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(Research Article)

Invasive aquatic flora and vegetation colonizing the surface of the Ouladine lagoon in Grand-Bassam (Southeast, Côte d'Ivoire)

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Abstract

The proliferation of invasive aquatic plants generally indicates poor waterway health. Ouladine lagoon, which has become the receptacle for a large part of the urban waterways of the city of Grand-Bassam, is currently overrun with vast clumps of aquatic vegetation. The objective of this study is therefore to improve knowledge of the invasive aquatic flora and vegetation colonizing the bed of Ouladine lagoon. To carry out this study, phytosociological surveys of aquatic vegetation were conducted at four stations on the surface of the lagoon. Floristic inventory identified nine species of invasive aquatic plants in Ouladine lagoon, the most invasive of which are: *Typha domingensis*, *Ipomoea aquatica*, *Paspalum vaginatum*, *Echinochloa pyramidalis*, and *Eichhornia crassipes*. An ascending hierarchical classification (AHC) combined with an analysis of indicator species using the IndVal method made it possible to distinguish five different groups of invasive aquatic plants. The proliferation of these invasive species reflects the pollution of lagoon waters. Indeed, it is becoming urgent to insist on the implementation of measures to combat the overproduction of biomass from these aquatic plants, ecological consequences of which can have socio-economic impacts on the lives of riverside populations.

Keywords: Invasive aquatic plant; Macrophyte; Plant groups; Ouladine lagoon; Côte d'Ivoire

1. Introduction

The invasion of waterways by aquatic plants is a global scourge [1]. This author also pointed out that in tropical countries around the world, there are now a multitude of harmful aquatic macrophyte species, causing ecological disturbances in invaded water bodies. [2, 3] mention, among other things, reduced light penetration, increased evapotranspiration and sedimentation rates, alteration of cycle of various nutrients, waterlogging, and drying out of lentic environments. In addition to these ecological consequences, there are numerous socio-economic impacts such as the deterioration of drinking water quality, the spread of waterborne diseases, disruption of fishing and irrigation activities, and hindrance to movement of goods and people [4, 5, 6]. In West Africa, the early 1980s marked the beginning of invasion of Côte d'Ivoire's inland waters by these invasive aquatic plants [7]. Over the past two decades, Ouladine lagoon, which receives huge quantities of urban wastewater from the city of Grand-Bassam, has been heavily invaded by vast clumps of aquatic vegetation. Like other lagoons around the world, which ecosystems are rich in biodiversity and widespread in coastal areas [8], Ouladine lagoon is a highly productive biological area, serving as a favorable habitat, spawning ground, and nursery for many animal species [9]. Today, the current state of health of this

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lagoon is becoming increasingly worrying, given the progressive encroachment of the water surface by invasive aquatic plants. Therefore, the need to take measures to combat these invasive plants should represent a priority for the public authorities. [4] noted that knowledge of floristic richness could promote better decision-making in preserving the integrity of an aquatic ecosystem. According to [10], any action to combat vegetation cluttering waterways requires a good knowledge of communities or groups of plant species that proliferate there. However, based on our current knowledge, there is a scarcity of recent and comprehensive data on the aquatic vegetation clogging the Ouladine coastal lagoon. Indeed, the main objective of this study is to improve knowledge of invasive aquatic flora and vegetation colonizing the surface of Ouladine lagoon. Specifically, it aims to: (1) analyze the invasive floristic richness of lagoon's water body and (2) characterize the invasive aquatic plant communities on the lagoon bed.

2. Methodology

2.1. Study area

Ouladine lagoon is a coastal wetland located along the Ivorian coastline on the Atlantic Ocean [11]. It connects to the ocean via the Grand-Bassam estuary, a town located in south-eastern Côte d'Ivoire. The Ouladine lagoon, extending along the entire southern part of Grand-Bassam, is located southeast of the city of Abidjan and southwest of the commune of Bonoua (Figure 1). It is an estuarine lagoon influenced by the flow of the Comoé River. It stretches from east to west over a length of 10 km and covers an area of 4.35 km^2 [12].

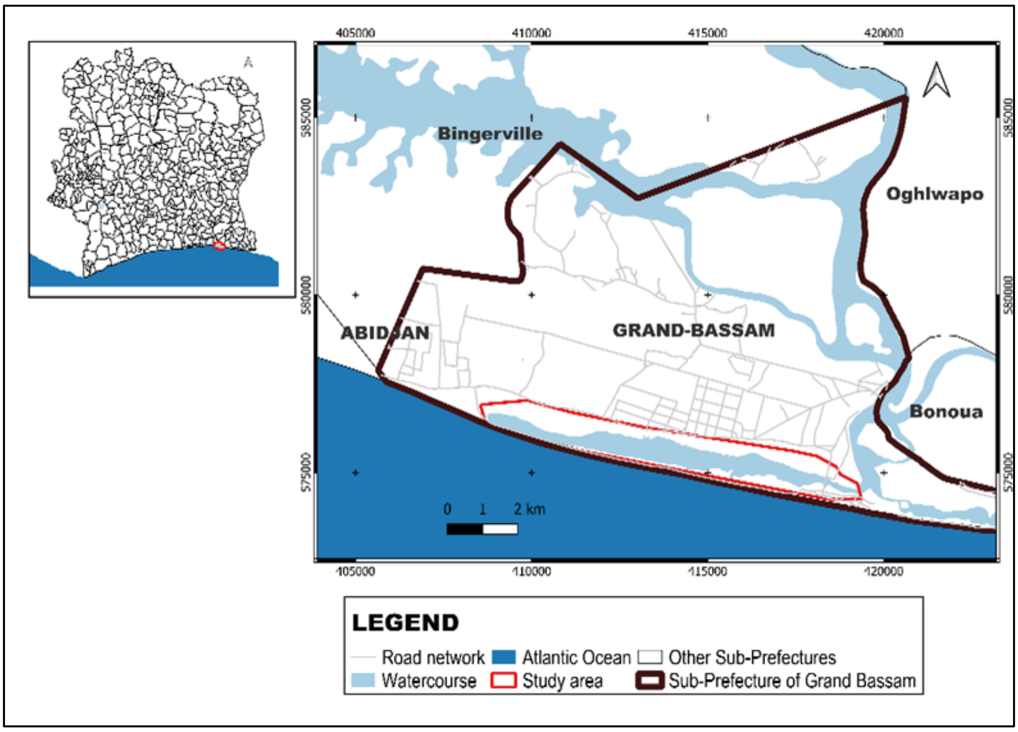


Figure 1 Geographical location of the Ouladine lagoon

2.2. Data collection

Four sites accessible along the Ouladine lagoon, whose surface is heavily overgrown with invasive macrophytes, were selected. These are: the mouth of the Comoé River (Site 1), the Victory Bridge (Site 2), the coconut groves (Site 3) and the village of Azuretti (Site 4). The floristic and vegetation inventories were carried out using the topographic transect method recommended by [13]. The transect, marked out by a rope graduated in metres, encountered plant species along its route and ran from the edge of the lagoon to the edge of the invasive plant clumps. Along the transect, 10 m^2 (5 m x 2 m) quadrats were set up. In the quadrats, all species present were recorded with their abundance-dominance coefficient according to the classic scale of [14] (Table 1). Three transects of varying lengths were carried out at each site, for a total of 12 transects. Abundance-dominance plots were carried out in 142 quadrats.

Table 1 Van der Maarel scale (1979)

AD	Définitions
1	1 individu
2	2 individus
3	Dr ≤ 5 %
4	5 < Dr ≤ 10 %
5	10 < Dr ≤ 15 %
6	15 < Dr ≤ 25 %
7	25 < Dr ≤ 50 %
8	50 < Dr ≤ 75 %
9	Dr > 75 %

Legend: AD = abundance-dominance coefficients 'Dr' represents the estimated coverage rate as a percentage of the survey area

2.3. Data analysis

Specific richness consisted of counting the number of species, genera and families across all four study sites. Each species inventoried was then assigned a biomorphological type in accordance with [15] classification, which distinguishes five groups of aquatic plants according to their growth form in the mud: (1) helophytes, described as aquatic plants with aerial vegetative organs; (2) rooted hydrophytes with organs floating on the surface; (3) rooted hydrophytes completely submerged; (4) free hydrophytes floating on the surface; (5) free hydrophytes completely submerged. The biological type of species was then determined using a classification based on water-related biological forms [16]. The following abbreviations were used in this study: Gr.Hy = Geophyte hydrophyte or rhizomatous hydrogeophyte; Gt.Hy = tuberous hydrogeophyte; Lnp Hy = lianescent hydrophyte belonging to the nanophanerophyte group; Hy.Th = hydrotherophyte; He.Ch = Helophyte chamephyte or Helochamephyte; H.Gr = Rhizomatous helogeophyte; He.Hc = Helohemicryptophyte; He.Lnp = Lianescent helophyte belonging to the nanophanerophytes; He.np = Helonanophanerophyte; He.Th = Helotherophyte.

2.4. Statistical data processing

An ascending hierarchical classification (AHC), carried out using R software version R-3.3.3, was used to determine the different plant groups colonising the surface of Ouladine lagoon. To determine the indicator species for each plant community, the IndVal method [17] was applied. For each group identified by the dendrograms, the indicator value or IV of all species found therein was calculated using IndVal 2.0 software [18]. Each discriminated group is named after the characteristic species with the highest indicator values.

3. Results

3.1. Richness and floristic composition

Nine species of invasive aquatic plants, divided into nine genera and distributed across eight families, have been inventoried on the surface of Ouladine lagoon. The most represented family is Poaceae, with two species. The other seven families each have one species. The sites have a specific richness ranging from five to nine species. Pont Victoire site is the richest with 9 species, 9 genera and 8 families. The sites at the mouth of the Comoé River and the coconut groves come second with 8 species each. The Azurretti village site is the poorest in terms of flora with 5 species, 5 genera and 4 families (Table 2). The plants inventoried are of three biomorphological types: 4 species of helophytes, 3 species of free-floating hydrophytes on the surface of the water body and 2 species of rooted hydrophytes. These species were grouped into five biological types: helonanophanerophytes, namely *Drepanocarpus lunatus* (L.f) G.Mey ; Rhizomatous helogeophyte : *Echinochloa pyramidalis* (Lam.) Hitch et Ch., *Paspalum vaginatum* SW et *Typha domingensis* (Pers.) steud. ; lhydrothérophyte : *Eichhornia crassipes* (Mart.) Solms-Lamb, *Pistia stratiotes* L and *Salvinia molesta* D.S.Mitchel ; lianescente hydrophytes belonging to the nanophanerophyte group, such as *Ipomoea aquatica* Forsk. and tuberous hydrogeophytes represented by *Nymphaea lotus* L. (Table 3).

Table 2 Flora richness of study sites

Sites	Mouth of the Comoé River	Victory Bridge	Coconut groves	Village of Azuretti
Specific richness	8	9	8	5
Number of genera	8	9	8	5
Number of families	8	8	7	4

Table 3 Biological characteristics of the invasive species inventoried

Species	Families	Biomorphological type	Biological types
Drepanocarpus lunatus	Papilionnaceae	Helophyte	He.np
Echinochloa pyramidalis	Poaceae	Helophyte	Hé.Gr
Eichhornia crassipes	Pontederiaceae	HLFS	Hy.Th
Ipomoea aquatica	Convolvulaceae	HEFS	Hy.Lnp
Nymphaea lotus	Nympheaceae	HEFS	Hy.Gt
Paspalum vaginatum	Poaceae	Helophyte	He.Gr
Pistia stratiotes	Araceae	HLFS	Hy.Th
Salvinia molesta	Salviniaceae	HLFS	Hy.Th
Typha domingensis	Typhaceae	Helophyte	He.Gr

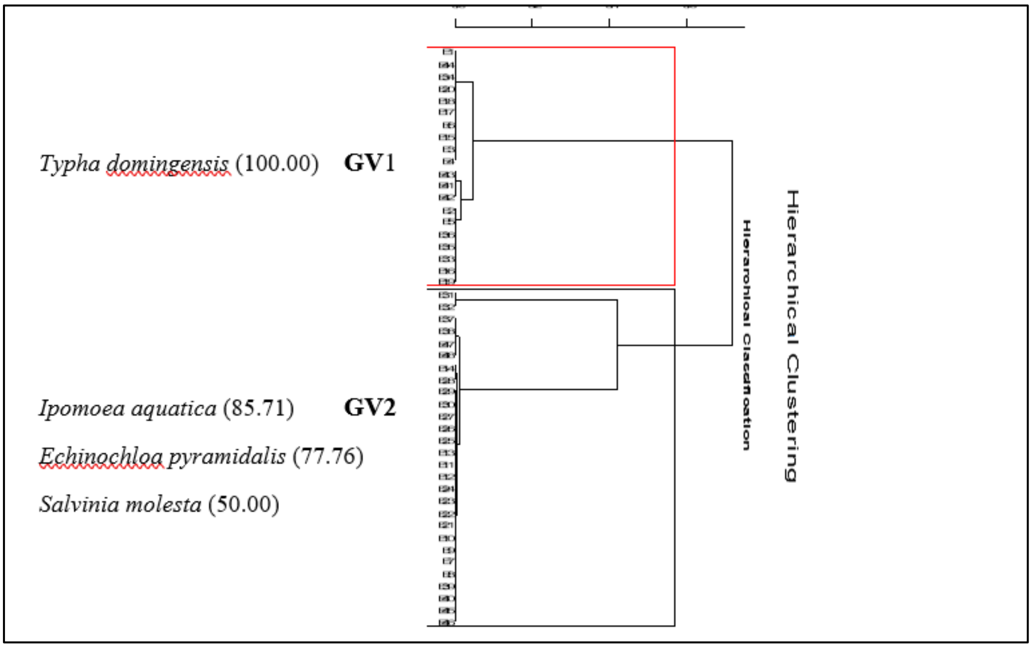
Legend: HLFS = Free-floating hydrophytes; HEFS = Rooted hydrophytes with floating organs; He.np = Helonanophanerophyte; Hé.Gr = Rhizomatous Helogeophyte; Hy.Th = Hydrotherophyte; Hy.Lnp = Nanophanerophyte Lianescent Hydrophyte; Hy.Gt = Tuberous Hydrogeophyte

3.2. Characterisation of plant groups cluttering the surface of the water body

3.2.1. Plant groups at the mouth of the Comoé River

Two plant groups were distinguished (Figure 2): *Typha domingensis* groups. It is dominated by the helophyte *Typha domingensis*, which forms reed beds along the edges of the Ouladine lagoon. This tall grassy vegetation also clutters the centre of the water body in the vicinity of the Victoire bridge up to the mouth of the Comoé River. This species has a very significant maximum indicator value of around 100.

Ipomoea aquatica and *Echinochloa pyramidalis* groups, this group is characterised by a high abundance of *Ipomoea aquatica*. This species of strict, fixed and liana-like hydrophyte lives in association with the helophyte species *Echinochloa pyramidalis*, which forms river and lagoon reed beds (Figure 3).



GV: Plant groups. The numbers in parentheses correspond to the indicator values for the species

Figure 2 Dendrogram of plant groups at the mouth of the Comoé River with some characteristic species

Figure 3 View of a reed bed of *Echinochloa pyramidalis* mixed with a few plants of Ipomoea aquatica, in the center of Ouladine lagoon in Grand-Bassam

Sometimes, this species is detached from the banks by the water current and associates with the islands of *Ipomoea aquatica*. *Echinochloa pyramidalis* forms a monospecific population in places on the edges of the lagoon.

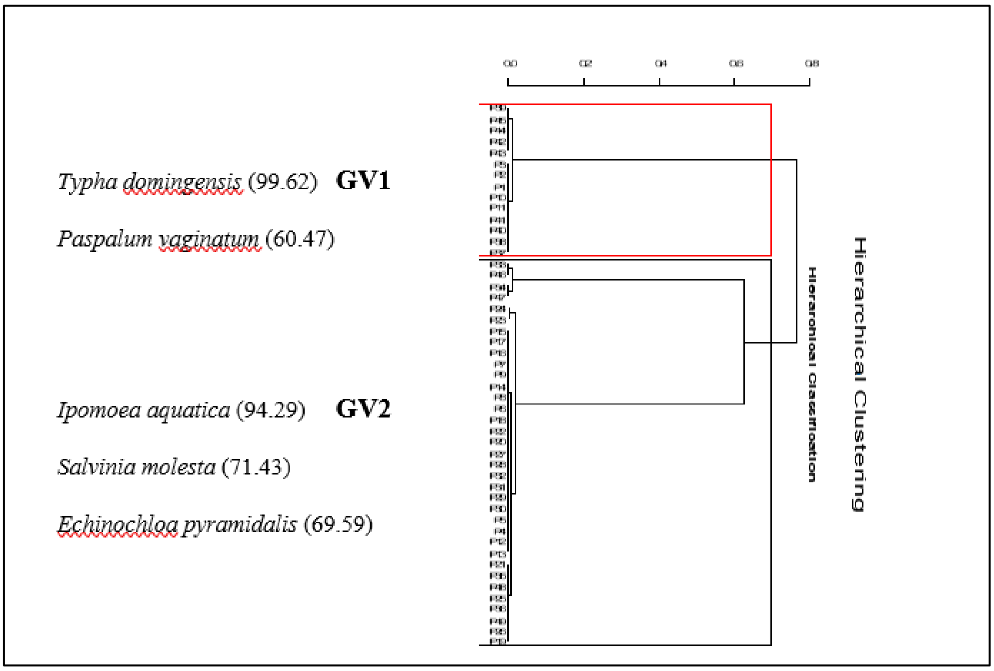
3.2.2. Plant groups in the Victory Bridge site

Two plant communities were also identified (Figure 4): *Typha domingensis* and *Paspalum vaginatum* groups. This community consists of a large herbaceous carpet characterised by *Typha domingensis* and *Paspalum vaginatum*. It makes up the vegetation of the coastal herbaceous savannahs. This group has currently invaded the centre of the Ouladine lagoon in Grand-Bassam (Figure 5).

Ipomoea aquatica and *Salvinia molesta* groups. This groups can be observed along the edge of the water body almost all along this lagoon. It is notable for *Salvinia molesta*, an aquatic fern that forms dense mats that float freely intertwined in the *Ipomoea* population.

3.2.3. Plant groups at the Cocoteraies site

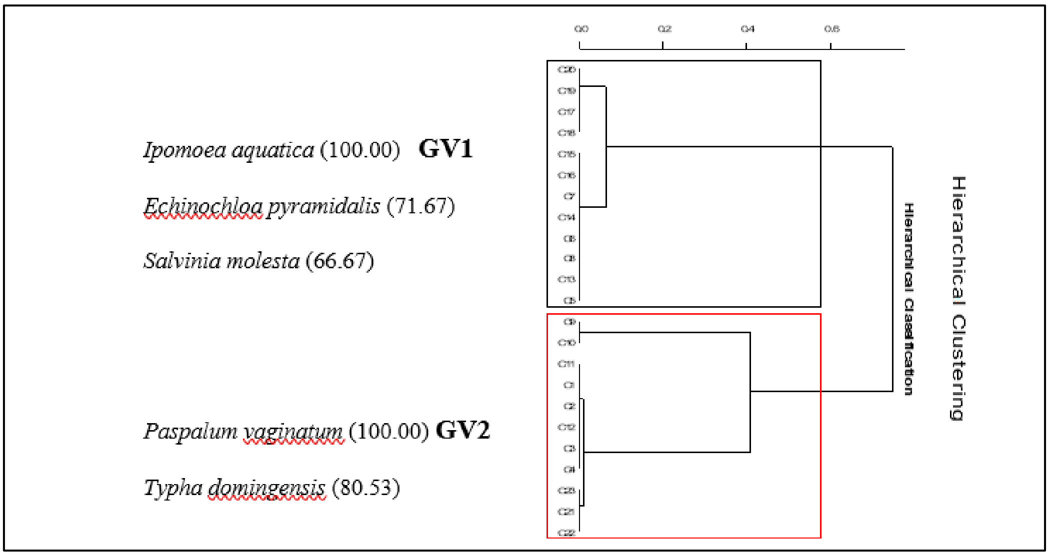
Two groups were also discriminated (Figure 6): The groups with *Ipomoea aquatica* and



GV: Plant groups. The numbers in parentheses correspond to the indicator values for the species

Figure 4 Dendrogram of plant groups at the Victory Bridge with some characteristic species

Figure 5 View *Paspalum vaginatum* and *Typha domingensis* plant groups cluttering the Ouladine lagoon water body



GV: Plant groups. The numbers in parentheses correspond to the indicator values for the species

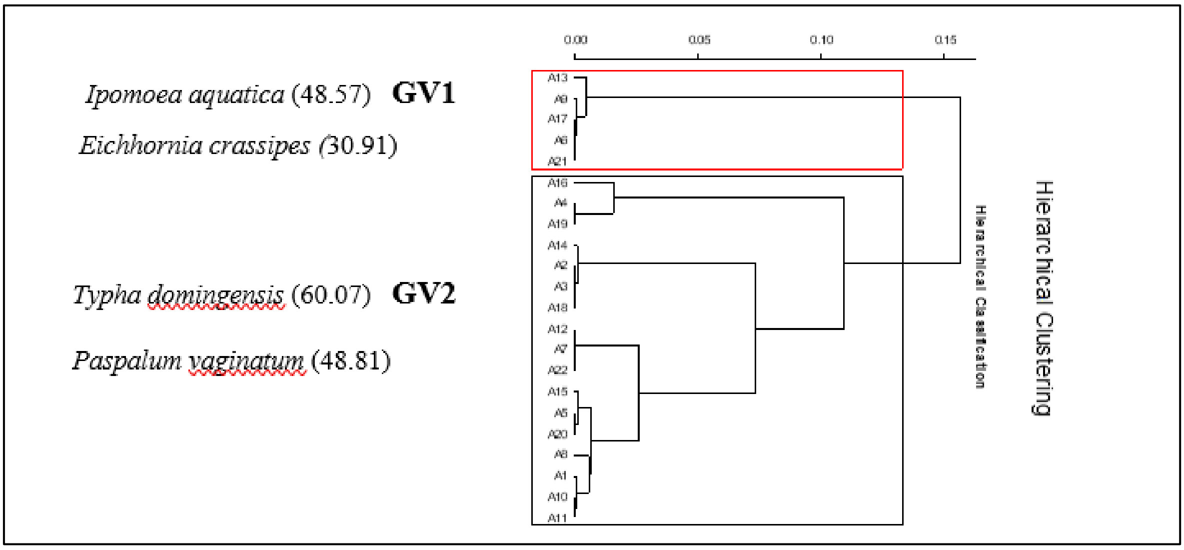
Figure 6 Dendrogram of plant groups at the coconut groves with some characteristic species

Echinochloa pyramidalis. This is the same plant group observed at the mouth of the Comoé River. Here, *Ipomoea aquatica* is highly indicative of this group, with a maximum indicator value of around 100.

Typha domingensis and *Paspalum vaginatum* groups. This is the same plant group observed at the Victory Bridge site. *Typha dominates* the vegetation thanks to its voluminous rhizome and tall stature, which give it a competitive advantage. However, across all quadrats, *Paspalum vaginatum* has a maximum indicator value of around 100.

3.2.4. Plant groups at the Azurretti village site

Two groups were also identified (Figure 7): *Eichhornia crassipes* and *Ipomoea aquatica* groups. It is characterised by two species of strict hydrophytes, including *Eichhornia crassipes*, which floats freely on the surface of the water. *Ipomoea aquatica* is a rooted, liana-like plant whose vegetative system floats on the surface. This plant community is less extensive.



GV: Plant groups. The numbers in parentheses correspond to the indicator values for the species

Figure 7 Dendrogram of plant groups at the Village of Azuretti with some characteristic species

Typha domingensis and *Paspalum vaginatum* groups. This is the same plant community found at the of the Victoire bridge and the coconut groves. In Azurretti, it grows in the shallow areas of the Ouladine lagoon, where fishermen use this hydrophytic vegetation cluttering the surface of the water to trap fish.

4. Discussion

With nine species recorded, the invasive aquatic flora of the Ouladine lagoon has a low species richness. This value is comparable to the ten invasive species counted by [4] in Daloa, Côte d'Ivoire. However, these figures are significantly lower than those of the census carried out by [17], which identified nearly 142 species of aquatic plants in the wetlands of south-eastern Côte d'Ivoire. This can be explained by the difference in scale and study objectives. [17] conducted an inventory of all aquatic flora (invasive and non-invasive) of a region (rivers, lakes, lagoons, marshes, shallows), while our study focuses on a specific site (a lagoon) and concentrates solely on invasive species. Poaceae is the most represented family. Our results corroborate those of [19] in the waters of the Kondi River in the city of Douala, Cameroon.

The Ouladine lagoon bed has little diversity in invasive aquatic plants. Floristic variation was observed from one site to another. The Victory Bridge is the richest in invasive plants. This result can be explained by the fact that this area of the Ouladine lagoon is subject to significant pollution, receiving enormous quantities of urban water from the city of Grand-Bassam. According to several authors, polluted waters rich in nutrients and sediments favour the establishment and proliferation of invasive aquatic plants [4, 5, 19, 20]. This assertion is justified by the dominance of helophyte species in the centre of Ouladine lagoon, whereas helophytes are generally rooted along the banks at the edge of the minor bed. In fact, these helophytes have established themselves in the centre of the lagoon bed on sedimentary deposits carried by polluted runoff from the adjacent banks.

Furthermore, this study focused on identifying the plant communities that colonise the surface of the Ouladine lagoon, because according to [21], knowledge of plant groups constitutes a fundamental source of important basic data for the conservation, development and sustainable management of natural ecosystems. Thus, the hydrophytic plant groups colonising the lagoon water surface are characterised by species with a wide ecological range that find favourable conditions there. These are: *Typha domingensis*, *Ipomoea aquatica*, *Echinochloa pyramidalis, Paspalum vaginatum* et *Echhornia crassipes*. The monospecific group of *Typha domingensis* forms a large reed bed on the edge of the Ouladine lagoon in shallow areas. As lagoons are brackish water ecosystems, they remain favourable habitats for the development of *Typha domingensis* once introduced into the environment, as [22] demonstrated that species of the genus *Typha* are moderately salt-tolerant. According to these authors, the growth of this plant would decrease significantly if the salinity level of water bodies is below 3 to 5 ppt, and mortality occurs between 10 and 25 ppt. [5] observed large beds of *Typha domingensis* covering a large area in the beds of numerous channels in Mali and Niger. Indeed, [23] showed that after germination, *Typha domingensis* multiplies by rhizomes over areas of up to 100 m^2 within two years. *Typha* domingensis has associated locally with *Paspalum vaginatum* to form the phytosociological group *Paspalum vaginatum* and *Typha domingensis,* which is very common on the surface of Ouladine lagoon. *Paspalum vaginatum* is a species that is mainly found in humid and salty coastal environments, such as rice field dykes, mangroves influenced by the tides, coastal marshes and deltas [23]. *Echinochloa pyramidalis* and *Ipomoea aquatica* groups has heavily covered the bed of the lagoon at the mouth of Comoé River, which flows into the Atlantic Ocean via the Grau de Grand-Bassam. It forms large grassy rafts in moderately deep waters and is therefore a serious concern in the Ouladine lagoon, as the *Echinochloa pyramidalis* grass species has reached heights of over two metres in some places. In Cameroon, this species characterises the aquatic macrophytic vegetation of the Kambo River in Douala in many places [20]. Its proliferation in the waterways of south-eastern Côte d'Ivoire is progressing at an alarming rate [17]. *Echinochloa pyramidalis* is strongly associated with *Ipomoea aquatica* in the Ouladine lagoon bed. The latter liana species prefers open environments and constitutes a significant biomass and vegetation cover that can alter water currents [22]. *Ipomoea aquatica* grows in certain areas alongside *Eichhornia crassipes* to form the *Eichhornia crassipes* and *Ipomoea aquatica* group. In Côte d'Ivoire, *Eichhornia crassipes*, commonly known as water hyacinth, is one of the three most invasive aquatic plants. The floating plants of the water hyacinth, which grow upstream of the Comoé River, are carried during the flood season towards the estuary, where they are driven by the wind and current towards the Ouladine lagoon near this estuary. [24] also observed the invasion of the artificial Assinie canal, located near this same coastal lagoon, by water hyacinth. As a result of the continuous discharge of urban wastewater from Grand-Bassam into the Ouladine lagoon, all phytosociological groups continue to multiply. Therefore, particular attention must be paid to the excessive enrichment of lagoon waters with nutrients, which is believed to be the cause of the proliferation of plant groups.

5. Conclusion

This study characterised the invasive aquatic flora and vegetation colonising the surface of Ouladine lagoon. Nine species of invasive aquatic plants were identified across the four sites surveyed along the lagoon. Five plant groups were distinguished within this invasive aquatic vegetation. The polluted waters of the Ouladine lagoon, which are highly enriched in nutrients, provide favourable conditions for the multiplication and proliferation of all invasive plants. As a result, all plant groups clutter the lagoon bed and contribute to the anoxia of aquatic fauna habitats. In view of this ecological change, which could lead to the decline and loss of ecosystem services in the Ouladine lagoon, combating the proliferation of invasive aquatic plants on the surface of the water body should be a priority objective for public authorities.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors have not declared any conflict of interest.

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