1. Chronological study

The study of the phytogeographical distribution (D.P) is inspired by the chorological divisions recognized for tropical Africa by [21-23, 25-29].

Species with a wide range

ü Cosmopolitan species (Cosm): plants that grow in both tropical and temperate climates.

ü Pantropical species (Pan) are plants observed in all tropical regions of the globe;

ü Plants found in Africa and tropical America are known as Afro-American species (Aa).

ü Paleotropical species (Pal) are plants found in the old world's tropical and subtropical zones (Africa and Asia).

ü Afro-Malagasy species (Am) are species from regions of tropical Africa and the island of Madagascar.

Species of the Guinean base element

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

ü Guinean-Congolese species (GC): plants found throughout Africa's equatorial forest (from Guinea to Congo);

ü Guinean species (G): plants whose distribution covers all of West Africa;

Congolese species (C): endemic species in the Congo Basin.

3. Results and Discussion

3.1. The floristic inventory of aquatic plants

The general floristic list of the different work sites indicates the presence of 19 species, including two Pteridophytes and 17 Angiosperms, divided into 19 families and 12 orders. The species are classified according to the alphabetical listing of species. The floristic list of the presence and absence of species according to the study sites is given in Table 2.

Table 1 presents the general list of species listed on the different sites; they are classified into clades, orders, and families according to the new APG III phylogenetic classification system and the Pteridophytes are determined according to Cronquist [30]. The list of the most invasive alien species on the sites is given in table 3, while figure 2 gives the prospecting sites.

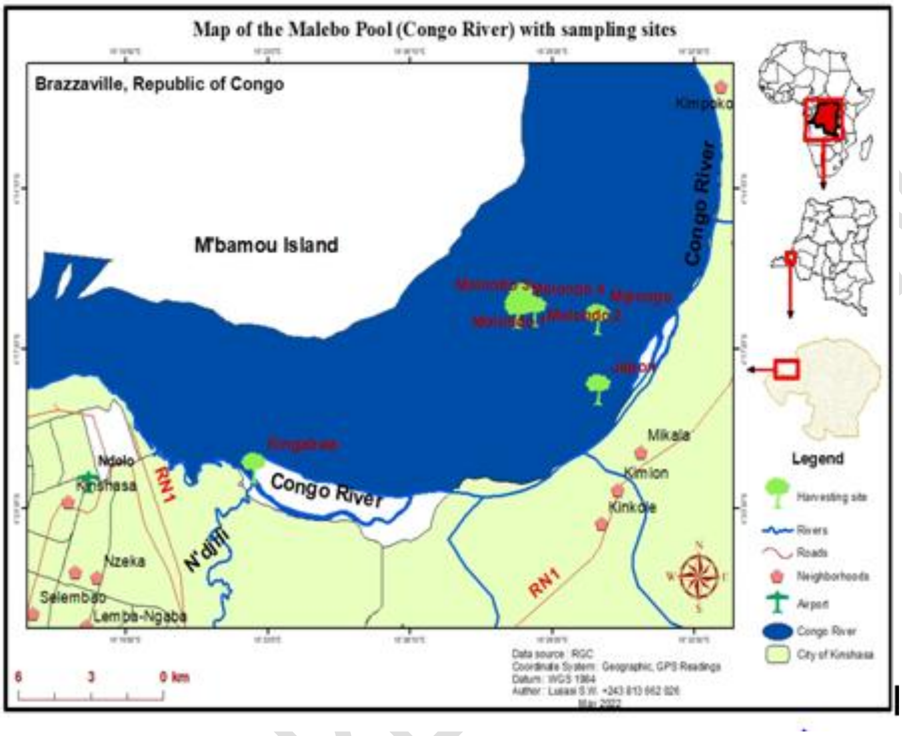

Figure 2. Mapping of prospecting sites

Table 1: General list of species recorded in the three Kinkole sites (Molondo, Mipongo, Japan and Kingabwa)

Phylogenetic Classification	BT	TD	DP

Clade Angiosperms			
Clade Rosidae/Malvidae			
O.1.Myrtales			
F1. Onagraceae			
Es1. Ludwigia abyssica A. Rich.	Chd	Sclero	GC
Es2..Ludwigia leptocarpa (Nutt) Hara	Chd	Sclero	Aa
Clade : True dicotyledonous core			
O.2. Caryophyllales			
F2. Amaranthaceae			
ES3. Alternanthera sessilis (L.) DC.	Ch	Sar	Pan
Clade : Lamidea			
O.4. Solanales			
F3. Convolvulaceae			
Es4. Ipomoa aquatica Forsk	**Hdfl**	Ptero	Pan
Clade : Angiosperms			
O.5Nymphaeales			
F4 Nymphaeaceae			
Es5. Nymphaea lotus L	Hd	Pleo	Pal
Clade : Angiosperm			
O. 6.Commelinales			
F5 Commelinaceae			
Es6. Commelina diffusa Burm.F	Chrp	Scléo	Pan
F6. Pontederiaceae			
Es7.Eichhornia crassipes (Mart)	Hd	Scléo	Pan
O.7. Alismatales			
F7. Araceae			
Es8. Pistia stratiotes L	Hdfl	Pléo	Pan
Es9. Colocasia esculenta (L) Schott	Gt	Sarco	Pan
O.8. Poales			
F8. Cyperaceae			
Es10. Cyperus papirus L	Grh	Scléro	C
F9 Poaceae			
Es11. Echinochloa pyramidalis(Lam)	Grh	Scléro	Pan
Es12. Leersia hexandra (Sw)	Grh	Pléo	Pan
Clade : Tracheophytes			
Clade : Angiosperms			
Clade : Eudicots			
O.9. Caryophyllales			
F10 Polygonaceae	ch	scléro	Pan
Es13. Polygonum lanigerum			
O.10.Caryophyllales			
F11Gisekiaceae			
Es14.Gysekia pharnaceiodes L.	Th	Scl	Pal
Clade : Angiospermes			
Clade : Dicotylédones vraies			
Clade : Noyau des dicotylédones vraies			
Clade : Rosidées			
Clade : Fabidées			
O.11. Fabales			
F12 Fabaceae	NnPh	Bal	At
Es15.Aeschynomene fluitans L.	NnPh	Bal	Am
Es16. Aechinomum sensitiva Swartz			
Clade : Asteridées			
Clade : Lamidées			
O.12.Gentianales			
F13 . Rubiaceae			
Es17. Oldenlandia affinis (	Th	Scléo	Pan

Roem.&Schult.). **Phyllum : Pteridophyta/ Filicopsida** **O.13. Selaginellales** **F14 Selaginellaceae** *Es18.Selaginella myosorus* L **O.14. Hydropteridales** **F15 Salviniaceae** *Es19. Salvinia molesta* D.S.Mitchell	 Grh Hd	 Pléo Pléo	 Gc Gc

Legend: Biological Types (BT): Msph = Phanerophytes, Ch= Chamephytes, Th=Therophytes, Hc=Hemicryptophytes, Hd= Hydrophytes, Geophytes, Nanophanerophytes (NPh). Type of Diaspore **(TD)**: Ptéro= pterochore, Pogo= Pogochore, Sclero= Sclerochore, Desmo= Desmochore, Sarco= Sarcochore, Ballo= Ballochore, Baro= Barochore, Plèo=Plèochore. Phytogeographical Distribution **(PD)**: Cosm= cosmopolite, pan= pantropical, Aa = Afro-american, Pal= Paleotropicale, At=Afro-malgasy, Gc= Guineo-congolese, Congolese C= congolese Am =Afro-malgasy.

Table 1 shows the overall list of aquatic plants harvested from various prospecting sites, which includes 19 species divided into 15 families and 14 orders **into** two Phyllums, including Pteridophytes and Angiosperms.

Table 2. Comparison of the vegetation of the sites studied

Families/spesies	Sites of collection			
	Molondo	Mipongo	Japon	Kingabwa
Onagraceae				

1.*Ludwigia abyssinica A. Rich.*	+	+	+	+
2. *Ludwigia leptocarpa* (Nutt) Hara	+	+	-	+
. **Amaranthaceae**				
3. *Alternanthera sessilis* (L)DC	+	+	+	-
. **Convolvulaceae**				
4. *Ipomoea aquatica* Forsk	+	+	+	+
. **Nymphaeaceae**				
5. *Nymphaea lotus* L	+	-	-	-
Commelinaceae				
6. *Commelina diffusa* Burm.F	+	+	+	-
Pontederiaceae				
7. *Eichhornia crassipes* (Mart)	+	+	+	+
Araceae				
8. *Pistia stratiotes* L	+	+	+	+
9. *Colocasia esculenta* (L) Schott	+	-	-	-
Cyperaceae				
10. *Cyperus papirus* L	-	-	+	-
Poaceae				
11. *Echinochloa pyramidalis*(Lam)	+	+	+	+
12. *Leersia hexandra* (Sw)	+	-	-	-
Polygonaceae				
13. *Polygonum lanigerum*	+	+	+	-
Gisekiaceae				
14. *Gysekia pharnaceiodes* L.	-	+	+	-
Fabaceae				
15. *Aeschynomene fluitans* L.	+	-	-	-
16. *Aechinomum sensitiva* Swartz	-	+	+	-
Rubiaceae				
17. *Oldenlandia affinis* (Roem.&Schult.).	-	+	-	-
Selaginellaceae				
18. *Selaginella myosorus* (Sw.) Alston.	+	-	-	-
Salviniaceae				
19. *Salvinia molesta* D.S.Mitchell	+	+	+	+
Total	15	13	12	7

Legend: (+) presence; (-) absence

3.2. Study of ecological spectra

3.2.1. Raw spectra of biological types

The spectrum of biological types is given in figure 3 below.

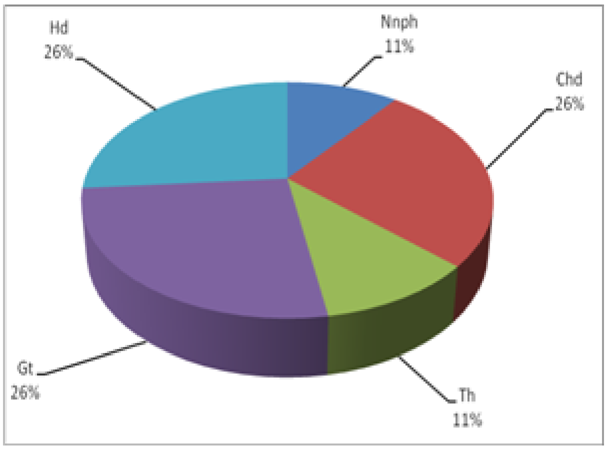

Figure 3: Raw spectrum of biological types.

This figure provides information on the strong dominance of Chaméphytes, Geophytes, and Hydrophytes, with a respective 26.3% each, followed by Nanophanerophytes and Therophytes with a low representation (11%).

Figure 4 gives the chorological distribution of different taxa inventoried.

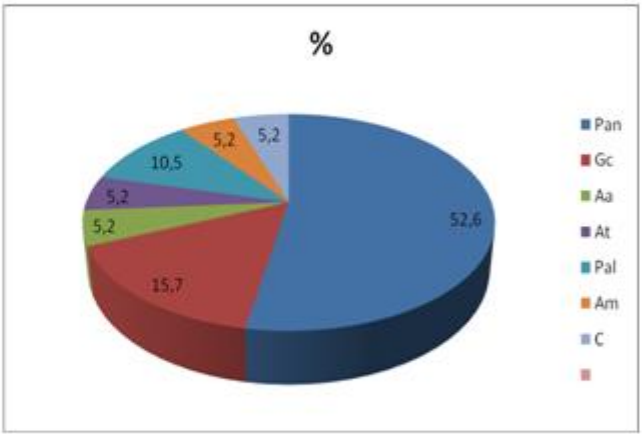

Figure 4: Raw spectrum of phytochoria distribution types.

Figure 4 revealed the strong dominance of Pantropical species (52.6%), Guineo-Congolese species (15.7%)**, and** Paleotropical (10.5%). The other phytochoria are poorly represented, with a respective 5.2% each.

The rough spectrum of the type distribution of the diaspores of the listed species is given in figure 5.

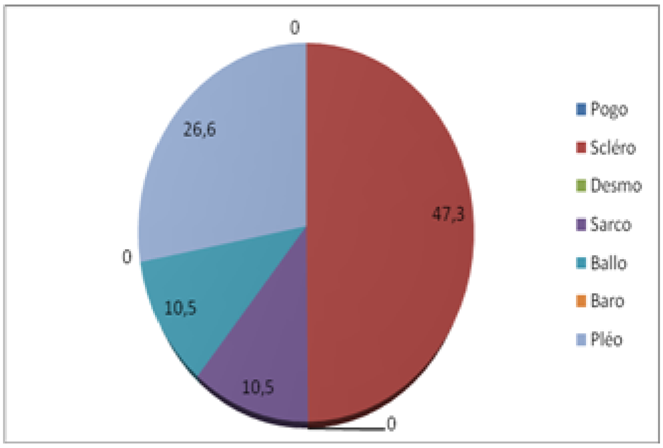

Figure 5: Raw spectrum of diaspore types

Figure 5 shows a clear predominance of sclerochore species (47.3%), followed by Pleochores (26.6%), while sarcochores and ballochores represent only 10.5 of the total florule studied. Note the absence of desmochorous species.

The two alien invasive species are listed in Table 3.

Table 3. Invasive alien species encountered at the three study sites

Invasive alien species	Observation
1 .*Echhornia crassipes* 2. *Echinochloa pyramidalis*	Very invasive: Formation of monospecific mats always in association with *E. pyramidalis*

Figures of different sites illustrating species invasions in Malebo Pool are listed below.

Figure 6: *Preairi monospecifique d' Echinochloa pyramidalis*
(Site of Mipongo)

Figure 7: invasion of two species *Eichhornia crassipes* et *Echinochloa pyramidalis* in Malebo Pool (Site of Kingabwa).

Figure 8: *Echinochloa pyramidalis* and *Eichhornia crassipes* site of Japon.

Figure 9: *Echhornia crassipes* and *Echinochloa pyramidalis* in site of Molondo

Figure 10: *Echinochloa pyramidalis* in the Malebo Pool

The study of invasive aquatic alien plants in the hydrographic network of the city of Kinshasa, in Pool Malebo, in the three islands (Molondo, Mipongo**, and** Japan), at the level of Kinkole, reveals 19 plant species, including 12 exotic species and 2 invasive aliens. These results show that the aquatic flora of Kinshasa is polluted by the presence of many exotic species (63.16%). This is explained by the fact that aquatic environments are often open, and hydrochory is one of the most effective modes of dispersal of diaspores. They are also reported by Mbale et al. [31] among the most frequent dominant invasive species in the pool malebo edition on the inventories of invasive exotic flora at Pool Malebo and other rivers, including the Lukaya and the Funa, which reveal Eichhornia crassipes and Echinochloa pyramidalis as invasive species. The results of this study also show that of the 19 plant species harvested in general, 12 species are exotic**, and** only 2 **exhibits** invasive behavior. As in Côte d'Ivoire, Eichhornia crassipes and Echinochloa pyramidalis are part of the procession of exotic species but also invasive alien species. The work of N'guessa and Pedia shows that the flora of Côte d'Ivoire contains 3853 plant species, including 240 species (6.2%) of exotic or introduced species. Of these, 20 species (8.3%) are invasive alien species. Ten species are found in the hydrographic network of Côte d'Ivoire. These **are** *Eichhornia crassipes*, *Echinochloa pyramidalis*, *Pistia stratiotes*, *Salvinia molesta*, *Nelumbo nucifera*, *Typha australis*, *Polygonum lanigenum var. africanum, Bacopa crenata, Hydrolea glabra,* and *Paspalum vaginatum* [32]. In Benin, the water hyacinth, discovered in 1977 on the Sô River, became ten years later the worst aquatic plant in the country. The population calls it "Togble", which means: "the country is in ruins". It is one of two invasive aquatic alien plants that have been reported in Benin: *Eichhornia crassipes* and *Pistia stratiotes* [33].

Conclusion and Suggestions

The floristic study of invasive exotic aquatic plants in Kinshasa is part of the work relating to the achievement of the Aichi objectives, Objectives 9 and 19 of the Nagoya Protocol 2010. The present study is a research interesting territory whose vegetation cover is increasingly subject to the impact of hydrological and anthropogenic parameters by the introduction of exotic species. Indeed, the anthropogenic activities of fishing, market gardening, and rice growing on the banks of the Congo River sometimes lead to the introduction of allocthonous species into the aquatic environment of the islands of the river. The inventory of the prospected flora reported the presence of 19 species including two Pteridophytes and 17 Angiosperms, divided into 19 families and 14 orders. This study reveals the presence of two invasive species in the environment: *Eichhornia crassipes* and *Echinochloa pyramidalis*. These two species deserve increased monitoring as they constitute major challenges for the navigability of rivers and the invasion of fishing sites, sometimes completely modifying the spawning grounds of fish. Ecological analysis revealed that this florule is mainly dominated by sclerochores and pleochores. The species listed in Kinshasa highlight the existence of a **disturbing** flora dominated by species with a very wide distribution, which, over time, have supplanted those of the Guinean base element, the disappearance of which in the prospected perimeter consecrates makes explicit anthropogenic regressive evolution. The Congo Basin is very large, and the Congo River has several tributaries susceptible to colonization by aquatic species. It is therefore recommended to broaden the field of prospecting in order to identify and list the exotic and/or invasive aquatic species of the aquatic flora of the Congo. 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, defenders of biodiversity, and political decision-makers are therefore invited to become aware of this aspect of the **problem** and to take appropriate measures to manage to protect the local aquatic flora and avoid the invasion by exotic species of the said flora.

Competing interest's disclaimer

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly **used** products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by **the personal** efforts of the authors.

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