BIOTIC AND ABIOTIC FACTORS PROMOTING THE DEVELOPMENT AND PROLIFERATION OF WATER HYACINTH (*Eichhornia crassipes* (Mart.) Solms-Laub.) IN THE WOURI BASIN (Douala-Cameroon) AND ENVIRONS, WITH IMPLICATIONS FOR ITS CONTROL

THESIS

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Frontispiece

Water hyacinth during high tide (A). One of the tributaries (water course) of the Wouri Basin at Petit Bonanjo invaded by water hyacinth (B).

Water hyacinth mat during the rainy season (August) at Forêt Bar (A). Water hyacinth mat blocking the river at Fiko (Abo’o District) (B).

Abstract

The Wouri River, situated in the Wouri Basin, is one of the main rivers of the Littoral Region in the city of Douala in Cameroon. It is a source of income and food for the population living around these areas. Since the 1990s, the fishing, transportation, irrigation and sand extraction activities have been impeded by the invasion of aquatic plants, specifically water hyacinth (*Eichhornia crassipes* [Mart.] Solms-Laubach: Pontederiaceae). Introduced in 1997 to the shore of Lake Chad, water hyacinth has invaded almost 114 ha of the Wouri Basin. Furthermore, Douala, the economic capital of the Cameroon and location for more than 70% of the country's industries, uses the Wouri River and its tributaries to deposit its effluent and waste, which has worsened the problem of water hyacinth.

This thesis examined the ecological and socio-economic impacts of water hyacinth in the Wouri Basin and its possible control.

An increase in the nutrients in the water has provided water hyacinth with appropriate conditions for its fast growth during both the rainy and dry seasons. The availability of nutrients in these areas is enhanced by the constant, daily tidal fluctuation of water, providing enough water to the plant for easy nutrient uptake. A survey of the impacts of water hyacinth on aquatic plant communities in the Wouri Basin showed that this plant is able to out-compete native species. Assessment of the impact of water hyacinth on the abundance and diversity of plant communities indicated that at some invaded sites, 65% of the vegetation consisted of water hyacinth. Species found in association with water hyacinth with a high level of abundance-dominance were *Pistia stratiotes* L. (Araceae) (another invader), *Commelina benghalensis* L. (Commelinaceae) and *Echinochloa pyramidalis* (Lam.) Hitchc. & Chase (Poaceae). This component of the study also showed that habitats rich in water hyacinth were poor in diversity, while habitats without water hyacinth were rich in diversity, thus raising awareness of the importance of monitoring invasive aquatic weeds along the Wouri Basin, and of implementing correct control management of all invasive aquatic weeds.

Communities living along the invaded rivers are well aware of the range of problems caused by the weed; because as the rivers and water bodies used for fishing, transportation, and sand extraction are progressively invaded by the weed, the riparian population is the first to feel the impact. The impact on people has been noticeable, with an increase in diseases, such as malaria,

cholera, diarrhoea, typhoid, filariasis, schistosomiasis, scabies and yellow fever increasing the need for a medicine and hospitalization. Economic losses due to the management of invasive aquatic weeds were recorded, and the Ministry of Environment spent an estimated US$1 200 000 between 2010 and 2015 to manage this scourge. In 2016, an amount of US$160 000 was transferred to these regions to manage invasive aquatic weeds, especially water hyacinth, although manual clearing is still the only method used to control this weed.

Isolation of fungi from diseased water hyacinth plants in the Wouri Basin revealed several fungal species, most of which have been isolated from water hyacinth species in water bodies elsewhere, which showed a higher diversity during the dry season than during the rainy season. These fungi included *Acremonium zonatum* (Sawada). W. Gams (Hypocreaceae), *Alternaria eichhorniae* Nag Raj & Ponnappa (Pleosporaceae), *Chaetomium* sp., *Colletotrichum* sp., *Curvularia pallescens* Boedjin (Pleosporaceae), *Curvalaria* sp., *Epicoccum nigrum* Link (Pleosporaceae), *Fusarium* sp., *Pithomyces chartarum (*Berk. & M. A. Curtis) M. B. Ellis (Montagnulaceae), to a lesser extent *Myrothecium roridum* Tode ex Fr. (Incertae sedis) and *Nigrospora* sp.

Although never released in Cameroon, arthropod biological control agents (*Neochetina eichhorniae* Warner (Coleoptera, Curculionidae) and *N. bruchi* Hustache (Coleoptera, Curculionidae)) were present, but their populations were relatively low. The slow spread of the insect population was explained by several factors, among them the tidal fluctuation of water, which has an impact on the population growth of the weevils. Whilst adults may be able to survive tidal fluctuations, larvae are severely impacted by them, contributing to the slow success of biological control. In this study, a significant increase in pathogen-induced disease severity and incidence was noted when *Neochetina eichhorniae* weevils were present, possibly because larvae tunnelling on the petiole created openings for the penetration of fungal spores.

This study highlights the negative impacts of water hyacinth, on the environment, people, and thus economy of Cameroon. The presence of biological control agents and pathogens offers Cameroon the possibility of initiating and properly implementing the biological control option, or an integrated management solution, to manage water hyacinth in the Wouri Basin, and in the rest of Cameroon.

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A walk of thanksgiving

I walk in thanksgiving
For the sunlit years of childhood
For tall trees and dewy morning grass
For warm winds and singing birds and yellow flower cups
For laughter and discovery and the gift of wonder …
And because I walk in thanksgiving, I walk in belief.

I walk in thanksgiving
For the years of growing awareness of life
Of a world peopled with life and alive with people
Of my own self as one among many selves
Fashioning myself through reaching out and up;
For the experience of growth through uncertainty,
The risk of life, of love, of liberty …
And because I walk in thanksgiving, I walk in trust.

I walk in thanksgiving
For friendship and insight and the gift of prayer
For windy nights and sun split waves
For the splendour of autumn on rocky peaks gold on green,
And flame against blue,
For music and balloons and the song of the world
For the intensity of life, for challenge and delight …
And because I walk in thanksgiving, I walk in joy.

I walk in thanksgiving
For life that comes, not as a whole, but in little pieces called people;
For tenderness and strength, for gentleness and warmth
For weakness and pain, for anguish and ambiguity
For laughter and courage and the gift of friends
For the risk of life and the risk of God …
And because I walk in thanksgiving, I walk in love.

I walk in thanksgiving for faith and hope and joy and love
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1 Chapter 1: General introduction

1.1 Introduction

Aquatic ecosystems are considered to be an integral part of human existence. Their economic importance is highlighted by use of water for agricultural purposes (irrigation), their role as an important source of food (fishing) and their use for waste water, sewage treatment and hydropower production (Gallina 2012). Lakes are freshwater bodies highly valued for recreational activities, providing drinking water and sustaining natural ecosystems that are home to many species. These habitats are biologically very productive, and people derive various benefits from them for their livelihood. They provide a variety of fish on which more than a billion people rely as their main or only source of animal protein (De Poorter *et al.* n.d.). They are also favourable sites for recreational activities, tourism and research.

Within freshwater ecosystems, macrophytes are a diverse conglomerate of macroscopic vascular plants that include some relatively "large plants" living either in, on, or at the periphery of freshwaters (Sculthorpe 1967). According to Cook (2004), they can be define as the "plants whose photosynthetically active parts are permanently or, at least, for several weeks or months each year partly or wholly submerged in water or which float on the surface of water". These aquatic plants include stoneworts, liverworts, quillworts, ferns, mosses and flowering plants, as well as large trees which grow in water and wetlands (Cook 2004) and they can be loosely divided according to their endemism or growth forms.

According to their growth habit, the plants can be divided into three groups:

1) Those which are totally submerged;
2) Those with vegetative parts totally submerged, and flowers emerging above the water surface;
3) Plants with leaves and/or stems floating on but not arising above the water (epihydates).

According to their growth form, plants can be divided and four main groups with one sub group per group:

1. plants not physiologically bound to open water but tolerating longer periods (weeks or months) of submergence;

1.1) plants physiologically bound to open water with at least part of the generative cycle taking place submerged in or floating on water;

2. plants attached to but not penetrating a solid substrate, as in the Hydrostachyaceae, Podostemaceae and some Bryophytina;

2.1) plants with parts penetrating a substrate or lying totally free, submerged in or floating on the surface of the water;

3. plants with the juvenile phase submerged in or floating on water and the adult (flowering) phase terrestrial;

3.1) plants developing flowers while at least partly submerged in or floating on water;

4. plants with all photosynthetic vegetative parts submerged;

4.1) plants with at least some photosynthetic vegetative parts in contact with air;

5. plants occupying the zone between the bottom and the lower surface of the water;

5.1) plants rooted in the surface;

6. leaves borne in a terminal or basal rosette;

6.1) leaves arranged along elongated stems;

7. plants free-floating on the surface of water, usually not attached to or penetrating the substrate;

7.1) plants with roots or modified shoots penetrating the substrate;

8. leaves and/or stems floating on but not arising above the water surface;

8.1) leaves and/or stems emerging above the water surface.

Plants play an important role in the aquatic environment. They provide food and shelter for other plants and animals, cover for micro- and macro-fauna that form part of the food chain, shade and shelter for small fish and fingerlings of game fish; they improve dissolved oxygen levels, cycle nutrients and reduce turbidity (Sculthorpe 1967). Fish, in particular, are vitally interdependent on aquatic plants (Petr 2000) and although invertebrates consume little macrophyte tissue directly, plants can provide suitable attachment sites and protection from predators and wave action (Lana & Guiss 1992). In return, herbivory by birds and other fauna can contribute to a significant reduction in aquatic macrophytes biomass (Van Donk & Otte 1996). Duarte *et al.* (1986) found that the composition of aquatic flora influences the phytoplankton, zooplankton and invertebrate communities, and therefore has a bearing on the abundance and composition of fish communities.

Unfortunately, most aquatic habitats have been severely threatened by human activity such as pollution or eutrophication, over-exploitation, habitat destruction, conflict of uses and by natural phenomena owing to climate change. In 2008, a technical report of the Intergovernmental Panel on Climate Change (IPCC) clearly stated how urgent and necessary it was to understand the effect of climate change on lakes (Bates *et al.* 2008).

In addition to all these threats to aquatic ecosystems, there is the phenomenon of biological invasion. Some plants, when transported to non-endemic areas will undergo rapid growth to out-compete native plants and become weeds. Such weeds are problematic and cause environmental and socio-economic problems (Mailu 2001) by disrupting the equilibrium of these ecosystems (Williams & Hecky 2005).

1.2 Invasive or Alien species

Historically, man has introduced exotic species for many reasons: initially, to develop agriculture, livestock, for hunting or fishing; secondly, for ornamental or domestic use. Globalization has greatly increased the distribution ranges of many species, both intentionally or accidentally, so that the problem of biological invasion is a growing concern (Gargominy *et al.* 1996; Kirchner & Soubeyran 2007).

In literature, various terms, such as alien or invasive, have been used to describe these species. Several synonyms are used to cite alien species: exotic, introduced, non-indigenous, undesirable and non-native species (Hytec & Mary 2010). So, alien species include those introduced and present in areas beyond their known historical range. This includes introductions from other continents, bioregions and those not native to the local geographic region (Melvin 1999; Richarson *et al.* 2000). Invasive species however, are those alien species that invade habitats and displace other species through rapid growth and spread. Invasive species are easily propagated asexually by root or stem fragments and / or mature rapidly, are typically prolific seed producers and have high seed germination rates (Auld *et al.* 1987). Invasive species have also been referred to as a form of biological pollution because they can upset the equilibrium between native species that has formed slowly over millennia within natural ecosystems (Williams & Hecky 2005). Unlike alien species, native species (indigenous) develop in their natural area of distribution, they disperse independently without human intervention (Hytec & Mary 2010) and their spread is moderate.

Invasive species can rapidly out-compete native species and dominate the ecosystem, consequently reducing biodiversity by their exponential proliferation, depriving in return the native species of space, nutrients and moisture, thus modifying the entire structure and functioning of the ecosystems (McNeely 2000). Ecosystem processes may change as a result of invasive species. Native ecosystems develop under and adapt to particular abiotic factors and ecosystem processes such as rates of nutrient cycling, rainfall patterns and fire regimes (Williams & Hecky 2005). The presence of alien species can alter these processes, which has a knock-on effect on the ecosystem as a whole (Flack & Benton 1998). Indeed, the modified ecosystem or flora deprives native animals of food and shelter and native plants or organisms of suitable conditions for their development. The exotics may also bring with them new pests and pathogens, or allergens and, in some cases, they can hybridise with native species (CSIR 2004).

1.2.1 Process of biological invasion

Several successive steps characterize invasion of an environment by invasive species. Although Blackburn *et al.* (2011) identified and proposed seven barriers in their unified framework for invasion biology, the four main phases described by Williamson (1996) and Richarson *et al.* (2000) were considered this work. These phases include: the introduction into a new ecosystem, establishment, naturalization, and ultimately the spread of the invasive species.

1.2.1.1 Introduction

The introduction of species into a new environment is achieved by propagules (including seeds) or individual plants. This happens through intentional or accidental anthropic actions (Hytec & Mary 2010). Horticulture is often pointed to as responsible for these introductions.

1.2.1.2 Establishment

The establishment of species depends on several intrinsic and extrinsic factors related to environmental conditions (Hytec & Mary 2010). The success of a new species in a new area is determined firstly by the abiotic characteristics of the medium (temperature, salinity, pH, clarity or turbidity, and water flow) and secondly by the ability of the species to adapt to the environment. Biotic factors (presence of predators, preys or competitors) also influence success or failure (Hytec & Mary 2010).

1.2.1.3 Naturalization

Although from two different authors and years, a naturalization process implies the viability of a population to sustain its own grown. Therefore, as described by Richardson *et al.* (2000) to be considered as naturalized, adult individuals of the new population should be able to maintain a long-term viable population without the contribution of new propagules or individual plants and without additional human intervention while for Blackburn *et al. (*2011) naturalization is achieved when a self-sustaining population is maintained over a period of time corresponding to multiple generations.

1.2.1.4 Spread

When all previous conditions (introduction, establishment, and naturalisation) are met, the non-native species that have accommodated to the new environment will be able to proliferate. The spread of alien species leading to invasion depends on biological characteristics such as capacity for growth, survival, rate, means of reproduction and environmental barriers (Hytec &

Mary 2010; Blackburn *et al.* 2011). Once bariers to dispersal are overcome, naturalized species will spread into new locations where individuals must survive and reproduce (Blackburn *et al.* 2011). As stated by Blackburn *et al.* (2011), "the more an alien spreads, the more dissimilar from the point of introduction the environment at these locations will be".

1.2.2 Potential for species to become invasive

Many studies have determined the ability of species to invade a new environment. Among these studies, Goudart (2007) noticed that the majority of invasive species can be distinguished by certain characteristic biological features such as:

- vegetative and / or asexual reproduction;
- high adaptability to environmental conditions including tolerance with reference to several environmental factors (temperature, salinity, nutrients, pollutants);
- significant genetic variability;
- large capacity to exploit resources: low specialization, high growth rates, consumption efficacy;
- greater competitiveness than other species in the same environment;

Given that invasive alien species possess a high adaptability to develop in a wide range of environments, disturbances like deforestation, fire, urban sprawl promote the establishment and development of alien species which easily compete the native species.

1.3 Impacts of biological invasion

The International Union for Conservation of Nature (IUCN) now considers biological invasions as one of the main threats to biodiversity and ecosystem integrity. According to the red list established by IUCN, invasive species are now considered the third most important factor threatening world biodiversity, after destruction of habitats and over-exploitation of species (Kirchner & Soubeyran 2007). Indeed, the United States Endangered Species Act estimated that alien and invasive species are implicated in 42% of the species listed as endangered or threatened (Melvin 1999). In the ecological, economic and health contexts, invasive alien species are one of the most significant drivers of environmental change worldwide.

From the ecological point of view, invasive alien species modify the structure and biocenosis composition of ecosystems and interfere with indigenous species, through competition and/or predation (Hytec & Mary 2010). The effect of this competition and predation may eventually lead to the disappearance or extinction of some native or endemic species (Kirchner & Soubeyran 2007). Under such conditions, the reduction of species richness and diversity can reach 90% (Hejda *et al.* 2009).

Aquatic invasive alien species generally cause significant financial losses wherever they are introduced. They interfere with the utilization of natural resources such as fishing, causing significant losses also to agricultural production and impacting food security which is a major concern for many African governments (MacDonald *et al.* 2003).

Finally from a human health perspective, invasive alien species can contribute to increased rates and severity of natural disasters, illness and loss of life (Hytec & Mary 2010). The effects of invasive alien species are, in most cases irreversible unless successful biological control can be implemented.

1.4 Factors exacerbating biological invasion

The main factors exacerbating biological invasion are climate change, travel and international exchange. Changes in climate and environmental factors may also enable existing introduced species to become invasive (Mooney & Hofgaard 1999). Climate change affects the frequency and intensity of extreme climatic events, which may have the greatest influence on invasive species by disturbing ecosystems and thus providing them with increased opportunities for establishment, dispersal and growth (McNeely *et al.* 2001). Travel by ship, vehicle, boats, car, trains or planes or international exchange by ships and containerized cargo, people and their belongings can facilitate the dissemination of invasive species. These different media may be ideal shelters for alien species, micro-organisms, reptiles and mammals. For example, the Asian longhorned beetle (*Anoplophora gabripensis* Motschulsky), the emerald ash borer (*Agrilus planipensis* Fairmaire) and the brown spruce long-horn beetle (*Tetropium fuscum* Fabricius) are alleged to have arrived in North America in packing material from Asia (Keiran & Allen 2004).

1.5 Invasive species in Cameroon

As a result of the country's geographic position and climatic variations, Cameroon is endowed with rich biodiversity in both variety and quantity (UNEP/MINEF 1997; GEF 2008). In floral biodiversity, Cameroon is second in Central Africa and fourth in Africa, while she ranks fifth in faunal richness in Africa (Anonymous 2008). The country is home to 84% of known African primates, 68% of African passerine birds, 66% of African butterflies and 9 050 plants (Onana 2008) with 160 of them being endemic (WCMC 1994). Most African ecosystems are represented in Cameroon, and with its high proportion of Guinea-Congolean rainforest, the country is therefore an important focal point for conservation in Africa (Anonymous 2008). Plants and animal species in Cameroon are particular interesting because of their abundance and diversity of adaptation, endemism and new discoveries. However, Cameroon, like many countries worldwide, has not escaped the introduction of invasive species. Ecological conditions have contributed to the survival of new plant and animal species which have been and are introduced as exotics in the fields of agriculture, forestry, horticulture, arboriculture, animal husbandry and pisciculture by ships, planes, wind or water and people (Anonymous 2008).

Particularly pasture lands, mangrove habitats, freshwater and farmlands are facing the challenge of invasive alien species. These invasion include *Striga* ((Wild.) Benth. Orobranchaceae) species parasiting cereals and legumes in the northern part of the country, *Nipa* palm (*Nipa fruticans* (Wurmb) Arecacea) in mangrove habitats, as well as *Pteridium* (L.) Kuhn, Dennstaedtiaceae, *Chromolaena odorata* (L.) King and Robinson (Asteraceae), *Mimosa* spp. L. (Mimosoideae), *Eichhornia crassipes* [Mart.] Solms-Laubach (Pontederiaceae) water hyacinth and *Nypa* species.

According to the data provided by the Global Invasive Species (GIS) (http://www.issg.org/database/species/search.asp?st=sss&sn=&rn=Cameroon&ri=19348&hci=-

1&ei=-1&fr=1&sts=&lang=EN) and Anonymous (2008), 57 species are invasive in Cameroon among which 23 are alien species or taxa, 27 are native species and seven species whose bio-status is unspecified (Table 1.1).

Table 1.1 Distribution of invasive species in Cameroon

INVASIVE SPECIES			
	Alien Species	**Bio-status non specified**	**Native species**
Tree	4	1	/
Herb	3	/	1
Sedge	1	/	/
Aquatic plant	1	/	/
Grass	1	/	5
Palm	1	/	/
Tree, shrub	1	/	/
Aquatic plant, sedge	/	1	/
Herb, fern	/	/	1
Fern	/	/	1
Vine, herb	/	/	1
Vine, climber, herb	/	/	1
Fish	3	/	5
Alga	1	1	/
Reptile	1	/	1
Insect	4	3	2
Microorganism	1	/	1
Fungus	/	1	/
Mammal	/	/	5
Bird	1	/	3
TOTAL	**23**	**07**	**27**

Of the 36 plants species at the IUCN list of the 100 world's worst invasive alien species disturbing the host ecosystem (Lowe *et al.* 2000), six are present and invasive in Cameroon (Table 1.2)

Table 1.2 List of invasive alien plant species in Cameroon according to the IUCN list of the world's worst invasive alien species (Lowe *et al.* 2000).

Invasive Alien plant species				
	Species	**Family**	**Synonyms**	**Common names**
Trees	*Cecropia peltata* L.	Urticaceae	*Ambaiba pelata* Kuntze, *Coilotapalus peltata* Britton	trumpet tree, parasolier snakewood tree
	Leucaena leucocephala (Lam.) De Wit	Fabaceae	*Acacia leucocephala* (Lamark) Link 1822, *Leucaena glabrata* Rose 1897, *Leucaena glauca* (L.) Benth. 1842, *Mimosa leucocephala* Lamark 1783	lead tree, faux mimosa, faux-acacia, fua pepe, horse/wild tamarind, wild mimosa, wild tamarind,
Land plant (Grasses)	*Imperata cylindrical* (L.) P. Beauv.	Poaceae	*Imperata arundinacea* Cirillo, *Lagurus cylindricus* L.	alang-alang, blady grass, paillotte, satintail, speargrass
	Mimosa pigra L.	Fabaceae	*M. pellita* Humb. & Bonpl. ex Willd	Giant sensitive plant
Herbs	*Chromolaena odorata* (L.) R.M. King & H. Rob.	Asteraceae	*Eupatorium affine* Hook & Arn., *Eupatorium odoratum* L.,	bitter bush, chromolaena, devil weed, Siam weed, herbe du Laos, Christmas bush,
Aquatic plants	*Eichhornia crassipes (Mart.) Solms-Laubach*	Pontederiaceae	*Eichhornia speciosa* Kunth, *Heteranthera formosa*, *Piaropus crassipes* (Mart.) Raf., *Piaropus mesomelas*, *Pontederia crassipes* Mart. (basionym)	water hyacinth, jacinthe d'eau, aguapé, bekabe kairanga

However, according to a recent work done by the Ministry of Environment, Protection of Nature and Sustainable Development (MINEPDED) under the supervision of the Cameroon Biosecurity Project, an updatedlist showed that 35 plants species are invasive in Cameroon (Table 1.3).

Table 1.3 List of invasive species - plants for Cameroon**,** Type of negative impact caused (1. Competition; 2. Predation; 3. Hybridisation; 4. Disease transmission; 5. Parasitism; 6. Poisoning/Toxicity; 7. Bio-fouling; 8. Grazing/Herbivory/Browsing; 9. Rooting/Digging; 10. Trampling; 11. Flammability; 12. Interaction with other invasive species; 13. Other; and 14. Disease.). Severity of its worst impact (*** Major, ** Patchy, and * Minor). Management activity (Y=Yes, N=no). Source" MINEPDED, 2014**.**

		Region taxon is known from												Worst impact			Management activity (Y/N)
Species name	**Common name in Cameroon**	**Adamawa**	**Centre**	**East**	**Far North**	**Littoral**	**North**	**Northwest**	**South**	**Southwest**	**West**	**Uses of the taxon**	**Types of negative impact**	***	**	*	
Acrostichum aureum	Swamp arum								1				1			1	
Ageratum conyzoides	King grass, chickweed, goatweed	1	1	1		1		1	1	1	1	Medicinal	1			1	Y
Bambusa vulgaris	China bamboo, bambou de chine Common bamboo, Indian bamboo		1	1					1			Making tools, fences, cultural	1	1		1	Y
Bidens pilosa	Tseh Neck, Spanish needle	1	1	1		1	1	1	1	1	1	Medicinal	1			1	
Cecropia peltata	Cecropia, Trumpet tree, pumpwood umbrella tree					1			1	1			1				
Cedrela odorata	Ylan-ylan, Spanish cedar, Mexican cedar		1									Ornamental, Shade tree				1	
Chromolaena	Dongmo,		1	1		1	1	1	1	1	1	Medicinal,	1	1			Y

		Region taxon is known from												Worst impact			Manage ment activity (Y/N)
Species name	**Common name in Cameroon**	**Adamawa**	**Centre**	**East**	**Far North**	**Littoral**	**North**	**Northwest**	**South**	**Southwest**	**West**	**Uses of the taxon**	**Types of negative impact**	***	**	*	
odorata	Bokassa, Paul Biya, Bokassa Grass, Siam weed, Zapi, Ndo milang											Soil improvement					
Cyperus papyrus	Papyrus		1		1	1						Water purification Ornamental	1	1		1	
Cyperus rotundus	Nut grass, nut sedge, herbe à oignons				1	1	1			1							N
Desmodium adscendens	Zarzabacoa, galana	1	1	1			1	1	1	1	1		1		1		Y
Echinochloa pyramidalis		1	1		1	1	1		1	1			1	1			
Echinocloa crus-pavonis	Manpower							1					1	* * *			Y
Eichhornia crassipes	Jacinthe d'eau, water hyacinth					1							1	1			Y
Elaeis guineensis	Leteuoh, palmier à huile, African oil palm		1	1		1		1	1	1	1	Food (oil, wine), Shade tree, making tools	1			1	
Hevea	Hévéa, natural					1			1	1		commercial	1			1	

Species name	Common name in Cameroon	Region taxon is known from: Adamawa	Centre	East	Far North	Littoral	North	Northwest	South	Southwest	West	Uses of the taxon	Types of negative impact	Worst impact: ***	**	*	Management activity (Y/N)
brasiliensis	rubber, Para rubber, rubbertree											Rubber tree					
Imperata cylindrica	N'neuh, cotton wool grass, silver spike, sword grass,	1	1				1	1		1	1	Covering roofs, soil fertilizer	1			1	Y
Ipomoea aquatica	Patate d'eau		1									Pisciculture	1			1	
Lantana camara	Tick berry, Spanish flag, lantana	1	1			1		1	1	1	1	Ornamental	1			1	
Lasimorpha senegalensis	Macabo d'eau		1			1			1	1			1	1			
Lemna paucicostata	Lentille d'eau, Duckweed		1	1		1						ornamental	1			1	
Leucaena leucocephala	White leadtree, jumbay		1			1				1	1	agro-forestery					
Loranthus spp.	Tsap-lah gui, Children's matches	1		1		1		1	1	1	1		5,1		1		Y
Mimosa diplotricha	Giant false sensitive plant												1				Y
Mimosa pigra	Giant sensitive tree	1	1	1		1	1			1			1	1			
Momordica	Balsamapple,		1		1	1	1		1	1		Medicinal	1			1	

Species name	Common name in Cameroon	Region taxon is known from										Uses of the taxon	Types of negative impact	Worst impact			Management activity (Y/N)
		Adamawa	Centre	East	Far North	Littoral	North	Northwest	South	Southwest	West			***	**	*	
charantia	balsampear, bitter melon																
Nymphaea lotus	Nénuphar ,Tiger lotus		1	1	1	1			1	1	1	Pisciculture	1		1		
Nypa fruticans	Palmier nypa, Nypa palm					1				1			1	1			Y
Panicum maximum	Guineagrass	1	1	1	1	1	1	1	1	1	1		1			1	Y
Pennisetum purpureum	Achuchung, herbe à éléphant, Elephant grass	1	1	1	1	1	1	1	1	1	1	Food, Cultural	1			1	Y
Pistia stratiotes	Water letuce, salade d'eau, nile cabbage, water cabbage		1		1	1							1	1	1		
Psidium guajava	Nguaya, goyavier, guava, lemon guava		1	1		1		1	1	1	1	Food	1			1	
Pteridium aquilinum	A zezang, fougèr aigle, Bracken fern	1	1			1	1	1			1	Food	1		1		
Striga gesnerioides					1		1						5	1			Y
Striga hermonthica	Purple witchweed	1			1		1				1		5	1			Y
Tithonia	Jalous flower,		1	1			1	1	1	1	1	Soil	1		1		Y

		Region taxon is known from												Worst impact			Manage ment activity (Y/N)
Species name	Common name in Cameroon	Adamawa	Centre	East	Far North	Littoral	North	Northwest	South	Southwest	West	Uses of the taxon	Types of negative impact	***	**	*	
diversifolia	marguerite, la fleur Margarette, la fleur Jalousie, Mexican sunflower											fertilizer					

1.6 Water weeds

Weeds, by definition, are recognized as plants that grow in the wrong place (Ajuonu *et al.* 2010; Holt 2011) or plants of low value to farmers, either because they are less palatable (or totally unpalatable) to sheep and cattle than preferred pasture plants, or because they compete with useful crops (Diamond 2005). Worldwide, water resources are extremely important for the environment, industry and agricultural purposes. In order to ensure sufficient water resources for domestic, agricultural and industrial uses, numerous dams, weirs and inter-basin transfer schemes have been constructed, which favour the invasion by water weeds. In Africa, several of these constructions have been invaded by aquatic vegetation with severe consequences (Hill 2003) particularly where water resources are often far from abundant (Twongo 1996).

Amongst the major aquatic weeds that invaded water bodies around the world (Table 1.4), at present, there are five which are especially problematic in Africa (Cilliers *et al.* 2003):

- *Azolla filiculoides* (Lam.), (redwater fern) native to North and South America, can form large dense mats that negatively impact the aquatic sytems;
- *Myriophyllum aquaticum* (Vell.) Verdc. (parrots feather), native to the Amazon river in South America and only found in South Africa;
- *Pistia stratiotes* L. (water lettuce), also from South America;
- *Salvinia molesta* (Mitchell) (salvinia), another South American free-floating aquatic fern species, and finally
- the most widespread and damaging aquatic plant species in Africa, *Eichhornia crassipes* (Mart.) Solms Laubach (water hyacinth) (Hill 2003).

The exact dates and modes of introduction of these species in some countries are often not known. Water hyacinth, for instance, was first recorded in Africa in the late 1800s (Coetzee *et al.* 2009a).

Table 1.4 Major aquatic weeds that have invaded water bodies around the world (from Coetzee & Hill 2011)

	Species	Common names	Family	Mode of reproduction	Region of origin	Effective method of control
Free floating	*Azolla filiculoides*	Pacific azolla, Red water fern	Azollaceae	Spores, plant fragments	South America	Biological
	Eichhornia crassipes	Water hyacinth	Pontederiaceae	Seed, vegetative budding	South America	Chemical, Biological
	Pistia stratiotes	Water lettuce	Araceae	Seed, vegetative budding	South America	Chemical, Biological
	Salvinia molesta	Giant salvinia, floating fern, Kariba weed	Salviniaceae	Fragmentation (sterile hybrid)	South America	Chemical, Biological
	Stratiotes aloides	Water soldier	Hydrocharitaceae	Seeds, stolons	Europe	Mechanical
Floating attached	*Alternanthera philoxeroides*	Alligator weed	Amaranthaceae	Seeds, stems fragments	South America	Chemical, Biological
	Myriophyllum aquaticum	Parrot feathers, Thread of Life	Haloragaceae	Stem fragments	South America	Biological
	Nymphaea mexicana	Yellow waterlily	Nympheaceae	Stolons	North America	Mechanical
	Trapa natans	Water chest-nut, bull nut	Trapaceae	Seeds	Eurasia	Mechanical, chemical
Emergent	*Hydrocotyle ranunculoides*	Pennywort	Apiaceae	Seeds, stem fragments	North America	Manual, Mechanical, chemical
Submerged	*Cabomba caroliniana*	Fanwort	Cabombaceae	Seed, stem fragments	Temperate and tropical America	Biological control under investigation
	Egeria densa	Dense waterweed	Hydrocharitaceae	Stem fragments	South America	Mechanical, Hydrological manipulation
	Elodea canadensis	Canadian waterweed	Hydrocharitaceae	Stem fragments	North America	Mechanical
	Hydrilla	Hydrilla	Hydrocharitaceae	Seed, stem fragments,	Asia, Australia,	Mechanical,

	verticillata			reproductive turions and tubers	Europe, Central Africa	Chemical, Biological
Submerged	*Lagarosiphon major*	Lagarosiphon, Curly water thyme, Curly waterweed	Hydrocharitaceae	Stem fragments	Southern Africa	Mechanical
	Myriophyllum spicatum	Spiked watermilfoil, Eurasion watermilfoil	Haloragaceae	Seeds, stem fragments	Europe, Asia, North Africa	Chemical, Hydrological manipulation

1.7 Water hyacinth

1.7.1 Origin

Native of the South Amazon basin, *Eichhornia crassipes* was first observed by a Western scientist in 1824, namely by the German naturalist, Karl Friedrich Philipp Von Martius (Barrett 1989), who formally described it as *Pontederia crassipes*. Sixty years later, Solms included it in the genus *Eichhornia*, as it had previously been described by Kuntz in 1829. Because of its striking beauty, *E. crassipes* has been transported round the world, and now grows uncontrollably over the world's rivers and lakes. It is mainly a weed of the tropics and subtropics, but extends to 40° N and 40° S latitude, including India, South Africa and parts of the USA (Holm *et al.* 1977; Gopal 1987; Center 1994). However, cold temperature impede its growth in areas of higher latitude (Tellez *et al.* 2008).

1.7.2 Description and morphology

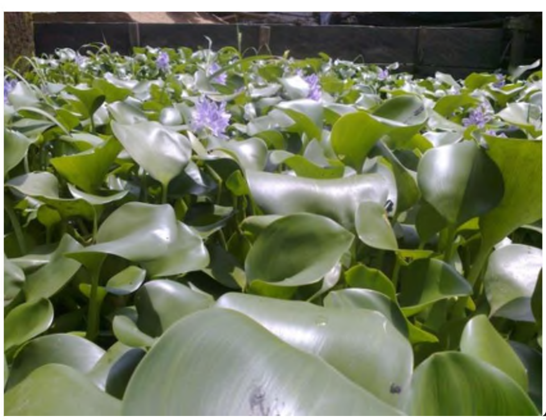
Eichhornia crassipes is a free-floating aquatic, perennial herb of the Pontederiaceae family. A mature water hyacinth consists of seed, flowers, leaves, stems (erect stems and stolons) and roots. The Pontederiaceae is one of the two monocotyledonous families which possess the form of floral heteremorphosm known as tristylis, in which all flowers of an individual plant are characterized by one of three distinct corresponding style and stamen length phenotypes (Barrett 1977; Eckenwalder & Barrett 1986). Theses style forms are:

- the long-styled form with two anthers levels below the stigmas (mid and short);
- the intermediate styled-form of with one set of anthers above the stigmas (long) and one set below the stigmas (short);
- the short-styled form with anthers at two levels above the stigmas (mid and long).

The intermediate styled-form is prevalent in the introduced range of *E. crassipes*, whereas the long styled-form occurs less frequently. The short styled-form predominates in areas of its native range in South America, but has not been recorded in its introduced range (Barrett 1977; Barrett & Forno 1982).

Each plant consists of a rosette of six to ten leaves attached to a rhizome with a well-developed fibrous root system (Hill *et al.* 2011) (Figure 1.2). The general growth form of the shoot is monopodial with the leaves being produced in a whorl (Center & Spencer 1981). Branching is sympodial with ramets formed from axillary buds on stolons produced through the elongation of internodes.

Eichhornia crassipes displays two different sizes and morphologies with intermediates, depending on the conditions in which it grows. There are two leaf forms ranging from the short swollen or bulbous leaf petioles up to 25 cm long but usually less, when growing at the edge of an infestation or otherwise not in dense mats (Center & Spencer 1981; Hill *et al.* 2011). In dense mats, as ramet production proceeds and crowding begins to occur, the petioles of the newly formed leaves tend to become elongate rather than swollen, up to 1.5 m in length (Center & Spencer 1981; Hill *et al.* 2011) (Figure 1.1).


A

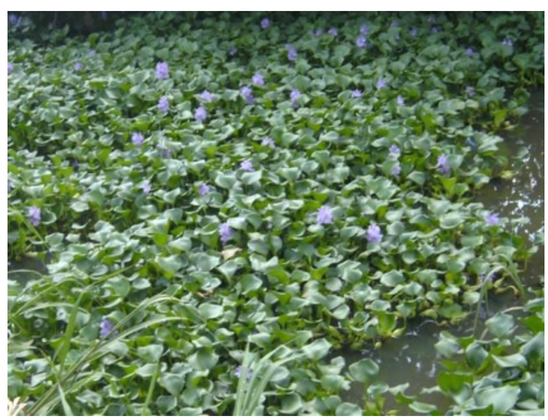

B

Figure 1.1 *Eichhornia crassipes* growing in dense mats (A) and growing at the edge (B) of a waterbody in Cameroon

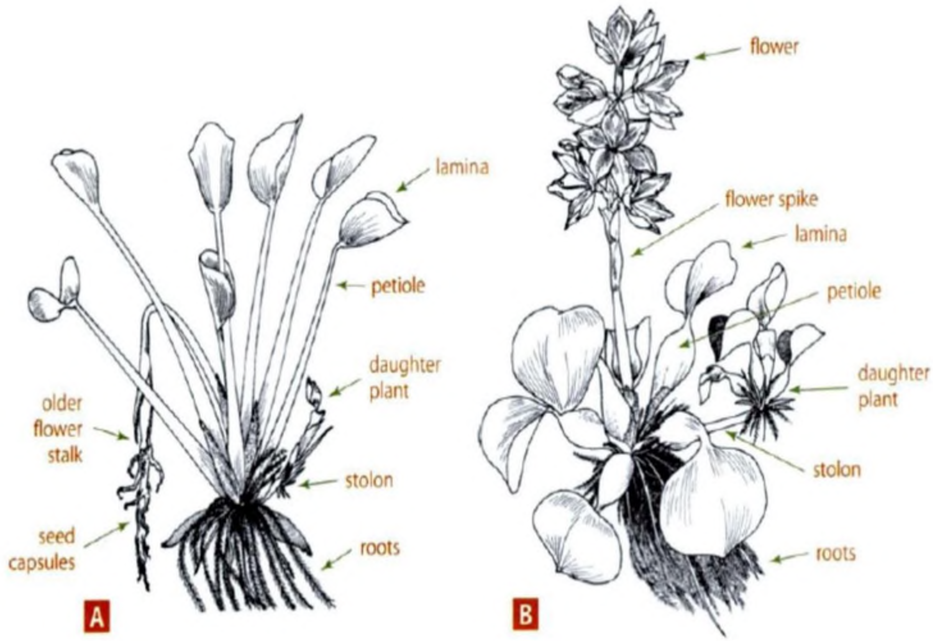


Figure 1.2 Morphology of water hyacinth (A) slender petiolesand (B) bulbous petioles. Source: Wright and Purcell, 1995 cited in Julien *et al.* 1999; Burton 2005.

The leaf consists of a stick petiole (2–3 cm in diameter), a narrow isthmus between the petiole and the blade, and a broad reiniform to lanceolate lamina (Center & Spencer 1981; Cho Mujingni 2012). The leaf blades or lamina are smooth, entire, glossy and with semi-parallel veins (Wright & Purcell 1981); the 6–10 glabrous leaves are arranged in a basal rosette, and each leaf lasts up to 6–8 weeks before senescence (Coetzee *et al.* 2009a) (Figure 1.3). At the top of a single spike, there are 8–15 conspicuously attractive flowers

The 14-day flowering cycle concludes when the flower stalk bends, positioning the spike below the water surface where seeds are released (Kohji *et al.* 1995). The flowers are bluish-purple or lavender to pinkish, funnel-shaped, 4–7 cm in diameter with 6 lobes or petals; the upper lobe with a yellow blotch in the centre surrounds (Wright & Purcell 1981).

The adventitious root system is usually suspended in the water, although the plants may become rooted if stranded in moist soil or in shallow water (Center & Spencer 1981) (Figure 1.3). Morphologically, the roots are highly plastic and tend to be like a “bottle brush” in form with a central axis and numerous unbranched side roots which are hanging, and the colour is sometimes dark because of its purple anthocyanin (Holm *et al.* 1977). The roots plasticity is related to nutrient availability to the water, especially phosphorus (P) (EPPO 2008). Indeed, Xie and Yu (2003) showed that at low phosphorus level, lateral roots are generally longer and denser than the roots growing at high phosphorus level, which is the inverse for the root-shoot ratio for the nitrogen nutrients (EPPO 2008). Weber (1950) examined the roots on one average-sized plant and found the total linear length of 158 adventitious roots and all lateral roots to be 11 481 m with a total area of 7.31 m^2.


(A)


(B)

Figure 1.3. Flower (A) and roots (B) of water hyacinth collected in one site in Cameroon.

Seeds are found in capsules which are 1–1.5 mm long and roughly egg-shaped with ridges from end to end (Cho Mujingni 2012); and each seed capsule normally contains fewer than 50 seeds, while each inflorescence can produce more than 3 000 seeds, and a single rosette can produce several inflorescences each year (Barrett 1980a).

1.7.3 Taxonomy

Eichhornia crassipes is a member of the pickerelweed family (Pontederiaceae), a taxonomically problematic family, which has recently been included in the Commolinales based on phylogenetic proposals (APG II (2003), Strange *et al.* 2004; EPPO 2008; Coetzee *et al.* 2009a).

The common names of *E. crassipes* are "water hyacinth", "waterhyacinth" or "water-hyacinth". The two-word spellings suggest that it is part of the true "hyacinth" family (Hyacinthaceae). Although no standardized usage exists elsewhere to name *Eichhornia crassipes*, the Weed Science Society of America uses "water hyacinth" as the standard spelling, (Coetzee *et* *al.* 2009). Therefore, for the purpose of this dissertation, the name "water hyacinth" will be used. The taxonomic placement of water hyacinth based on Cronquist (1988), Thorne (1992) and Takhtajan (1997) is as follows:

Kingdom	Plantae	Plants
Subkingdom	Tracheobionta	Vascular plants
Super-division	Spermatophyte	Seed plants
Division	Magnoliophyta	Flowering plants
Class	Liliopsida	Monocotyledonous
Subclass	Commelinidae (Liliidae [Cronquist 1988; Thorne 1992])	
Super order	Commelinanae ((Thorne 1992)	
Order	Pontederiales (Liliiales [Cronquist 1988]; Phylidrales [Thorne 1992])	
Family	Pontederiaceae	
Genus	*Eichhornia*	
Specific epithet	*crassipes* (Martius) Solms – Laubach	
Species	*Eichhornia crassipes*	Water hyacinth

Eight other genera occur in this family of predominantly neotropical, freshwater aquatics, and eight species in the genus *Eichhornia* (Cook 1998), all of which originated in South America except *E. natans* (P. Beauv.) which is endemic to tropical Africa. Only *E. crassipes* is regarded as a pan-tropical aquatic weed (Gopal 1987; EPPO 2008; Coetzee *et al.* 2009b; Hill *et al.* 2011).

1.7.4 Similarities to other species

Because of their similarity in appearance, *E. crassipes* and *E. azurea* (Swartz) Kunth. are often misidentified (Figure 1.4). This misidentification occurs because they have a similar morphology, especially as concerns the flower, but *E. crassipes* is the only floating one (EPPO 2008). Also from South America, *E. azurea* has been reported in southern Florida and Indiana in the USA and in Japan as a temporary occurrence only (Kadono 2004). The same error is made in Florida, USA, where a floating form of the native aquatic plant, *Limnobium spongia* (Bosc) Rich. ex Steud. (Hydrocharitaceae) is confused sometimes with *E. crassipes* (EPPO 2008). Other species similar to *E. crassipes* are *Monochoria vaginalis* (Burm.f) C. Presl. (Pontederiaceae) and *Monochoria africana* (Solms) N. E. Br. (Pontederiaceae) (EPPO 2008). *Monochoria Africana* is known from relatively few and scaterred collections in eastern Africa, extending from southern Sudan, Kenya, South Africa (Limpopo Province, Mpumalanga), Tanzania, Uganda, Zambia, and Zimbabwe and to Rwanda. *Monochoria vaginalis* on the contrary is widely distributed in South East Asia from Iran, Philippines and Indonesia, to China, Korea, Japan and North Australia.

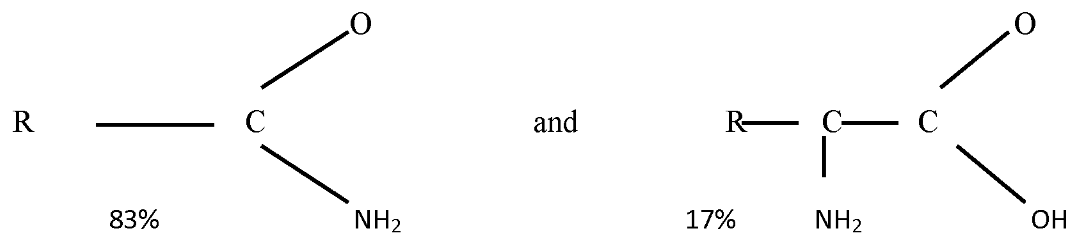
Figure 1.4. Flowering *Eichhornia azurea* from EPPO (2008).

1.7.5 Chemical composition

Several studies carried out around the world showed that water hyacinth is constituted by 80–90% of water and between 15–20% of solid material (Ndimele *et al.* 2011). When dried, it contains about 25–35% proteins with about 17% amino acids, the rest being amides which are usually toxic (Ndimele *et al.* 2011).

Edewor (1988), showed that, dry water hyacinth contains about 36–40% carbon conferring to the plant its cellulosic structure, whereby an amino group is directly attached to the carbon structure (Figure 1.5).

Further investigations have revealed that most of R consists of an aliphatic chain. Overall, the elemental composition of water hyacinth consists of about 12.8% nitrogen, 36–40% carbon, 8% hydrogen and about 13–14% oxygen (Ndimele *et al.* 2011).



Where R could be CH_2 or long chain CH_2-CH_2

Figure 1.5. Representation of carbon structure in water hyacinth (Source: Ndimele *et al.* 2011)

When the weed grows in polluted water, it also contains heavy metals such as iron, magnesium and zinc, which are used during the phytoremediation process (Ndimele 2012; Ndimele & Jimoh, 2011), and also contains other trace elements such as phosphorus and calcium (Edewor 1988).

1.7.6 Biology

Water hyacinth reproduces both by vegetative and sexual reproduction both being characterized by the potential for producing large numbers of individuals in a short period of time (Barrett 1980b). Vegetative reproduction is the most widespread form of propagation in *E. crassipes*; indeed, reports of different parts of the range of the species indicate that, in many populations, sexual reproduction is rare or non-existent (Barrett 1980a).

1.7.6.1 Sexual reproduction

Even after complete eradication of vegetative parts, *E. crassipes* is observed to reappear, which suggests that new plants must have developed from seeds (Parija 1934). Subsequently, several other studies also described the presence of seeds and seedlings. It appeared that the germination of seed into mature plants is markedly improved by high light intensity, water temperature, and oxygen (Obed & Taggel 1976; Ashton *et al.* 1979; Barrett 1980), emphasizing the importance of seedling production as a source of infestation in tropical countries. Indeed, Barrett (1989), in one of his studies, noticed that, seed production was twice as great in tropical regions as temperate regions because in the tropical regions, there are more insects which are attracted to the flowers and the frequent fluctuations in water level provide suitable ecological conditions for seed germination and seedling establishment. Amongst the insects that are attracted to the flowers, *Trigona* species, and four groups of bees *Ancyloscelis* sp., and Megachilidae were noted in Indonesia. Similarly, *Trigona* and various species of Meliponidae and Halictid*ae* were observed to visit flowers in the lower Amazon (Barrett 1980b). Seed dispersal is likely to contribute to the spread of this weed. Seeds are released directly into the water column, where they can be carried long distances downstream. They can also be easily transport by vehicles, boats or pedestrians passing through infested areas (Julien *et al.* 2001). The optimum climatic conditions for maximum fruiting occur at a relative humidity greater than 90% and temperatures between 22.5 and 35 °C (Gopal 1987; Hytec & Mary 2010).

Seeds sink following release from the seed capsule and may subsequently germinate as water levels change (Wright & Purcell 1995; Julien *et al.* 2001). After pollination of the flower, the inflorescence bends, submerging the fertilized capsule which rapidly ripens and disintegrates allowing the seeds to sink to the substrate where they can remain viable for 15–20 years (Manson & Manson 1958; Matthews 1967; Ashton *et al.* 1979; Malik 2007; Coetzee *et al.* 2009), and flowering can occur 10 to 15 weeks thereafter (Barrett 1980). Each inflorescence may have between 4–16 fruits, and each fruits may give 2–450 seeds (Batcher 2000) (Figure 1.6).

Major factors limiting sexual reproduction in *E. crassipes* are low and "inefficient" pollinator services (absence of pollinating agents, pollen viability, and genetic barriers like self-incompatibility) which limit fecundity, and the absence of suitable ecological conditions for seed germination and seedling establishment (Barrett 1980; Gopal 1987).

1.7.6.2 Vegetative or clonal reproduction

Another term to describe vegetative reproduction is “clonal reproduction”: The clone is a plant produced without fertilization of male and female gamete and represents an identical copy of the parent plant (Barrett 1989).

Eichhornia crassipes possess prolific powers of clonal propagation which constitute the major factor contributing to its success as a weed in lakes, reservoirs and canals (Barrett 1989). Mature plants are able to undergo rapid vegetative propagation by producing offsets which are connected to the parent plants by brittle stolons. Indeed, the stolons decay or break separating them from mother plant once roots appear (EPPO 2008). The stolons are easily broken by wind or wave action, fishing nets and water-craft, and the offsets are set free to act as potential colonizers (Ashton *et al.* 1979; Julien *et al.* 1999).

When the plants are less disturbed by wind or wave action, the stoloniferous growth habit results in the formation of large mats of inter-locked plants (Ashton *et al.* 1979). Under favourable temperature conditions of and nutrient availability in enriched water, the vegetative propagation is very fast and a single plant can develop into a substantial infestation in a very short time, but may be low in pristine waters with no or low flow (EPPO 2008). The edge of the mat can advance by 60 cm/month and the doubling time varies from 11-18 days (Penfound & Earle 1948; Edwards & Musil 1975). Plant canopy shade reduces the quantity of light available to the plants thereby limiting the growth, but clonal plants such *E. crassipes* might increase light interception via horizontal growth of stolons or rhizome and placement of new ramets in less shaded microsites (Methy *et al.* 1990). However, low oxygen in infested areas slows down vegetative reproduction (Gopal 1987).

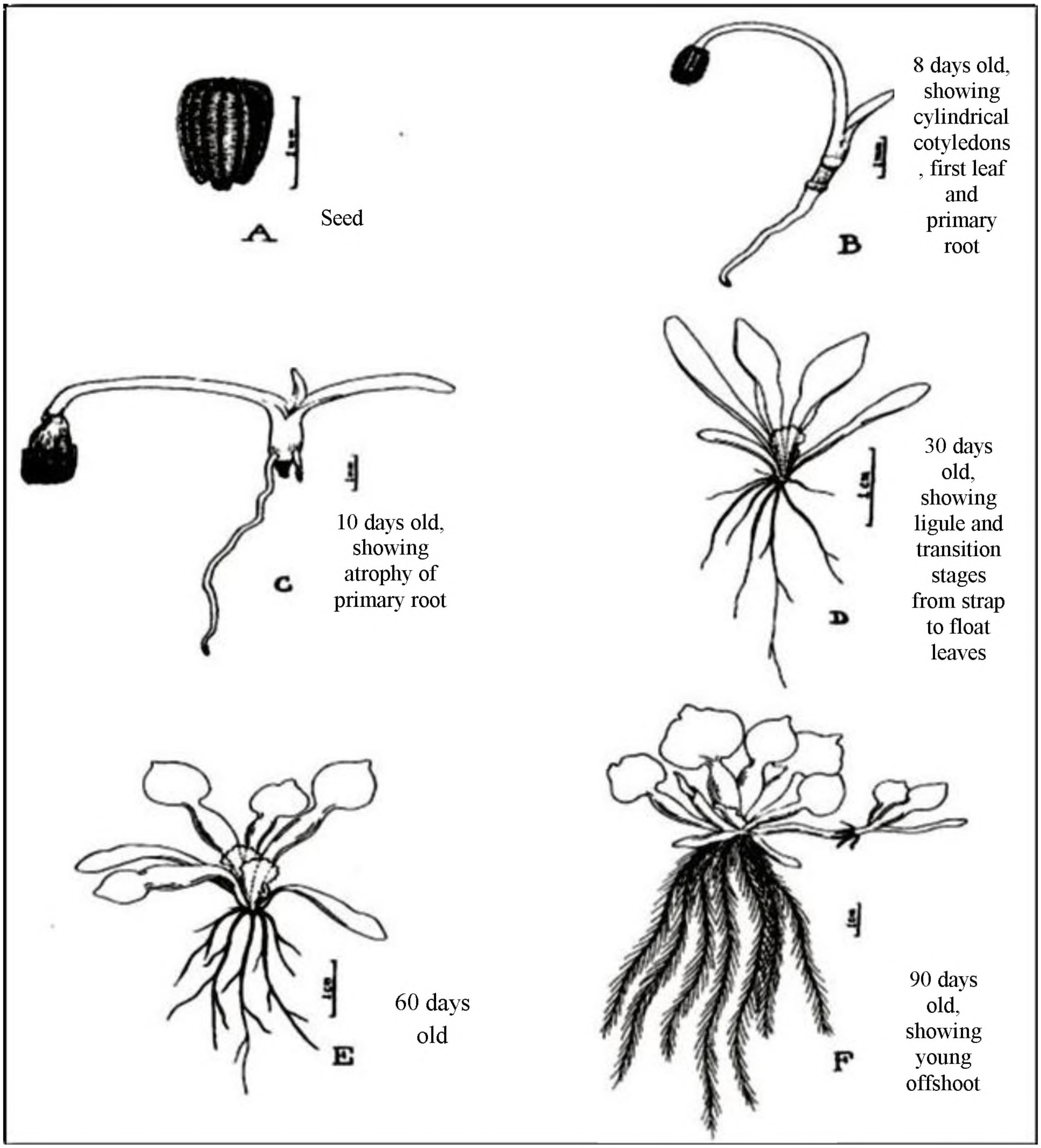


Figure 1.6. Stages in seed germination in water hyacinth. Source: Penfound & Earle (1948).

1.7.7 Ecology

1.7.7.1 Habitat

Water hyacinth, a free-floating aquatic plant, grows in a variety of freshwater habitats, from shallow temporary ponds, marshes, estuarines, urban areas and sluggishly flowing waters to large lakes, reservoirs and rivers, habitats which present a broad spectrum of physico-chemical environments (Gopal 1987). Water hyacinth prefers calm waters or a low current even though it can withstand seasonal variations in the flow velocity with tolerance to brakish and saline water (Penfound & Earle 1948; Muramoto *et al.* 1991; Batcher 2000). High light intensity and nutrient-rich water also encourage population build-up. Low air humidity (15–40 % R.h) has been found to reduce water hyacinth growth rate, but this may be a side-effect of growing plants in small containers (Allen *et al.* 1997). *Eichhornia crassipes*, as a heliophilous plant, can grow under a broad range of light intensites from 24 000 lux to 240 000 lux, its preferred range (Tellez *et al.* 2008).

1.7.7.2 Temperature

Temperature has an important and pervasive influence on the distribution and abundance of organisms through its effects on physiological processes such as photosynthesis, and nutrient fixation (Somero 2002). Water hyacinth reproduction and development is also greatly influenced by temperature.

The plants can develop in a wide range of temperatures, between 12–35 °C, but their optimal growth occurs at temperatures ranging from 25–30 °C (Malik 2007; Hytec & Mary 2010; Center 1987), while growth ceases when water temperature drops below 10 °C (Gopal 1987; Dugast 1992) or rises above 34 °C (Penfound & Earle 1948; Knipling *et al.* 1970; Center 1987a). Indeed, prolonged cold temperature below 5 °C results in the death of the plants, limiting the distribution of *E. crassipes* in high latitudes (Gopal 1987; Owens & Madsen 1995), but re-infestation from seeds follows during later warmer periods (Penfound & Earle 1948). During these times of stress, stored carbohydrates from the stems are used as energy reserves (Owens & Madsen 1995). Plants stranded on moist sediments can survive several months (Parija 1934b), and in freezing temperature ranging from -0 to -16°C, they can survive for at least 24 hours (Owens & Madsen 1995).

1.7.7.3 Salinity

Water hyacinth is a species which is strictly limited to freshwater environments. It has very little tolerance *vis-a-vis* the salinity of the medium but can sustain very low salinities of about 0.6 ‰ (Penfound & Earle 1948; Batcher 2000; Mille 2005). Haller *et al.* (1974) studied the effect of salinity on the growth of several aquatic plants. This study showed that the growth of water hyacinth decreased when the salt content of the medium was 0.83 ‰ (the dry weight of species passed from 12.48 g at salinity of 0.83 ‰ to 9.84 g at 1.66 ‰ of salinity) and water hyacinth died when the salinity was between 2.5 ‰ and 3 ‰.

During these periods of salinity stress, significant lesions appear: first, the level of chlorosis gradually twists the leaves, causing them to die, which is followed by the death of the whole plant (Haller *et al.* 1974; Penfound & Earle 1948).

1.7.7.4 pH

Optimum growth of water hyacinth occurs in eutrophic, still or slow-moving fresh water with a neutral pH (7). It can tolerate pH levels from 4.0 to 10.0 (Haller & Sutton 1973), but not more than 20–25 % sea water (Muramoto *et al.* 1991). On the other hand, during its growth, water hyacinth generally modifies the pH of the medium; indeed Penfound & Earle (1948) in their studies, showed a decrease in the pH of the Mississippi pond and canal where water hyacinth grew: pH was 7.2 in the area without water hyacinth and between 6.2 and 6.8 below the water hyacinth plants. Haller and Sutton (1973) stated that the development of water hyacinth would tend to bring the pH of the medium close to neutral.

1.7.7.5 Utilization of nutrients

The growth rate of water hyacinth depends strongly upon the concentration of dissolved nitrogen (N) and phosphorus (P) (Moorhead *et al.* 1988; Debusk & Dieberg 1989; Reddy *et al.* 1989), as does *E. crassipes* biomass accumulation (Gossett & Norris 1971; Reddy *et al.* 1990). Consequently, eutrophication of water, or a steady flow of less enriched water that provides a continuing supply of nutrients to the roots leads to thick stands of water hyacinth (Coetzee *et al.* 2009b). A study carried out by Heard and Winterton (2000) showed that water hyacinth grew twice as high in eutrophic conditions in comparison to a poor-nutrient environment. Further, other plant nutrients such as calcium and iron are also important. Water hyacinth grown in a medium that lacked calcium did not reproduce and a threshold of 5 $mg.L^{-1}$ was determined with this element being essential for seed formation; likewise Fe deficiency (<0.3 $mg.L^{-1}$) inhibited growth and resulted in chlorosis of the leaves (Gopal 1987).

1.8 Worldwide distribution of water hyacinth

Before the interference of man, the distribution of water hyacinth was restricted to tropical South America and perhaps parts of Central America and the larger Caribbean islands (Pieterse n.d.). During the flowering season, water hyacinth presents a beautiful flower and consequently it has been introduced into many parts of the world as an ornamental plant. Today it is found in more than 50 countries on five continents (Barrett 1989).

1.8.1 North America

It was first introduced into North America in 1884 at the Cotton States Exposition, Louisiana, in New Orleans, where it was distributed as gifts imported from the Lower Orinoco River in Venezuela by a Japanese delegation (Barrett 1989; Center *et al.* 2002). Now, water hyacinth proliferates in the south-eastern States, where it is present along the Mexican frontier, Mexico Gulf, Texas and Florida passing through the Louisiana, Mississippi, Alabama and Georgia. Water hyacinth is also present in California where it was recorded for the first time in 1904 (Toft 2000).

According to the data provided by Jacono and Richerson (2003), at present, water hyacinth is well established in 150 watersheds, distributed in 10 states including the southern states of Virginia and, North Carolina and in Hawaii. *E. crassipes* is also present in more temperate regions of the United States, especially in New Jersey, Kentucky, Tennessee, Missouri, Arkansas, Maryland, Alabama, Florida, Georgia, Texas, Mississipi, Louisana and Illinois (EPPO 2008; Hytec & Mary 2010). The plants cause substantial economic losses in the USA estimated to total US$ 120 billion annually (Pimentel *et al.* 2005; Kettunen *et al.* 2009).

In Mexico, more than 40 000 hectare of reservoirs, lakes, canals and drains are infested with *E. crassipes* (Jimenez & Balandra 2007).

1.8.2 South America and Caribbean

Eichhornia crassipes is well distributed in South America and around the Caribbean. In its native range, the first record of *E. crassipes* in Argentina was in 1942, 1902 in Brazil, 1959 in Paraguay, 1976 in Venezuela, 1979 in Chile (Tellez *et al*. 2008). It also present in Bolivia, Columbia, Ecuador, French Guiana, Guyana, Surinam and Uruguay (Gopal 1987; Jones 2009).

In the Caribbean, water hyacinth has been observed in Jamaica, Bermuda, the Bahamas, Haiti, Cuba, Puerto Rico and the Dominican Republic since 1971 (Tellez *et al.* 2008; Hytec & Mary 2010).

1.8.3 Central America

Apart from its native range, *E. crassipes* is also present in Guatemala, Honduras, Nicaragua, and Costa Rica, in Central America and in Peru, on the west coast of Columbia (Hytec & Mary 2010). Its first record was in 1965 in El Salvador, 1966 in Panama (Tellez *et al.* 2008).

1.8.4 Pacific

A study carried out by Pacific Island Ecosystems at Risk (PIER) discovered an important distribution of *E. crassipes* in the Pacific Ocean and Asia. In the main islands of the Pacific Ocean, *E. crassipes* has been recorded in Polynesia, Micronesia, Melanesia, Australia and New Zealand (Healy & Edgar 1980; Mackee 1994; Space *et al.* 2000; Space & Flynn 2002; Mille 2005; EPPO 2008).

Water hyacinth is especially abundant in French Polynesia in the Society Archipelago, and in the Marquises Archipel. In the Federated States of Micronesia and Melanesia, water hyacinth has been found mainly in the Nauru Republic, Northern Marianne Islands, Fiji, Solomon Islands, Vanuatu Island, New Caledonia (Mackee 1994; Mille 2005; EPPO 2008) and, finally, in Papua New Guinea where it was first recorded from the dredge ponds in old gold fields of Bubolo in 1962 (Harley *et al.* 1996). *Eichhornia crassipes* is also present in America Samoa, Guam, Marshall Islands, Palau, Samoa and minor outlying islands of the United States (EPPO 2008).

According to Hytec and Mary (2010), it was introduced into Australia as an aquarium plant in the late 1890s and was observed for the first time in New South Wales in 1895, where it has spread rapidly in the Royal Botanic Gardens ponds in Sydney. In the early 1900s it infested the entire Australian East Coast, Kiama in New South Wales, as far as the Cape York Peninsula in Queensland and it is now considered one the most harmful species in this region (Burton 2005). At present, besides its propagation along the east coast, *E. crassipes* is found in Perth on the Australian west coast, Darwin in north, in Queensland in the Mitchell River, in the area of Mount Isa and in Georgetown (Burton 2005; Hytec & Mary, 2010).

The first recorded sighting of water hyacinth in New Zealand was in 1914 where its spread has been highly aggressive, leading the government to prohibit importation in 1927 (Hytec & Mary 2010). Despite the eradication programmes implemented by the New Zealand government, water hyacinth is present especially in the North Island, Auckland, Wellington, as well as Cook Island (Healy & Edgar 1980).

1.8.5 Asia

Together with *Salvinia molesta*, *E. crassipes* is considered the worst plant in the Asian continent (Mansor 1996). It is widespread on freshwater wetlands over the entire continent, including the islands of South East Asia. It was introduced into Asia towards the end of the 19^{th}

century via Japan and Indonesia (Ueki *et al.* 1975) where it naturalized in rice fields in Indonesia, and was grown as an ornamental plant in the Botanical Gardens (Baker 1951).

Water hyacinth is also present in the Middle East especially in Israel, Palestine, Lebanon and Syria, but also in South Asia especially in the Maldives, Bangladesh, India and Sri Lanka where it has caused heavy siltation in the wetlands of the Kaziranga National Park, India (Biswas *et al.* 2007; Hytec & Mary 2010).

Eichhornia crassipes is also strongly represented in east Asia, South Korea, Japan, China and Taiwan. It was first introduced in China in about 1901, spread very quickly and is now found in 17 provinces. It causes significant problems in at least 10 of these provinces, especially in Yunnan, Guangdong, Zhejiang, Fujian and Taiwan (Jianqing *et al.* 2000; Chu *et al.* 2006).

In South East Asia, it occurs in several regions: Burma, Vietnam, through Thailand, Laos, Cambodia, and several islands especially Brunei, Malaysia, Singapore, Indonesia and Philippines (Hytec & Mary 2010).

The first record in India was in Bengal at the beginning of 1890, where it spread throughout the country except in the more arid western part of Rajasthan, in the rugged regions of the north and in Kashmir (Tellez *et al.* 2008).

1.8.6 Europe

In Europe, *E. crassipes* was first recorded in 1939 where it was introduced into Portugal as an ornamental plant (Tellez *et al.* 2008; Hytec & Mary 2010). Water hyacinth is mainly established around the Mediterranean, especially in France, Italy, Israel, Jordan, Spain (Dutartre *et al.* 1997; Golan de Mera & DeCastro 2003; Marchante 2005; Moragues Botey 2005; EPPO 2008; Anonymous 2013). Casual records are known from Belgium, Czech Republic, Hungary, the Netherlands and Romania (EEA 2012 in Anonymous 2013). It is a particular threat in Spain and Portugal (Della Greca *et al.* 2009). Indeed, in Spain, according to Tellez *et al.* (2008), the first documented record of the presence of water hyacinth dates from 1989, where it appeared sparsely and sporadically between parallels 36° and 43° N. There, the plant occurs in small populations that disappear when the wetlands and ponds in which they are present are dried out, or because of increasing salinity of the habitat.

In Portugal, it rapidly spread over the central west of the country through irrigation canals; it is most invasive in the middle and lower Sado and river Tagus Basin, and also in the Paùl do Boquilobo biosphere Reserve in central Portugal where it is considered the most obvious threat by forming dense floating mats over extensive areas of wetlands (Guerreiro 1976 in Tellez *et al.* 2008). In Spain, its greatest damages were recorded in the middle reaches of the river Guadiana in the SW Iberian Peninsula with the highest level of risk for the municipality of Gaureña (38° N) and in the zone of the mouth of the Búrdalo tributary (38° N); the other zones of extremely high risk of infestation mentioned are Don Benito and the Ruescas river (Tellez *et al.* 2008). In the Guadiana River, it occupied an area of approximately 200 ha covering 75 km of river and has produced a biomass of 175 000 tm during the period of October to November (Tellez *et al.* 2008).

1.8.7 Africa and Indian Ocean

Africa has been particularly affected by the introduction and spread of water hyacinth, facilitated in part by a lack of natural enemies. Thus, the invasion of dams, rivers and lakes represents one of the largest threats to the socio-economic development of the continent (Cilliers *et al.* 2003).

Modelling suitable climates suggests that, with the exception of the drier areas of the continent (Sahara and Kalahari deserts), water hyacinth would be able to infest most of the countries of the continent (Wise *et al.* 2007; Jones 2009).

Following its introduction in Egypt during the 1880s, *E. crassipes* quickly spread over the entire continent up to the Indian Ocean (Barrett *et al.* 1989; N'dah & Arfi 1996; Julien 2000; Navarro 2001; Labrada & Fornasari 2002). Water hyacinth now is found along the west coast of Africa where it is recorded from Senegal to Congo, by passing Guinea Bissau, Equatorial Guinea, Sierra Leone, and throughout the Gulf of Guinea, Liberia, in Gabon, passing through Ivory Coast, but present in Ghana, Togo, Benin, Nigeria, and Niger. It is also localized in lentic areas of the Niger River, in the entire territory of Niger, Nigeria, Cameroon and Equatorial Guinea (Table 1.5).

Table 1.5 Distribution of water hyacinth in African Countries. Data of the first record in these countries not yet available (?).

Country	First Record	References
Angola	1942	Gopal 1987
Benin	1942	Gopal 1987
Burkina Fasso	1989	Ouedraogo *et al.* 1999
Burundi	Late 1950–57	Navarro & Phiri 2000; Hytec & Mary 2010
Cameroon	1997–2000	Forpah 2009
Central African Republic	1970	Gopal 1987
Congo	1950–51	Gopal 1987
Democratic Republic of Congo	1952	Greathead & deGroot 1993
Egypt	1879–1892	Barrett 1989; Fayad 1999; Labrada & Fornasari 2002
Equatorial Guinea	?	Barrett 1989
Ethiopia	1956	Navaroo & Phiri 2000
Gabon	?	Barett 1989
Ghana	1984	Greathead & de Groot 1993
Guinea Bissau	?	Barrett 1989
Ivory Coast	1980s	Koffi Koffi *et al.* 1999
Kenya	1982	Ochiel *et al.* 1999
Liberia	?	Barrett 1989
Madagascar	?	EPPO 2008
Malawi	1960–1968	Navarro & Phiri 2000; Mironga *et al.* 2012
Mali	1987	Navarro & Phiri 2000
Mauritania	?	EPPO 2008
Mauritius	?	EPPO 2008
Mozambique	1942	Gopal 1987
Niger Republic	1987	Ouedrago *et al.* 1999
Nigeria	1982	Charudattan *et al.* 1995
Reunion	?	EPPO 2008
Rwanda	Late 1950s	Hytec & Mary 2010
Senegal	1963	Gopal 1987
Sierra Leone	?	Barrett 1989
South Africa	1908	Julien 2000 ; Stent 2000
Sudan	1954	Navarro & Phiri 2000
Swaziland	?	Barrett 1989 ; Brendock *et al.* 2003
Tanzania	1955	Mallya 1999
The Gambia	?	Barrett 1989
Togo	1987	Ouedrago *et al.* 1999
Uganda	1988–89	Ogwang & Molo 1999 ; Hytec & Mary 2010
Zambia	1960–65	Mailu *et al.* 1999 ; Mironga *et al.* 2012
Zimbabwe	1937	Chikwenhere *et al.* 1999 ; Cho Mujingnie 2012

In West Africa, it is found in Burkina-Faso where several lakes are infested. There, the wet biomass is estimated at between 17 000 and 21 000 tons and the economic losses are estimated at US$ 35 000–45 000 annually, especially because the three largest reserves of drinking water are blocked: Kompienga in the watershed of the river Niger (20 000 ha), and reserves of Bagre (25 000 ha) and Bougouriba in the watershed of the river Volta (Hytec & Mary 2010). In central Africa, water hyacinth is also found in the Congo and the Democratic Republic of Congo.

In East Africa, water hyacinth developed during the years 1980–1990 (Labrada & Fornasari 2002). It is recorded in Sudan, Ethiopia, Uganda, Kenya, Rwanda, Burundi and Tanzania. Indeed, rivers in Rwanda and Burundi were being colonized in the late 1950s, while the rivers Sigi and Pangani in Tanzania were infested in 1955 and 1959, respectively.

The plant was recorded from lakes Kyoga in Uganda in 1988–89, Victoria in 1989–90, Malawi and Nyasa in 1996 and Tanganyika in 1997. Lake Victoria in Africa is the second largest freshwater lake in the world and currently supports approximately 30 million people. Infestation of water hyacinth in this lake has been a serious nuisance, generating a public outcry (Kateregga & Sterner 2007; Gichuki *et al.* 2012). At its peak, it was estimated that the weed was growing at three hectares (12 acres) per day on the lake (Ayodo & Jagero 2012).

In southern Africa, water hyacinth is recorded in Malawi, Zambia, Angola, Zimbabwe, Mozambique, South Africa and Swaziland (Barrett *et al.* 1989; Julien 2000; Navarro 2001; Labrada & Fornasari 2002; Brendock *et al.* 2003).

Water hyacinth was first recorded in South Africa in 1908 (Stent 1913) where it is believed to have been introduced as an ornamental aquatic plant for garden ponds and aquaria, owing to its attractive flowers (Ashton *et al.* 1979). The estimated economic costs due to invasive alien species in South Africa are currently more than US $ 700 million (R6.5 billion) per annum or 0.3% of South Africa's GDP, and could rise to over 5% of GDP if invasive plants are allowed to reach their full potential (Van Wilgen & De Lange 2011).

The first record of water hyacinth infestation in Zimbabwe was in 1937, in the Mukuvisi River in Harare, but the plant only attained its pest status in the early 1950s on Lake Chivero (Chikwenhere *et al.* 1999; Cho Mujingni 2012). The plant also colonized the Kafue River in

Zambia in the 1960s, the Shire River in Malawi in 1968 and Lake Navaisha in Kenya in 1986 (Mironga *et al.* 2012).

On the Indian Ocean islands, *E. crassipes* is also present in Madagascar, especially in watersheds and waterflows of Ankarajantsika National Park on the east of the island, and in the Seychelles, Mascareignes, Mauritius and Reunion Islands (Barrett 1989). Water hyacinth is also found in Christmas Island, in the Indian Ocean as on Norfolk Island (Burton 2005; Hytec & Mary 2010).

1.8.7.1 Distribution in Cameroon

Since its introduction in Cameroon, *E. crassipes* has been a threat to the riparian communities, causing several problems such as hindering boats and swimming, and causing starvation as inhabitants of riparian communities cannot fish (Forpah 2009). Also, touristic activities are hindered and transportation of goods through rivers is no longer possible because propellers are hooked by the water hyacinth mats. Therefore, this species limits the use these communities have of the river.

Water hyacinth was first reported in Cameroon between 1997 and 2000 on the shore of Lake Chad and since then, some of the country's wetlands have become infested by the weed (Forpah 2009). Since its introduction, it has spread throughout numerous provinces (six of the 10 provinces that make up Cameroon) and several rivers and lakes in varying degrees of infestation (Figure 1.7).

The main rivers infested are Wouri, Nkam, and Sanaga in the Littoral Region, Nyong in the Centre Region, Benoue and Lake Lagdo in the North Region, rivers Sangha, Ngoko, Dja, Boumba in the South and East Regions (Forpah 2009).

1.9 Threats posed by water hyacinth

Water hyacinth presents a feature common to most weeds: the ability to grow fast and multiply in habitats that are disturbed by human activity. Two special characteristics allow water hyacinth to reign over this rich aquatic domain: high mobility and clonal propagation (Barrett 1989). All these have led to water hyacinth being listed as one of the most reproductive and worst plants on earth (Hill 1999; Malik 2007). With its characteristic thick fringes and floating mats, water hyacinth has had a serious impact on many aspects of life.

Figure 1.7. Map of the Republic of Cameroon showing the distribution and location of water hyacinth (green patches) (Cho Mujingni 2012).

Mats double in size in five days, and a mat of medium sized plants may contain two million plants per hectare weighing 270 to 400 tonnes (Malik 2007). These dense mats interfere with navigation, recreational activities, irrigation and power generation (Epstein 1998).

Infestations block access to recreational areas and decrease water-front property values, oftentimes harming the economies of communities that depend upon fishing and water sports for revenue (Center 1987). The weed has impeded navigation, even in motorised boats, and transportation costs have risen due to the necessity of taking alternative, indirect routes or as a result of motoring through the mats which, if physically possible, increases fuel consumption (Williams & Hecky 2005). Fishermen also use more fuel, up to three times as much, to push their boats through the heavy weeds (Akinyemiju 1987). The mats indirectly deplete dissolved oxygen, thereby asphyxiating and killing native fish and phytoplankton (Barrett 1989; Williams & Hecky 2005). As the weed drives away fish, it jeopardizes human nutrition in riverine communities where fish are the primary source of protein, without which, health suffers (Barrett 1989; Williams & Hecky 2005). Moreover, the mats of water hyacinth are breeding grounds and an excellent microhabitat for carriers of human and animal diseases such as malaria, schistosomiasis, encephalitis and river blindness (Barrett 1989; Williams & Hecky 2005; Coetzee *et al.* 2009). In addition, because water hyacinth mats harbour venomous snakes, crocodiles and hippopotamous, the collection of water by the population living around the infested zones becomes dangerous, sometimes fatal (Gopal 1987; Navarro & Phiri 2000). Large rafts accumulate where water channels narrow, sometimes causing bridges to collapse. The blockage of canals, pumps and rivers can enhance dangerous flood damage to roads, rail bridges and hydroelectric power-generation schemes. For example, Zambia lost water for power generation and eventually lost revenue of about US$15 million every year for the power company (ZESCO 2008); in Uganda, the cost of cleaning intake screens at the Owen Falls hydroelectric power plant at Jinja were calculated to be US$15 million per annum (Mailu 2001).

In addition, increased evapotranspiration and siltation due to water hyacinth can have serious implications where water is already scarce (Hill 1999; Malik 2007) and the weed has reduced the quality of drinking water causing bad odour, taste, colour, increased turbidity, and causing difficulties for water extraction (Hill 1999; Williams & Hecky 2005).

Although water hyacinth rarely competes with agricultural crops, it impedes the flow of water through irrigation canals and pumps, and thereby hinders crop production. This impediment is manifested in rice production by three ways (EPPO 2008): the direct suppression of the crop and inhibition for its germination, the loss of water and the rise of cost of harvest since the plants get caught up in mechanical harvesters of water hyacinth. This impact on rice production was reported in India, Sri Lanka, Bangladesh (cost of 15 millions dollars according to Gopal 1987), Burma, Malaysia, Indonesia, Thailand, Philippine, Japan, and Portugal especially by the inhibition of germination seeds, and on the rape seed in Japan (Gopal 1987).

Water hyacinth is blamed for the reduction of aquatic biodiversity as well. A study carried out in Florida showed that water hyacinth has a negative impact on the abundance and diversity of communities of benthic macro-invertebrates, mainly marked by the disappearance of two major groups of insects in the presence of water hyacinth (Toft 2000; Midgley *et al.* 2006). There has also been a sharp decrease in the occurrence and mean abundance of all the other faunal groups, including diphtherians and the concentration of chlorophyll which was significantly affected by *E. crassipes* mats (Toft 2000; Midgley *et al.* 2006).

1.10 Water hyacinth control

Worldwide, huge sums of money and enormous efforts have been expended to control water hyacinth, which is absolutely essential because of all its threats (Anonymous 2013). It has become a serious problem in its non-native range because of the absence of natural enemies (Cilliers 1991). To combat the problems caused by the water hyacinth, various efforts to control its spread have been taken up, efforts that include weed management such as physical or mechanical removal, chemical methods (application of herbicides) and the release of biological control agents (Harley *et al.* 1996).

1.10.1 Mechanical or physical

The physical method of controlling water hyacinth involves draining the water body, manually removing the weeds or pulling nets and mechanical harvesters (Patel 2012) through the infestation. For many years, this method was the first method used in the removal of water hyacinth and especially preferred over other methods in disadvantaged countries (Dugast 1992). In these countries, manual removal with simple mechanical devices is still practiced (Julien *et al.* 1999).

This method of control is effective only for small infestations, as it is labour intensive and sometimes too expensive. Approximately US$600–1 200 per hectare is spent in employing machines like weed harvesters, crusher boats and destruction boats (Malik 2007; Villamagna & Murphy 2010). The cost of water hyacinth management in China was estimated to amount to around € 1 billion annually (EEA 2012 in Anonymous 2013). Dagno *et al.* (2007) reported that mechanical management of the weed in Mali cost around US$80 000–100 000 per year. Yet, while mechanical removal has been effective to a considerable extent, the infestations soon return because shredded bunches of the weed are carried by waves to other unaffected areas where they establish and start proliferating (Shanab *et al.* 2010), or the long-lived seed germinate and re-infest sites soon after they are exposed to light by the mechanical and chemical removal of the plant (Edwards & Musil 1975).

1.10.2 Chemical control

Chemical control using herbicides is worldwide, one of the most commonly used methods of macrophyte control. Chemicals can be applied from the air, boat, water or land and with degree of accuracy as to where the herbicide lands (Williams & Hecky 2005). It is relatively expensive, although it has the advantage of being quick and temporarily effective (Coetzee *et al.* 2009).

Several herbicides have been used against water hyacinth such as Paraquat, 2,4-Dichlorophenox-yacetic acid (2,4-D), Disquat, Amitrole, and Glyphosate (Gopal 1987; Villamagna & Murphy 2010). They have resulted in successful control in small, single-purpose water systems such as irrigation canals and dams (Wright & Purcell 1995; Hill *et al.* 2011). However, whatever the operational costs, if the weeds grow faster than chemicals can be applied, then the control of the invasive is clearly not accomplished (DeGroot 1993). Moreover, if the dead or dying weed is not removed, the rotting biomass can lead to localised deoxygenation which, in turn, can lead to other detrimental impacts upon the water body (Mallya 1999). Whilst plants may appear to have been controlled, the problem may not have been solved and subsequently, herbicides must be regularly and frequently reapplied (Center *et al.* 1999). In Louisana (USA), where water hyacinth has made most damages, a cost of 2 millions USD has been spent in herbicide annually by the Department of Fisheries to treat about 25 000 acres of *E. crassipes* mats (EPPO 2008).

Long-term use of herbicides may degrade water quality and put aquatic life at risk, with significant socio-economic impacts on human health if beneficial or designated uses of the water body such as drinking water, washing, fishing, preparing food are affected and the fish also die (Chikwenhere 1994; Julien *et al.* 1999; Malik 2007; Coetzee *et al.* 2009; Hill *et al.* 2011; Dagno *et al.* 2012).

The herbicide control of water hyacinth is often not appropriate in developing countries as it is expensive, requires highly skilled personnel, and because herbicides are often perceived as poisonous (Hill *et al.* 2011). Further, herbicide application is not permitted near or on water in some countries, thus reducing the management options for water hyacinth (Hill *et al* 2011). However, although used in the past, it is important to note that most of mentioned chemical above have now been forbidden on the market, especially in Europe and North America.

1.10.3 Biological control

In recent years, focus has shifted to natural enemies of water hyacinth including pathogens (Dagno *et al.* 2012; Villamagna & Murphy 2010). The aim of any biological control is not to eradicate the weed, but to reduce the weed's abundance to a level where it is no longer problematic. Biological control agents depend entirely upon the host plant for survival (Debach 1974). They impose a stress on water hyacinth populations which reduces plant vigour and growth rates (Center 1994).

Biological control is the use of host-specific agents that are naturally occurring enemies of invasive weeds in their native bio-region to reduce population density of the targeted pest (Howard & Harley 1998; Williams & Hecky 2005). Biological control has proved to be the most sustainable, environmentally safe, cost-effective and efficient solution for most alien invasive plants (Harley *et al.* 1996; Gassmann *et al.* 2006), and its process is slow and will likely be most effective where persistent populations are subjected to frequent control operations (Center 1987). The two draw-backs, assuming that host specificity is guaranteed, is that biological control usually takes between 3–5 years for the insect population to reach a level where control can be achieved (Julien *et al.*

1999) and it does not always work (Salmah *et al.* 1991; McFayden 2000; Julien *et al*. 2001). Through plant damage caused by feeding, biological control agents disrupt the competitive balance between plant species, in favour of native species (Van *et al.* 1998).

Biological control agents have been used successfully to control water hyacinth, *Salvinia molesta*, red fern, and water lettuce in a number of locations around the world, including Africa (Cilliers *et al.* 2003, Coetzee *et al.* 2009).

Research into the biological control of water hyacinth was initiated in 1961 by the United States Department of Agriculture, and the first control agents were released in Florida about 10 years later (Perkins 1972, 1973). Since this time, there have been a number of surveys in South America with the purpose of identifying natural enemies (phytophagous, insects, mites and pathogens) which might be suitable as biological agents for release on the weed in its introduced range (Center 1994; Hill 1999).

1.10.3.1 Different agents used in biological control

Arthropods, fungi and other new agents have contributed and continue to contribute to biological control of water hyacinth in about 34 countries around the world (Limon 1984; Harley & Wright 1984; Julien 1987; Julien 2001; Coetzee *et al*. 2009; Coetzee *et al.* 2011a; Coetzee *et al.* 2011b).

1.10.3.1.1 Arthropods

Perkins (1974) listed more than 70 species of arthropods that feed on water hyacinth and stated that the list was not definitive. Despite the length of this list (which includes records of North America and India), the number of species considered candidates for classical bio-control programmes were few. Indeed, to date, the two weevils species *Neochetina eichhornia* Warner (Coleoptera: Curculionidae), and *Neochetina bruchi* Hustache (Coleoptera: Curculionidae), *Niphograpta albiguttalis* Warren (= *Sameodes albiguttalis* (Warren)) (Lepidoptera: Pyralidae) are the most successful, widely-used agents and have been released in 32, 30, and 13 countries respectively since 1971 where biological control against water hyacinth has been implemented

(Julien & Griffiths 1998; Julien *et al.* 1999; Batcher 2000; Julien 2000; Julien *et al.* 2001) (Table 1.6).

1.10.3.1.1.1*Neochetina eichhorniae* and *Neochetina bruchi* (Coleoptera: Curculionidae)

Originating in Argentina (Center 1985; DeLoach & Cordo 1976), the whole life cycle of weevils *N. eichhorniae* and *N. bruchi* take place on *E. crassipes* and its control is enhanced when the two occur together (Julien *et al.* 1999). The number of eggs lay by weevil's adults varries from one area to another one, and can in some areas reach 7.3 and 8.5 eggs / female / day for *N. eichhorniae* and *N. bruchi* in Argentina respectively (DeLoach & Cordo 1976). These eggs are lay during the night by adults on leaf and petiole tissues. After a period of seven to 10 days, the eggs hatch and the development from larval stage to adult can take up to 30 to 45 days for *N. eichhorniae*, although the development of *N. bruchi* develop can be faster (Coetzee *et al.* 2009a). Once they emerge, the adults start to feed on the plant by depriving it from cholorophyll (DeLoach & Cordo 1976). As with the development of larval, when their life cycle is compared, 96 days are needed for *N. bruchi* to pass from egg to adult while for *N. eichhorniae* it is 120 days (DeLoach & Cordo 1976). Three generations can be produced in a year for both species in their area of origin, while in areas where they are introduced the different conditions occurring such as temperature and nutrient status may influence their control (Coetzee *et al.* 2009a). Because their life cycle is so close, both species can coexist together, however, *N. bruchi* will have a preference for old and bulbous petioles for its oviposition, while *N. eichhorniae* will prefer young central leaves (Harley 1990). Growth population of *N. eichhorniae* and its damages are more efficient in areas where *E. crassipes* plant has a high concentration of nitrogen, than *N. bruchi* which is more dependent on better quality plant material (Heard & Winterton 2000).

Table 1.6 Biological control agents against *E. crassipes* used, with the countries and years of introduction (from Julien 2000; Coetzee *et al.* 2011; Tipping *et al.* 2014)

	Coleoptera : Cucurlionidae		**Lepidoptera : Crambidae**	**Hemiptera : Miridae**	**Acarina : Saroptiformes : Galumnidae**	**Lepidoptera : Pyralidae**	**Mycospha-erellales : Mycospha-erellaceae**	**Orthoptera : Acrididae**	**Hemiptera: Delphacidae**
Species Countries	***Neocheti na bruchi***	***Neochetina eichhorniae***	***Niphograpta albigutallis***	***Eccritotarsus catarinensis***	***Orthogalumna terebrantis***	***Xubida infusellus***	***Cercospora piaropi***	***Cornops aquaticum***	***Megamelus scutellaris***
Australia	1990	1975	1977			1981 ; 1996f			
Benin	1992	1991	1993	1999					
China	1996	1996		2000					
Congo	1999	1999							
Cuba	1995								
Egypt	2000	2000							
Fiji		1977							
Ghana	1994	1994	1996						
Honduras	1989	1990							
India	1984	1983			1986				
Indonesia	1996	1979							
Kenya	1995	1993							
Malawi	1995	1995	1996	1996					
Malaysia	1992	1983	1996						
Mexico	1995	1972							
Mozambique	1972	1972							
Myanmar		1980							
Nigeria	1995	1993							
Panama	1977		1977						
Philippines	1992	1992							
PNG	1993	1986	1994			1996			
Rwanda	2000	2000							
Solomon Islands		1988							
South Africa	1989	1974	1990	1996	1989		1987	2011	2013
Sri-Lanka		1988							
Sudan	1979	1978	1980						

	Coleoptera : Cucurlionidae		**Lepidoptera : Crambidae**	**Hemiptera : Miridae**	**Acarina : Saroptiformes : Galumnidae**	**Lepidoptera : Pyralidae**	**Mycospha-erellales : Mycospha-erellaceae**	**Orthoptera : Acrididae**	**Hemiptera: Delphacidae**
Species Countries	***Neocheti na bruchi***	***Neochetina eichhorniae***	***Niphograpta albigutallis***	***Eccritotarsus catarinensis***	***Orthogalumna terebrantis***	***Xubida infusellus***	***Cercospora piaropi***	***Cornops aquaticum***	***Megamelus scutellaris***
Taiwan	*1993*	*1992*							
Tanzania	1995	1995							
Thailand	1991	1979	1995			1999			
Uganda	1993	1993							
USA	1974	1972	1977						2010
Vietnam	1996	1984							
Zambia	1997	1971 ; 1996	1971 ; 1997	1997	1971				
Zimbabwe	1996	1971	1994	1999					
Total	**30**	**32**	**13**	**6**	**3**	**3**	**1**	**1**	

1.10.3.1.1.2 *Niphograpta albiguttalis* (Lepidoptera: Pyralidae)

Also originating from Argentina (Center 1987), *Niphograpta albiguttalis* larvae cause damage by feeding within the petioles, through necrose and moisture to the growth meristems (Coetzee *et al.* 2009a). With an average of 370 eggs produce in their life cycle, female of *N. albiguttalis* lay their eggs in the aerenchyma of *E. crassipes* leaves (Center 1994). The development from egg to larvae takes 14 days, and thereafter, the larvae can pupate inside the petiole from which emerge adults after a period of seven to 10 days (DeLoach & Cordo 1978). Compared to *Neochetina* species which produce three generation in a year, *N. albiguttalis* can produce until five generations, and the life of an adult ranges between four to nine days (Center 1994). During their development, damages cause on the petioles by *N. albiguttalis* are severe (DeLoach & Cordo 1978), and in return, the plant respond by increasing the leaf's production, which replaces the leaves damaged by herbivory (Center 1984b). These damages therefore affect the plant which can no longer floated, reducing the transfer of nutrients to the plant (Center & Van 1989). For the establishment of this biocontrol agent to be successful, *E. crassipes* mat should be at a young stage, with small, luxuriant shoots with inflated leaf petioles typical of the colonizing form of the plant (Center 1982; Center 1984a). Although they cause various degrees of damages to the leaf of the plant, *N. albiguttalis,* does not kill *E. crassipes* shoots, (Center 1984b).

1.10.3.1.1.3 *Orthogalumna terebrantis* Wallwork (Acarina: Galumnidae)

Orthogalumna terebrantis is a leaf-mining mite that is extremely damaging to water hyacinth. However, it has not yet been released in all the coutries where the other agents have been (EPPO 2008). Nevertheless, they also lay their eggs on the leaf of the plant, especially in areas where they fed, which are considered to be ideal oviposition sites (Coetzee *et al.* 2009a). After the eggs have hatched (after eight days), one larval and three nymphal stages take place, and the development is achieved after 15 days (Cordo & DeLoach 1975, 1976). Adults live up to 85 days after they have emerged from exit holes (Coetzee *et al.* 2009a). Three generation can be produced per year, although in their native area (Argentina), Cordo & DeLoach (1976) found that *O. terebrantis* population numbers varied considerably from year to year another one. However, this mite has not been able to establish in colder climates and is presently restricted to the warmer parts of Africa (Akpabey 2012).

1.10.3.1.1.4 *Eccritotarsus catarinensis* Carvalho (Hemiptera: Miriadae)

Released in South Africa in 1996 (Hill et al. 1999) Eccritotarsus catarinensis is a leaf-sucking mirid, and the one of the recent agent against E. crassipes. Eggs are lay underneath of the leaf and hatch after nine days. In the late 1990s and early 2000s respectively, the mirid was released in Malawi (Phiri et al. 2001), and China (Ding et al. 2001), but whether it has established in these countries is uncertain. It was also released in Benin in 1999, but failed to establish, although the reasons for this are unclear (Ajuonu et al. 2007).

1.10.3.1.1.5 *Xubida infusella* Walker (Lepidoptera: Pyralidae)

This moth has only been released in Australia and Papua New Guinea, in 1996 and 1997, respectively, and has established in both countries (Julien & Stanley 1999 in Coetzee *et al.* 2009a). Folder leaves are ideal sites for egg, and when they hatch, they tunnel the petiole of the plant from the base (Coetzee *et al.* 2009a). Their damages are noted on the leaf petiles but also on the shoot of the plant where they feed on the apical meristems; and two months is sufficient for them to complete their development (Coetzee *et al.* 2009a). *X. infusella* was also imported into South Africa for host-specificity testing, butdue to other priorities, the importation stopped (Hill & Cilliers 1999).

1.10.3.1.2 Pathogens

Of the nearly 70 recorded fungi and bacteria found on water hyacinth, only 15 have been properly tested and found to be highly virulent (Charudattan 2001). Three of these: *Acremonium zonatum* (Sawada) W. Gams (*Ascomycotina*), *Alternaria eichhorniae* Nag Raj & Ponappa, *Cercospora piaropi* (= *C. rodmanii* Conway) Tharp have proved effective in controlling water hyacinth (Martyn & Freeman 1978; Charudattan *et al.* 1985; Shabana *et al.* 1995).

1.10.3.1.2.1 *Acremonium zonatum* (Sawada) W. Gams (Ascomycotina)

This fungus causes necrotic zonate leaf spots, distinguished by spreading lesions primarily on the upper leaf surface (Martyn & Freeman 1978)

1.10.3.1.2.2 *Cercospora piaropi* Tharp (= *C. rodmanii* Conway*)* Mycosphaerellales: Mycosphaerellaceae

These two species have recently been merged into one species *C. piaropi* (Tessman et *al.* 2001), which is capable of decreasing *E. crassipes* biomass by a dark brown spot that it causes on *E. crassipes* leaves which can become necrotic and, in some instances, has caused the substantial decline of *E. crassipes* populations (Freeman & Charudattan 1984; Charudattan *et al.* 1985; Martyn 1985; Morris 1990). *Cercospora Piaropi* was released for the first time in South Africa in 1987 (Coetzee *et al.* 2011a).

1.10.3.1.2.3 *Alternaria eichhorniae* Nag raj & Ponappa

It was first reported as a potential control agent for *E. crassipes* in India in 1970. It is a highly virulent, host-specific pathogen that induces distinct necrotic spots surrounded by yellow halos on the leaves. Its potential as a mycoherbicide was investigated in Egypt (Shabana *et al.* 1995, 1997, 2001).

1.10.3.2 New agents

Although many of the *E. crassipes* control agents have been successful in controlling populations of *E. crassipes* in many parts of the worlds, there remain numerous geographical regions where *E. crassipes* infestations still cause considerable problems. As a result, bio-control practitioners are increasingly under pressure to improve predictions of success and to determine the potential impact of a candidate agent on the target plant prior to release (Pantone *et al.* 1989; Sheppard 2003, Balciunas 2004). Pre-release efficacy testing is now considered a critical aspect of pre-release studies (Balciunas 2004; McClay & balciunas 2005). Several additional species of insects occurring on *E. crassipes* in South America could be considered for introduction as biological control agents (Cordo 1999). These include *Bellura densa* Walker (Lepidptera: Noctuidae), *Cornops aquaticum* (Bruner) (Orthoptera: Acrididae), *Megamelus scutellaris* Berg (Hemiptera: Delphacidae), *Taoxa inexacta* Walker (Hemiptera: Dictyopharidae) and several other species like *Trypticus* sp. (Diptera: Dolichopodidae) (Center *et al.* 2002; Center 1985; Bownes *et al.* 2010).

Bellura densa is an oligophagous moth, native from North-America. Although very damaging to *E. crassipes*, its natural host is *Pontederia cordata* L. (Pontederiaceae). The larvae bore down through the petioles and attack the crowns of water hyacinth, causing the death of the plant. Despite the extreme damage it causes on *E. crassipes*, Center & Hill (2002), recommended that it not be introduced outside its native range because although it prefers plants in the Pontederiaceae family, it is not restricted to this family and can be a threat for plant in the Araceae.

Cornops aquaticum is a grasshopper, which too, is extremely damaging to *E. crassipes*. Native of South America, it is widely distributed in its native range, inhabiting lowlands from Mexico to Central Argentina and Uruguay (Adis *et al.* 2007). It was first introduced into quarantine in South Africa in 1995 for host-specificity testing which showed it to be oligophagous, utilising species in the family Pontederiaceae (Bownes *et al.* 2010). Both the nymphs and adults of *C. aquaticum* are defoliators and, at high densities, they destroy water hyacinth flowers and strip the epidermis from the petioles (Coetzee *et al.* 2011b).

It was approved for release in South Africa in 2007, but further testing is required to determine its impact on *E. crassipes* under different nutrient conditions, its thermal tolerance, and its interactions with the control agents already released in South Africa, and the rest of Africa (Coetzee *et al.* 2009) especially about the potential impacts *C. aquaticum* could have on the level of control already exerted by the *Neochetina* weevils, the most widely used and successful agents released in Africa, if *C. aquaticum* spreads from South Africa. It was first released in South Africa early in 2011 (Coetzee *et al.* 2011b).

The delphacid bug, *Megamelus scutellaris* is a more promising monophagous agent. Field data and laboratory host-specificity testing in its native range have confirmed its host specificity (Sosa *et al.* 2007). *M. scutellaris* is a sap feeder that occurs throughout the range of water hyacinth in South America. It is a multivoltine insect, producing overlapping generations each year (Sosa *et al.* 2005). Adults mate soon after ecdysis, and females lay their eggs in the leaf laminae and upper petioles. Nymphs emerge 1–2 weeks later; and complete five instars, feeding extensively on the leaf lamina and petioles, and producing honey-dew (Sosa *et al.* 2005).

Based on abundance and distribution, the most promising agents are *Thrypticus truncates* Bickel & Hernadez and *T. sagittatus* Bickel & Hernadez, both specific to *E. crassipes*, whose larvae cause damage by mining the petioles, auguring well for their use as biological control agents (Bickel & Hernandez 2004; Hernandez *et al.* 2007). Both species are from Argentina (Bickel & Hernandez 2004; Hernandez *et al.* 2007). Because of the use of other species for biological control of water hyacinth in South Africa, *Trypticus* species, unfortunetaly is not yet considered for release in field despite the fact it reach high densities on the field (Coetzee *et al.* 2011a).

Amongst *Taosa* species (Hemiptera: Dictyopharidae), *T. inexacta* (Walker) and *T. longula* (Remes Lenicov) appear to be very specific to *E. crassipes* (Remes Lenicov & Hernandez 2010). *Toasa inexacta* has shown to be a species that is associated with the Pontederiaceae in the Americas (Cruttwell 1973 in Remes Lenicov & Hernandez 2010). However, until the completion of the research conducted by the SABCL with the collaboration of the MLPA on the evaluation of the capacity of *T. longula* as biological control agent on *E. crassipes*, *T. longula* cannot yet be released in the field (Remes Lenicov & Hernandez 2010)

1.10.3.3 Impact of release of biological control agents

Although *E. crassipes* still remains a significant problem in the South of China (Ding *et al.* 2001; Chu *et al.* 2006), India (Kathiresan 2000), Mexico (Jiménez & Balandra 2007), the South America, and some parts of Australia despite intensive implementation of biocontrol programmes, control has been successful in tropical countries. In these countries, only *N. eichhorniae* and *N. bruchi* have been released and ther impact quantified. Satisfactory contolwas achieved in Papua New Guinea (Julien & Orapa 1999, 2001), Malawi (Phiri *et al.* 2001), Lake Victoria (Ogwang & Molo 1999; Cock *et al.* 2000; Albright *et al.* 2004; Wilson *et al.* 2007), Sudan (Bashir 1984; Beshir & Bennett 1985), and to a lesser degree in Benin (Ajuonu *et al.* 2003). In several more countries, like Ghana, Nigeria, Niger, Burkina Faso, suubstancial reductions have been observed without being quantified.

In Australia, where *Neochetina eichhorniae* was first released in 1975 and *N. albiguttalis* in 1977, the first reported collapse of water hyacinth was in 1978, followed by severe damage by *N. eichhorniae* at an infested site at Rockhampton (Wright 1979).

In India, releases of *N. eichhorniae* began in March 1983 and continued until December 1986 with more than 22 000 adults of this species and 3 500 of *N. bruchi* being released in eight water hyacinth-infested tanks in and around Bangalore, with a total surface area of about 1 000 ha. At several sites, a reduction of about 90% was recorded within three years, and following these preliminary successes, both *Neochetina* species were released in other parts of the country, and there, similar results were obtained (Jayanth 1987; 1988).

The first successful biological control on the African continent was in the Sudan (Beshir & Bennett 1985). There, *N. eichhorniae* was introduced in 1978, *N. bruchi* in 1979 and *N. albiguttalis* in 1980. Here, every water hyacinth plant was scarred by feeding marks of the adult weevils and control of water hyacinth throughout the Nile in Sudan. Since then, there have been no accumulations of water hyacinth and few plants can be observed (Bashir 1984; Beshir & Bennett 1985).

Around Lake Victoria's shoreline in Kenya, Tanzania and Uganda, water hyacinth covered an estimated 20 000 ha at the peak of the infestation, creating socio-economic and health problems for lakeside residents (Mailu 2001). The two *Neochetina* weevils were released there in 1995. Numerous weevil rearing stations were erected around the lake and with aid of fishing communities, several million weevils were released. Together with mechanical efforts, the water hyacinth biomass was reduced by an estimated 80% within a period of four years on the Ugandan part of the lake (Cock *et al.* 2000).

On the Kenyan shores of the lake, some four years after introduction, adult weevil numbers varied from 0 to 32 per plant with an average of six adults per plant, and weed coverage had been reduced by up to 80% (Ochiel *et al.* 2001).

In Tanzania, an integrated control approach which included manual removal of the weed from fishing beaches and the introduction of the two weevils resulted in a 70% reduction of water hyacinth within three years (Mallya *et al.* 2001). In all three countries the main agent was *N. bruchi*.

Elsewhere in the region, the weevils reduced water hyacinth coverage by 80% on Lake Kyoga in Uganda (Ogwang & Molo 1999). The release of the weevils on the Sigi and Pangani rivers in Tanzania in 1995 reduced the amount of the manual removal required to keep the river channel open (Mallya 1999).

Weevils have also been released in Democratic Republic of Congo in 2000 and 2001; reductions were observed 2-3 years after release, which is too short to assess final impact (Mbati & Neuenschwander 2005).

The biological control programme in South Africa, started in 1974, has released seven arthropods and one pathogen as natural enemies against water hyacinth. In some of these areas, good control has been achieved, while in other areas, low temperature in high altitude climatic areas, and interference from other control options have retarded biological control.

Malawi has a successful water hyacinth biological control programme on the Shire River (Phiri *et al.* 2001) and the weed is under good control on Lake Kariba in Zimbabwe and Zambia (Chikwenhere *et al.* 1999).

In northern Egypt, *N. eichhorniae* and *N. bruchi* were released in August 2000 on two lakes. By July 2001, water hyacinth on Lake Edko was reduced by 90% (Akpabey 2012), but on Lake Mariout, reduction was slower due to water pollution.

At Tevedji, Lihu, and Kafedji on the Ouémé River in Benin, where *N. eichhorniae,* the dominant species is widely dispersed, and *N. bruchi* is confined to the release localities, water hyacinth cover was reduced from 100% to 5% within eight years. The same result has been obtained in Lake Azili, while the same level of control was achieved in just five years, where the weevils had dispersed from the release site to 15 km away (Ajuonu *et al.* 2003).

In Ghana, biological control using *Neochetina* weevils was initiated in 1994 with releases in the Abby-Ehy-Tano River and lagoon complex in south western Ghana in March. Reports from Accra indicate that there has been considerable decline in the water hyacinth infestation since the release of *Neochetina* weevils (Akpabey 2012).

Biological control projects on water hyacinth have also been initiated in Burkina Faso, Togo, Mali, Niger, and Nigeria. *Neochetina eichhorniae* and *N. bruchi* were released in Lake

Kainji in 1993/95 by the Nigerian Fisheries Research Institute in New Bussa in collaboration with the International Institute of Tropical Agriculture. From there, beneficials spread on their own all along the Niger River and into the watershed of Cross River, .i.e., very close to Cameroon. This work was locally published by the Fisheries Authorities, with Femi Daddy as main author. The establishment and spread of the weevils was confirmed by Ajuonu (unpubl. results, IITA) in 1998. However, to date, biological control has not yet been introduced in Cameroon.

1.10.3.4 Limitations to successful biological control

In the history of weed biocontrol, many agents have become established and built up good numbers, but have failed to have an impact on the target plant (Myers 2000; McClay & Balciunas 2005). Indeed, the success of biological control programmes on water hyacinth, as exemplified by the impact of control agents on *E. crassipes*, is without a doubt affected by the plant's quality, which in turn, is determined by the nutrient status of the water in which it grows (Heard & Winterton 2000; Coetzee *et al.* 2007). In some locations, the enriched nutrient status of the plants adversely affects the impact of the insect control agents on the plant as the insects are unable to suppress the growth rate adequately, because the plants proliferate too quickly (Hill & Cilliers 1999; Coetzee *et al.* 2007). Therefore, the role of contamination of waterways that causes eutrophication and the toxicity that affects the biology and population dynamics of biological control agents remains unresolved. These and other issues limit effectiveness of the agents and the level of control that can be achieved (Julien 2001).

For example, Hammarsdale Dam, in Kwazulu-Natal, South Africa, is a highly eutrophic system that receives runoff from a wastewater treatment plant, which collects effluent from textile factories and a chicken farm (Hill & Olckers 2001). There, both *N. eichhorniae* and *E. catarensis* have been released, and despite having reached high population densities, they have had minimal impact on the *E. crassipes* infestation, presumably due to the high growth rate of the plant (Hill & Olckers 2001).

Another factor affecting biological control of *E. crassipes* is the hydrology of the smaller water bodies where the weed is a problem (Hill & Olckers 2001; Julien 2001), because the worst

E. crassipes infestations occur in a small, shallow water bodies. Although biological control might be effective, the plants cannot sink and might therefore survive.

Periodic flooding and drought of impounded water systems also cause variable results in the control of *E. crassipes* (Hill & Cilliers 1999; Julien 2001). In India, these factors compromise *E. crassipes* biocontrol because the life cycles of the biocontrol agents are interrupted in hot summers by the complete drying up of water bodies, and then, by heavy rainfall during the monsoon seasons when plants and insects are washed away in flood waters (Kathiresan 2000).

Climate certainly has an effect on the level of control of *E. crassipes*, especially in temperate regions where winter frosts occur. Cold winter temperatures hinder successful biocontrol of *E. crassipes* in the more temperate regions of the USA, South Africa and China (Coetzee *et al.* 2009). Indeed, the active growing season for *E. crassipes* and its agents is restricted to the warmer summer months (Hill & Cilliers 1999), but both are assumed to remain dormant over winter (Hill & Olckers 2001). Consequently, the cold induced mortality of the control agent populations and its reduced reproductive output are responsible for the lack of impact (Coetzee *et al.* 2009).

Possibly one of the biggest factors affecting successful biocontrol of *E. crassipes* is interference from herbicide operations (Center *et al.* 1999; Hill & Olckers 2001). To obtain immediate results, sometime herbicides are spread, and then, agent populations crash or disperse as a result of plant mortality, resulting in *E. crassipes* mats proliferating after regeneration from seed and isolated untreated plants, in the absence of control agents (Hill & Olckers 2001).

Overall, biological control has markedly reduced the threat of *E. crassipes* in many parts of the world and represents the highest return on investment of any of the control options. Hill & Julien (2004) maintain that the key to success of any biological control programme, but particularly in poorer rural countries, is appropriate transfer of technology and flexibility of the programme. Furthermore, political support is vital to the success of any *E. crassipes* control programme, engendered through the publicizing of the success, where the impact can be observed at the landscape level and real impacts accrue to affected communities.

1.10.4 Integrated control

A definition of integrated control could be the use of two or more control methods to achieve the optimum control of the weed in a given area (Hill 1999). These systems include physical, chemical and biological methods as components of an overall management strategy. This relies on the assumption that the control methods being integrated are compatible (Hill 1999). The development of effective, properly integrated management strategies for floating aquatic weed is a very complex task demanding extensive knowledge of weed biology, ecology and management techniques. Its success also largely depends on detailed planning, good administration and management, coupled with adequate financial support and long-term commitment (Findlay & Jones 1996). Since any of the above control methods alone may be ineffective, a logical and site-specific integration of different techniques is desirable (Guitiérez *et al.* 2000). Indeed, the integrated control using at the same time, biological control agents and herbicide control, is currently the most advocated control used, especially on the basis that both are compatible and that the formulation used in these herbicides should not be toxic to the natural enemies (Hill & Olckers 2001; Hill *et al.* 2012)

A study by Wright and Bourne (1990) showed that the use of 2,4-D could affect both *Neochetina* weevils and the moth *N. albiguttalis* as the chemical softened the leaf and petiole epidermis and it was therefore easier for the insects to enter the plants. However, the herbicide 2,4-D was applied to the plants without its surfactant, which Wright and Skilling (1987) had earlier found to be toxic to the insects.

Another study carried out in Cruz Pintatda reservoir in Mexico by Jiménez and Balandra (2007) showed that, one month after the establishment of insect *Neochetina* spp. and the spread of the mixture of pathogens (*Cercospora piaropi* and *Acremonium zonatum*), a reduction of 59% in the number of plants per square meter and 29% on wet weight were observed. Further, the number of green leaves per plant diminished 65% and the number of new ramets by 85%. Within three months after the combined biocontrol the reservoir was free of *E. crassipes*. Furthermore, Jahdav *et al.* (2008), during their studies in laboratory showed that water hyacinth sprayed with glyphosate at 0.8% of concentration were still alive at the end of the experiment and for the both biological control agents used (*N. eichhorniae* and *N. bruchi*) the proportion of damaged petioles of water hyacinth were greater than on the plants used as control which were not sprayed. In a more recent study, Hill *et al.* (2012), showed that, the glyphosate contained in herbicides Rodeo® and Roundup® resulted in low mortality of the mirid at all the concentrations tested, while the surfactants added killed between 60–100% of the mirid depending on the concentration.

Integrated control presents the only long-term and sustainable solution to *E. crassipes* management in which biological control agents can play a key role (Jiménez & Balandra 2007). For instance, Center *et al.* (1999) suggest that biological and herbicidal controls should be integrated, using herbicides to maintain water hyacinth infestations below management thresholds, but in a manner that conserves biological control agent populations. Further, to the success of integrated control, timing and mode of application need to be well managed (Hill *et al.* 2012).

1.10.5 Utilisation of water hyacinth

Although water hyacinth is often seen as a weed responsible for many of the problems outlined above, there are other schools of thought that advocate useful applications for the plant (Malik 2007). One hectare of *E. crassipes* may contains more than two million individual plants with a total wet mass of >300 T (Center & Spencer 1981). Due to its fibrous tissue, high energy and protein content, and its high biomass, there is speculation that water hyacinth can be used in waste water treatment, heavy metal and dye remediation, as a substrate for bioethanol and biogas production, electricity generation, industrial uses, medicines, animal feed, agriculture and sustainable development (Patel 2012).

1.10.5.1 Agricultural use

Decomposed water hyacinth can be used on the land as surface mulch or as compost (Woomer *et al.* 2000; Lindsey & Hirt 2000) that improves poor quality soil (Ndimele *et al.* 2011). After decomposition, the detritus of water hyacinth can be mixed with ash, soil and some animal manure (Lindsey & Hirt 1999). Microbial decomposition breaks down the fats, lipids, proteins, sugar and starches. The mixture can be left in piles to compost, the warmer climate of tropical countries accelerating the process and producing rich pathogen free compost which can be applied directly to the soil.

Mulching field crops with water hyacinth was found to increase the production of lady's finger (Okra) (67%), potato (14%) and tomatoes (90%) as compared to control (no mulching) treatment (Sannigrahi *et al.* 2002). In developing countries where mineral fertiliser is expensive and soil quality is poor, it is a practical solution to the water hyacinth proliferation (Ndimele *et al.* 2011). However, its high alkalinity (pH>9) and potentially toxic metal contents would restrict its use to flowering-plants, with no allowable application to horticulture for edible vegetables (Chunkao *et al.* 2012; Zhang 2012). Besides, due to the excessive labour necesariy to move such masses of leaves, the main condition for mulching to be possible it is the field is close to infested waterways.

1.10.5.2 Phytoremediation

Water hyacinth has the potential to clean up various contaminated waters and therefore can be used to aid the process of purification of water (Mahamadi & Nharingo 2010; Rhaman & Hasegawa 2011; Smolyakov 2012). It can be used to treat wastewater from dairies, tanneries, sugar factories, pulp and paper industries, palm oil mills, distilleries etc. (Jafari 2010). The plant can absorb into its tissues large quantities of heavy metals as well as persistent organic pollutant from the water column and grows very well in water polluted with organic contaminants and high concentrations of plant nutrients (Chunkao *et al.* 2012).

For example, Zhu *et al.* (1999) have studied the ability of water hyacinth to take up and translocate six trace elements namely As (V), Cd (II), Cr (VI), Cu (II), Ni (II), and Se (VI) under controlled conditions. Cd, Cr. Cu, Ni, and As were more highly accumulated in roots when the concentrations are high. Moreover, water hyacinth had high trace element bio-concentration factors (BCF) when supplied with low external concentrations of six elements, particularly Cd (highest BCF = 2150), Cr (1823), and Cu (595).

In California, water hyacinth tissue was found to have as good a concentration of mercury as the sediment beneath, suggesting that plant harvesting could help mediate mercury contamination (Greenfield *et al.* 2007).

While water hyacinth's capacity to absorb nutrients makes it a potential biological alternative for treatment of agro-industrial wastewater, one of the major challenges is how to properly dispose of the vast amount of the plant material which may have to be considered as toxic waste (Zhang 2012).

1.10.5.3 Biogas production

Water hyacinth fulfils all the criteria deemed necessary for bioenergy production; it is perennial, abundantly available, a non-crop plant, biodegradable and has high cellulose content. The biomass can be subjected to biogas production to generate energy for household uses in rural areas (Chuang *et al.* 2011). Indeed, the process is one of anaerobic digestion which takes place in a reactor or digester (an air-tight container usually sited below ground) and the usable product is methane gas which can be used as fuel for cooking, lighting or for powering an engine to provide shaft power (Calvert 2002). However, use of the water hyacinth for digestion in a traditional digester presents some problems (Mshandete *et al.* 2004) such as large digester size, lower biogas conversion efficiency (due to very high water content) and mandatory pre-treatment before digestion (to remove air trapped in the tissue).

It can also be used to produce ethanol, but technical and logistic challenges need to be overcome before a commercial scale ethanol production becomes reality because of the high tissue water content (Ndimele *et al.* 2011).

1.10.5.4 Animal fodder

The high water and mineral content of water hyacinth indicates that the nutrients in a water hyacinth may be available and suitable to some animals. Sun-dried water hyacinth has been found to be rich in protein, vitamins and minerals. Boiled and chopped water hyacinth along with vegetable waste, rice bran, copra cake and salt is used to make a suitable feed for pigs in China. In Malaysia, Indonesia, Philippines and Thailand cooked water hyacinth is used as a supplement feed for pigs, ducks and fish (Vandermeer & Verdegem 1996).

Dehydrated water hyacinth has been added to the diet of channel catfish fingerlings to increase their growth (Gopal 1987). Water hyacinth has also been recommended as cattle feed (Kivaishi & Mtila 1995). However, it is not recommended for use if it has been primarily used to remove heavy metals or toxic substances from wastewater (Chunkao *et al.* 2012). The use of water hyacinth for animal feed in developing countries could help to solve some of the nutritional problems that exist in these countries (Malik 2007).

1.10.5.5 Other

As a readily available resource, the fibres from the stems of the water hyacinth plant have been used in several small cottage industries in the Philippines, Indonesia and India for rope, basket, mats, shoes, sandals, bags, wallets, vases and even good quality paper if blended with waste paper or jute (Malik 2007; Ndimele *et al.* 2011; Patel 2012).

Despite the wide range of uses of water hyacinth, the scope for large-scale utilisation of water hyacinth is limited because of the transport costs. Further, water hyacinth, because it contains more than 90% water, is very heavy and bulky to transport. Any large-scale application must, therefore, be situated close to where water hyacinth grows. Yet, these small-scale industries are rarely successful reducing at infestations and the market for these products is far too small to have any impact on water hyacinth populations. In addition, income generation may facilitate its spread to new, uninvaded water bodies (Anonymous 2013).

1.11 Aims and objectives of the study

Aquatic weeds have contributed to several problems worldwide. Water hyacinth the world's worst one has caused more serious damage, especially in the developing countries where the lack of knowledge, the real extent of the impacts of the socio-economic status and welfare of the population who depend on the affected water is not often well quantified and documented. Furthermore, institutional, technical and financial problems are the main constraints in the fight against the proliferation of the weed. An appropriate measure to manage this scourge is especially important in Cameroon, where water hyacinth is a continuous threat for the riparian communities and their development. This research is intended to provide important knowledge for research teams and experts involved in this domain.

The principal aim of this study is to investigate the biotic and abiotic factors which contribute to the proliferation or the invasion of *Eichhornia crassipes*, assess the impact that the biological control and the fungal pathogen could have on the spread of *E. crassipes* in the city of Douala and its environs and finally, to quantify the socio-economic impact of water hyacinth in the riparian communities.

Chapter two provides a detailed description of the littoral region, the level of water hyacinth infestation along this region and assesses the impact of biotic and abiotic factors on productivity of water hyacinth in Cameroon. The baseline record of water hyacinth infestation in the city of Douala and environs is provided as well as the distribution of this weed in this area. The investigation addresses how the biotic and abiotic factors in Cameroon, and especially in the infested areas, can affect its growth and proliferation. During this investigation, the physical and chemical parameters, hydrological status of the water body and nutrient content in the plants were measured, the plant biodiversity associated with water hyacinth collected and analyzed and finally the plant growth correlated with these parameters.

The impact of water hyacinth on aquatic plants communities in the Wouri River Basin (Douala-Cameroon) was investigated to understand the impact of water hyacinth on the abundance and diversity of plant communities in the selected sites, to assess the species which are especially associated with water hyacinth in the Wouri River Basin, Cameroon, to associate the growth of these species with the physico-chemical parameters of the water in these ecosystems and finally make comparisons between the plant diversity of sites invaded by water hyacinth and those without water hyacinth (Chapter 3).

The social, economic, and health impact of water hyacinth on the life of riparian communities was investigated in chapter four. The impact of this aquatic weed was surveyed, using a questionnaire aimed at the population living in these areas, and discussing also control and management options that have been put in place so far to reduce the level of infestation, and thus impacts.

The status of fungal pathogens associated with *E. crassipes* in the city of Douala was evaluated in chapter five. The fungi on water hyacinth were identified, and their infection process and subsequent colonization on *E. crassipes* determined under specified conditions.

In chapter six, the status and distribution of biological control agents in the Wouri Basin, and implication for biological control of water hyacinth in Cameroon was assessed. First of all, the entire Wouri Basin was surveyed to confirm if biological control agents were present already in Cameroon, and if present, assess their impact on the decrease of water hyacinth mat. This included measuring the biological control agent populations and water hyacinth plant parameters and population densities, in order to determine which biological control agents are likely to be most effective at the different sites. Chapter seven presents the results of experimental studies of the influence of a tidal regime on the population dynamic of two biologicalcontrol agents on water hyacinth. Chapter eight provides a general discussion and conclusion of the study and make recommendations for enhancing the control of invasive alien species, especially water hyacinth, in the aquatic systems in Cameroon.

2 Chapter 2. Site description and impacts of abiotic factors on the growth of *Eichhornia crassipes* (Mart.-Solms) Laubach

2.1 Introduction

Cameroon, officially the Republic of Cameroon, is a country in the west central region of Africa. In 1472, a Portuguese sailor, Fernando Po, arrived in Cameroon via the river Wouri in Douala and, having discovered many shrimps in the river, he named it *Rio dos Camaroes* (River of Shrimps), whence the name Cameroon is derived. The Republic of Cameroon extends from 2°N to 13°N and between 8°25' W and 16°20' W, bordering the Bight of Biafra between Equatorial Guinea and Nigeria. The Cameroon coastline lies on the Bight of Biafra, part of the Gulf of Guinea and the Atlantic Ocean. The country has a total surface area of 475 650 km^2, of which 466 050 km^2 is land, and 9 600 km^2 is water (Anonymous 2010a), and it is referred to as "Africa in miniature" because of its geological, climatic and cultural diversity (Anonymous 2008). Natural features include beaches, Sahel zones, mountains, rainforests, savannah grassland and ocean coastland. Cameroon is bordered by Chad to the north, Nigeria to the west; to the south by Congo, Gabon, and Equatorial Guinea; to the east by the Central African Republic and a 350 km stretch of Atlantic Ocean coast-line (Anonymous 2008) (Figure 2.1).

Cameroon is divided into ten regions: Central, Littoral, North, South, South-west, North-west, Adamawa, Far North, West and East, and has a total population of 22 179 707 inhabitants (January 2015 estimate), 58% of whom live in urban areas. The population growth rate is 2.5% (Anonymous 2010b). The highest point in Cameroon is Mount Cameroon in the Southwest region (4 095 m), and the largest cities are Yaoundé (capital of Cameroon) with 2 765 568 inhabitants and Douala (economic capital, which is also the capital of the Littoral region) with 2 768 436 inhabitants (Figure 2.1). Cameroon is home to over 200 different linguistic groups (Anonymous 2008).

The country has four drainage systems. In the south, the principal rivers flow south-westward or westward directly into the Gulf of Guinea; the Wouri, and lesser Dibamba, Bimbia and Mungo flow into the Cameroon estuary near Douala; the Sanaga, Nyong, and Ntem flow further south along the coast into the sea; the Akwayafe and Manyu and the lesser Ndian and Meme flow out of the northern part of the coast. The Dja and Kadeï, however, flow south-easterly into the Congo River. In northern Cameroon, the Benoué River (Benue) runs north and west, eventually into the Niger, while the Logone River flows northward into Lake Chad. Only part of Lake Chad lies within Cameroon. The rest is in Chad, Nigeria, and Niger. The lake varies in size according to seasonal rainfall. Some of the borders of Cameroon follow rivers, including the Aïna, Akwayafe, and Ntem or Campo (Cho Mujingni 2012). The climate varies with terrain, from tropical along the coast to semi-arid and hot in the north.

2.2 Littoral Region

Located along the edge of the Atlantic Ocean at the bottom south eastern end of the Gulf of Guinea and at the mouth of the river Wouri, Douala, the headquarters (Capital) of the Littoral Region, possesses the largest port in the country and the most important one in the Central African Region. It is the most industrialized municipality in Cameroon with about 60% of the country's industries (Dieudoné 2006). The Littoral Region is bordered to the north by the West Region, to the West by the South-west Region, to the South by the Atlantic Ocean and the Southern Region and to the east by the Central Region (Figure 2.1).

According to projections for the year 2015 made by the Central Bureau of the Census and Population Studies (BUCREP 2010 a, b), based on the third general census of the population in 2010, the Littoral Region of Cameroon is home of 3 354 978 inhabitants constituting 14.8 % of the total population of Cameroon, with a density of 141.5 inhabitants per km^2 (Anonymous 2010a, 2010b). Four divisions made up the Littoral Region namely Mungo with 11 sub-divisions, Nkam with four sub-divisions, Sanaga-Maritime eight sub-divisions and Wouri which has six sub-divisions.

The urbanisation rate for the Littoral Region is 92.6 % (Anonymous 2010b). The riparian populations living in the Abo and Dibombari sub-division (Mungo division), Yabassi sub-division (Nkam division), and Douala I, Douala IV and Douala V sub-division (Wouri division) with a total of about 1 335 324 inhabitants, who derive direct benefits from the Wouri River Basin (Anonymous 2010b). These communities depend on the fresh water resources of the river for their livelihood.

Figure 2.1 Administrative map of Cameroon.

The main activities of these riparian communities are fishing, farming, transportation, logging of mangroves, hunting, palm wine tapping and sand extraction, and Douala is the closest city where they can sell their products and purchase goods. Douala lies between longitudes 9°40'

E and 9°50'E of the prime meridian and within latitudes 4°00'N and 4°54'N of the equator (Epule *et al.* 2011). It covers an area of 31 984 km², occupies about 18 000 hectares and has nearly 2 768 436 inhabitants (Anonymous 2010b). The annual population growth rate is 5% with a population density estimated at 3 830 inhabitants per square kilometre (Anonymous 2000).

For the population living in the Littoral Region and especially in the Douala sub-division, the river is important as a source of essential goods; it needs to be protected from all kinds of invasions. In order to protect their livelihood, it is important to discover the factors that promote the distribution of water hyacinth in Cameroon, especially in the Wouri Basin (Douala, Cameroon) and its environs.

2.3 Aims and objectives

2.3.1 General objective

The main objective of this study was to characterize the Wouri River Basin and quantify the impact of biotic and abiotic factors that influence the spread of water hyacinth at selected sites in this basin.

2.3.2 Specific objectives

The specific objectives were to:

- map the distribution of water hyacinth in the Wouri River Basin which encompasses the city of Douala;
- assess the biomass, density (number of individuals per quadrat of 0.5 x 0.5 m (0.25 m²)), and the growth parameters on 10 plants of water hyacinth in each site monthly;
- determine the physico-chemical parameters of the selected water bodies and soil samples that water hyacinth has infested;
- determine the relationship between the physico-chemical parameters and water hyacinth growth in each river sampled.

2.4 Characterization of Wouri River Basin

2.4.1 Presentation of the study zone and importance for riparian population

Considered to be one of the biggest division of the Littoral Region, the Wouri division is made up of six sub-divisions, namely: Douala I, Douala II, Douala III, Douala IV, Douala V and Manoka. The Wouri division includes the Wouri estuaries and lies between longitude 009°547'63''E and 009°849'16''E and within latitude 04°145'50''N and 04°002'28''N (Tsague 2013).

The Wouri River Basin is important for the population living around it because harbors many fish and crustacean species. The mangroves, which act as habitat for variety of species also protect the coast from cyclones, floods, sea–level rise, wave action and coastal erosion (Cho Mujingnu 2012).

2.4.2 Climate

The climate of Douala is equatorial (Din *et al.* 2002) with two seasons: a dry and rainy season, with the three driest months (December–February) and rainiest months between July and September. The maximum precipitation is recorded in July and August, while December and January are the warmest months (Figure 2.2).

Rainfall, temperature and wind are the factors which have a significant influence on the composition and quality of the vegetation of the forest area (Din 2007). Annual rainfall is between 3000 mm to 4000 mm with the highest rainfall in August, and the lowest rainfall in January, temperatures are relatively high with annual averages of about 26.7°C and very small thermal variations of 3 to 4°C (Din *et al.* 2008). The relative rate of humidity varies between 80–90% during the rainy season and 45–55% during the dry season (Priso 1994, Din *et al.* 2008). The wind speed is low (< 3m/s) during the non-monsoon period (Din 2007).

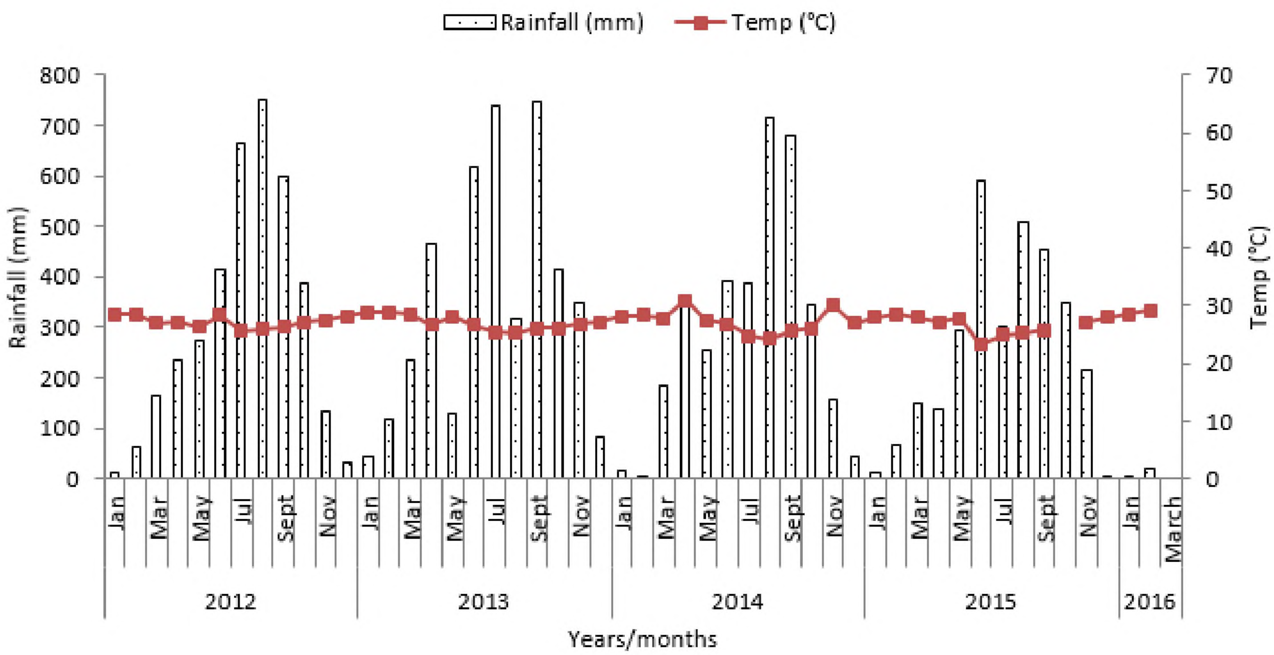


Figure 2.2 Umbro-thermal diagram Bagnouls and Gaussen (1957), Douala (2012-2014). (Meteorological Station Douala, 2014).

2.4.3 Relief

The relief is flat and the city is consequently subject to frequent floods almost all year round. Several factors favor the expansion of floods: the absence of natural or man-made drainage, an extensive low-lying area, and a high water table. The topography surrounding Douala varies from an altitude of approximately 57 m in the east to 3 m along the Wouri River in the west (Gue'vart *et al.* 2006). Generally, the land is dominated by plains presenting several swampy areas. This combination results in rapid and widespread inundation (Onana *et al.* 2005). The most frequently flooded areas in Douala are Mabanda and Bonanda in Bonaberi to the north (Douala IV) and the Youpwe area in the south (Douala I) (Gue'vart *et al.* 2006). As can be expected, these floods affect the economy and life of the city.

The catchments of the city of Douala vary from one area to another. Eleven catchments are recorded in the city with the largest in Tongo-Bassa (about 4200 hectares) and the smallest in Beseke (about 173 hectares) (Figure 2.3).

2.4.4 Hydrographical Network

The hydrographic network of Douala is very dense and tangled, mainly due to the impermeability of the crystalline formation of the basement (underground). All the streams are generally oriented north-east or south-west (Anonymous 2011a) (Table 2.1).

Table 2.1 Main watercourses of the Littoral Region

Water course	Orientation	Length (km)
Wouri	NE–SW	250
Mungo	N–S	150
Dibamba	E–W	150

The Wouri, Dibamba and Mungo are the rivers which constitute the drainage system of the entire Littoral Region; the Dibamba and Wouri drain the Douala metropolis. All these eventually drain into the Atlantic Ocean (Tening *et al*. 2013; Takem *et al.* 2010).

The Wouri flows within the Akwa, Bonaberi and part of the Bassa while the Dibamba flows on the eastern outskirts of the town (Tening *et al.* 2013). These rivers are fed by several streams, before finally joining the Gulf of Guinea.

The hydrographic network of the Wouri River extends about 45 000 km^2, and the surface temperature varies between 25 to 28 $^{\circ}C$ (Tsague 2013). All these rivers are normally loaded with the solid and liquid wastes channeled from industries, households, and waste dumps (Tening *et al.* 2013).

Although influenced by tides, communities of plants and animals especially adapted to this environment are supported by sheltered tidal water, with a wide range of habitats around the estuaries, including beaches, dunes, rocky foreshores, marshes and other wetlands, mud and sand flats, sea grass meadows, kelp forests and rocky reefs (DPIWE 2012).

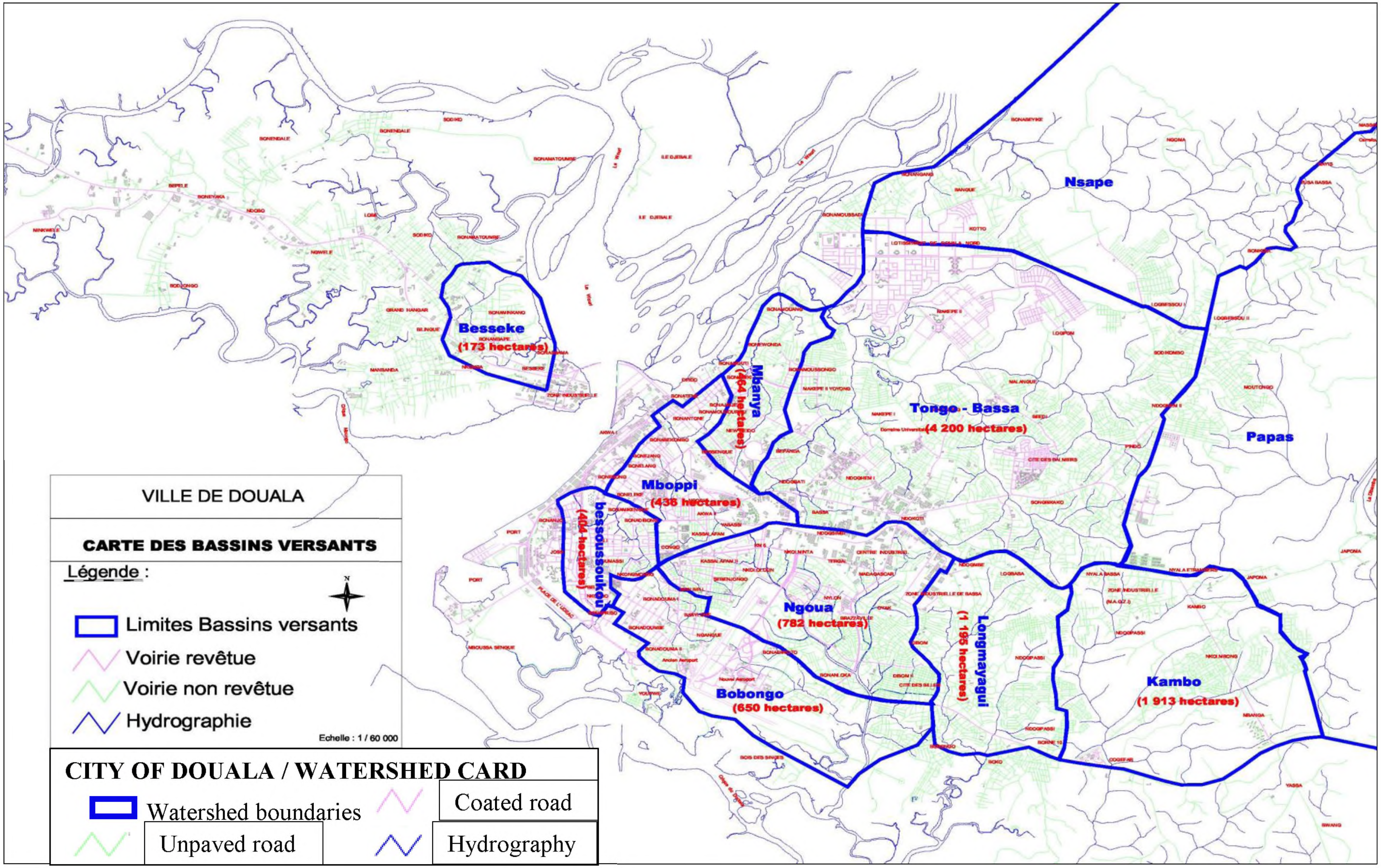


Figure 2.3 Watersheds of the city of Douala (Source: Douala Municipality).

2.4.5 Geology and Soil

The study zone is a part of the Douala sedimentary basin of the Cretaceous to Tertiary age, with a total cover area of 7000 square km and a maximum width of 60km (Takem *et al.* 2010, Tening *et al.* 2013). The stratigraphy of the Douala sedimentary basin according to Ntamak-Nida *et al.* (2010), consists of the Cretaceous Mungo River formation overlaid by the Mpundu formation. The Mungo River formation consists mainly of sandstone with a few intercalations of limestone and shale, while the Mpundu formation consists of poorly consolidated grits and sandstone that occasionally display bedding (Tening *et al.* 2013).

The city of Douala west to the Wouri section of the Mpundu formation which overlies the Mio-Pliocene stratum; it is generally constituted of unconsolidated fine-to coarse-grained sand and gravely sandstones mixed with silt and clay in various proportions (Takem *et al.* 2010, Tening *et al.* 2013).

The soil of the city of Douala is alluvial, resulting from the decomposition of sedimentary rocks. The composition of alluvium is dominated by quartz and koalinite with a general thickness that ranges between 50 and 60m (Djeuda-Tchapnga *et al.* 2001). Therefore, most soils are highly permeable for discharges of industries and agriculture.

2.4.6 Vegetation and Fauna

The Littoral Region is generally characterized by a mosaic vegetation which offers a diversity of habitats. This diversity is accentuated by factors like proximity of the sea, drainage, the nature of soils or ground altitudes, and several other anthropic activities, besides urbanization and agriculture (Ajonina 2006). The flora of Douala is chiefly ruderal plants next to which are found the mangrove forests which extend for about 30% of the actual limits of Douala (Din *et al.* 2008). The swamps situated behind these mangroves are dominated by tall herbaceous plants which include *Commelina benghalensis* Linn. (Commelinaceae), *Cynodon dactylon* L. (Poaceae), *Cyrtosperma senegelense* Schott (Araceae), *Echinochloa pyramidalis (*Lam.) Hitch. & Chase (Poaceae), *Eleusine indica* (L.) Gaertn (Poaceae), *Mimosa invisa* Brenan (Fabaceae), *Panicum maximum* Jacq. (Poaceae), *Polygonum limbatum* Meisn (Polygonaceae), and *Pueraria phaseoloides* (Roxb.) Benth (Fabaceae) (Priso *et al.* 2010a)

The fauna of the Wouri estuaries (Douala) is diverse. This is one of the most productive type of ecosystems on earth and also one of the most valuable (Anonymous 2011b) and is composed of:

- Mammals: an inventory of the region revealed the presence of more than 66 species of mammals, quantitatively dominated by the vivenidae, cercopithecideae, colobideae, sciurideae and cepholophineae.
- Birds: there are over 100 species of birds, 62 of which are aquatic
- Aquatic fauna: this group is widely diversified and is made up of vertebrates and invertebrates. The species found in the zone area include *Parachana obscura* Gunther (Channidae), *Pteriophtalmus* sp.
- Reptiles: crocodiles, turtles, snakes, lizards are found in the area.

2.5 Material and methods

2.5.1 Material

2.5.1.1 Experimental design and survey of the Wouri-Basin

After a first survey of the region and most of the sites invaded by water hyacinth in the Wouri Basin by boat and car (Figure 2.4), ten sites (which are all tributaries of the Wouri Basin) located at Bonaberi (Douala IV) in the Wouri Basin were chosen for a long-term study, to obtain a detailed understanding of the impacts of water hyacinth on the riparian communities (Figure 2.5). The location of each chosen site was determined using the Global Positioning System (GPS) (Garmin) and for each site, the surface and the depth of the river were evaluated according to the data provided by the municipality and a previous graduated measuring stick, respectively.

The selected sites were: Petit Bonanjo 1 and Petit Bonanjo 2, Grand Hangar, Bonawater (Château), Grand Baobab 1 and Grand Baobab 2, Bonassama Vallée, Centre Equestre, Forêt Bar, Saint Richard (Figure 2.4 and Table 2.2).

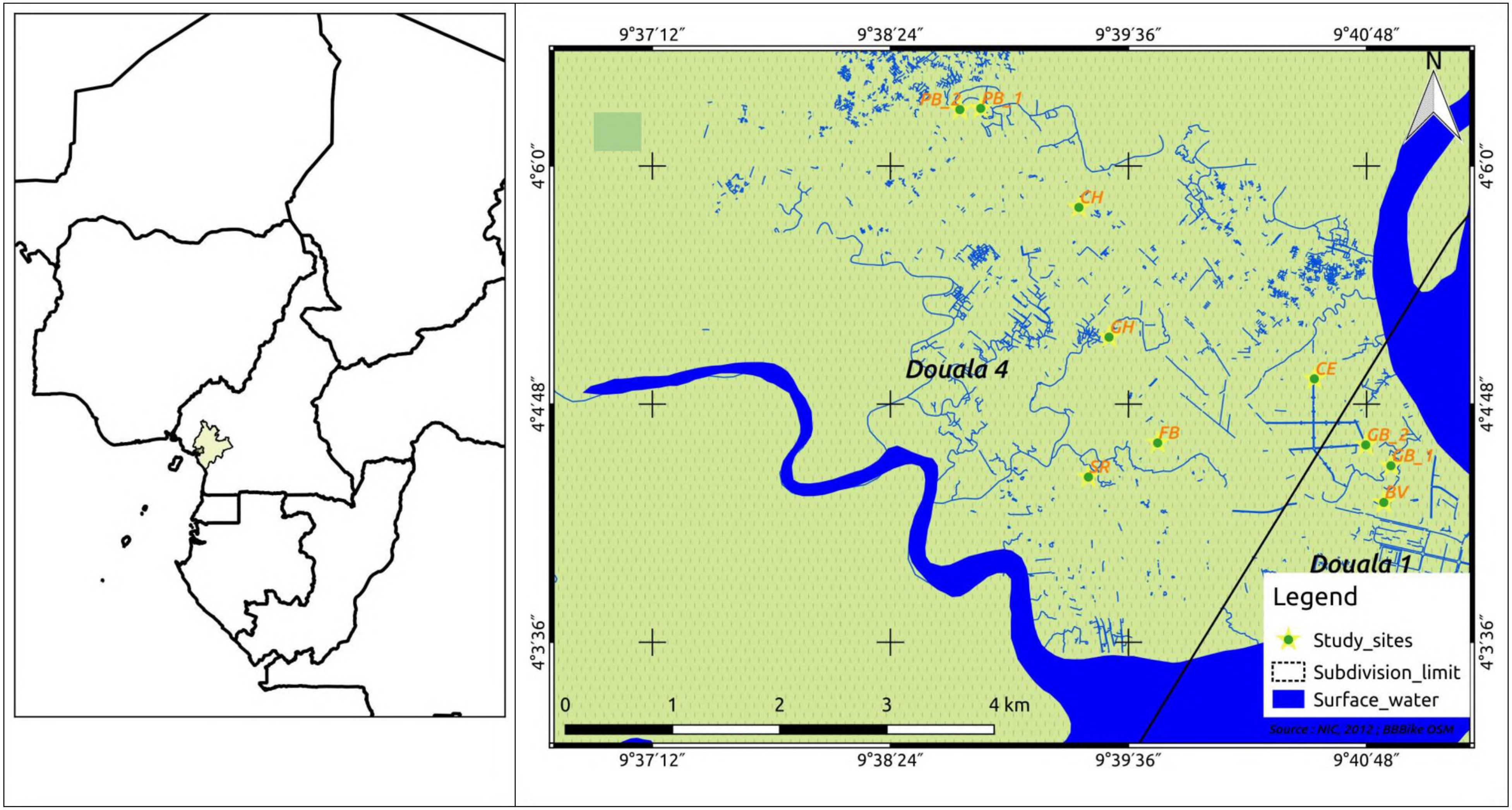


Figure 2.4 Different sites surveyed and selected in the main river channel of the Wouri River, where the main focus was around the accessible sites within the delta and the city limits.

Table 2.2 The sites for the long term study of water hyacinth with the GPS coordinates and observations.

Names of sites	Abbreviation	GPS Coordinates	Observations
Petit Bonanjo 1	PB 1	N: 04.06230 E: 009.38511	The main channel of the river, area completely invaded by water hyacinth.
Petit Bonanjo 2	PB 2	N: 04.10561 E: 009.64744	A medium pond between the houses, infested by water hyacinth.
Bonawater (Derrière Château)	CH	N: 04.09967 E: 009.65998	A small pond between houses which flows to the main channel, invaded by water hyacinth
Grand Hangar	GH	N: 04.08591 E: 009.65645	A small pond between the houses with water hyacinth
Centre Equestre	CE	N: 04.08482 E: 009.67486	Branch of the Wouri River invaded by water hyacinth
St Richard	SR	N: 04.07463 E: 009.65756	The main channel of the river, the infestations are tall plants.
Forêt Bar	FB	N: 04.04261 E: 009.39297	Houses surrounded by water hyacinth mats
Grand Baobab 1	GB 1	N: 04.07520 E: 009.68221	The main channel of the river, area completely invaded by water hyacinth.
Grand Baobab 2	GB 2	N: 04.07719 E: 009.68171	A small channel between the houses, infested by water hyacinth.
Bonassama Vallée	BV	N: 04.07722 E: 009.68184	A small pond between the houses with water hyacinth

The studied rivers were selected on the base of their size, importance of the river for the local communities, accessibility, and the existence of potential sources of pollution which could modify the quality of the river water (pigsties, toilets on stilts, public dumps, industrial waste, and slaughterhouses). All these criteria were taken into consideration when estimating the discharge from the populations and industries of Douala, and the effect on the spread and proliferation of water hyacinth in this area.

2.5.1.2 Characteristics of the sampled sites

The site phenostage and plant phenostage used in the description of each site is explained in Table 2.3.

Table 2.3 Description of site (characteristic of plants in the whole site) and plant phenostage (charactherisic of one single plant recorded) used during the survey.

PLANT PHENOSTAGE:		**Height in cm**
A (Short)	Small healthy plants, inflated petioles	20−49
B (Medium)	Medium height, healthy plants, petioles inflated to attenuating	50−79
C (Tall)	Tall healthy all attenuated petioles	80 – >100
D (Impacted)	Small to moderate plants, tough spindly petioles, curled laminas	< 20

SITE PHENOSTAGE:	
1 (Incipient)	Few small plants, inflated petioles
2 (Scattered)	Patches of small plants, open canopy
3 (Coalescing)	Medium plants, large mat, closed canopy
4 (Mature)	Mainly tall plants, attenuated petioles

2.5.1.2.1 Petit Bonanjo 1 and 2

The Petit Bonanjo River is one of the largest river among the selected sites where people used to fish and use the river water for other purposes. Nowadays, it is completely invaded by water hyacinth (100 %). Because it has the largest surface area of the sites, at least 10 000 m^2, it has been divided into two parts and named Petit Bonanjo 1 and Petit Bonanjo 2 (Pictures in Annexure).

Petit Bonanjo 1 consists of the main channel of the river and is surrounded by houses; Petit Bonanjo 2 is a medium-sized channel located between the houses.

The different activities situated around these sites are small shops and notably, the only slaughterhouse of the Wouri division, which is located uphill of the site. The main sources of pollution come from: the slaughterhouse, all the wastes of which flow into the river, the local population who throw waste into the river, and from the toilets, most of which are built on stilts outside the dwelling. The water hyacinth plants infesting the river vary in size from tall to moderate.

2.5.1.2.2 Bonawater (Derriere chateau)

This site is a small channel covering an area of 3 000 m^2 and is surrounded by houses. The only real activity around the river is a garage located nearby. The source of pollution comes from the houses located around the river. The water hyacinth infestation consists mainly of medium-sized plants.

2.5.1.2.3 Grand Hangar

This is an area with rivers and ponds invaded by water hyacinth. The area covered by water hyacinth is 5 000 m^2 and is surrounded by houses. The activities present around the site are small shops and a large market which gives the area its name. The source of pollution is the houses located around the river where all the toilets are constructed outside on stilts, coupled with neglect of the rules of hygiene. The infestation of the river by water hyacinth varies between tall to moderate plants.

2.5.1.2.4 Centre Equestre

This area is a quiet residential area with big houses. Almost all the tributaries or branches of the river in this area are invaded by water hyacinth which covers a surface area of 2 000 m^2. The activities around the site are a hotel, a school and shops. The source of pollution is the population whose drainage flows directly into the river. The water hyacinth infestation consists mainly of tall plants.

2.5.1.2.5 Saint Richard

This is the second biggest and most densely infested site. The presence of water hyacinth is noticeable along the river; all around the river wherever there is water present, and the conditions are favourable for water hyacinth growth. The whole site covers an area estimated to be at least 8000 m^2 and is the site where most of water hyacinth plants are damaged by pathogens. The infestation of the site varies from medium to small plants. Activities around the site are small shops and houses with the sources of pollution coming from the local population, whose toilets feed directly into the river and from the garbage dump located close to the river.

2.5.1.2.6 Forêt Bar

Water hyacinth has invaded half the main channel of the river and the area between the houses, covering 5 000 m^2. The sources of pollution come from the local population who throw all their waste into the river. The water hyacinth mat consists of medium plants with pathogens infesting the leaves at some places.

2.5.1.2.7 Grand Baobab 1

The river is fed by water from Bonassama Vallee and Besseke. The main channel of the river is completely invaded by water hyacinth covering a surface area of 5 000 m^2. Despite the infestation of the river by water hyacinth, people continue to use the river for transportating wood that they collect from the mangrove marshes. The river is polluted by the local population who throw all their waste there, and, in some places, garbage dumps. Water hyacinth mats are comprised mainly of tall plants.

2.5.1.2.8 Grand Baobab 2

The Grand Baobab 2 is a small channel between the houses; it is infested by water hyacinth which covers a surface area 1 000 m^2. Here, pollution comes from the local populations. The infestation of the site varies from medium to tall plants.

2.5.1.2.9 Bonassama Vallee

This is a river fed in some places by water from the Industrial Zone and Besseke and polluted by the local population. The surface area covered by water hyacinth varies from 3000 to 3 500 m^2, with the infestation varying from medium to small plants.

2.6 Methods

2.6.1 Sampling procedures

The field work took place at two different periods of the year. The first survey was from June 2014 to October 2014 (5 months), while the second survey took place from November 2015 to April 2016 (6 months). According to the data gathered from the meteorological station, the sampling period of the first survey was considered as the rainy season, given that the highest precipitation is recorded during this period of the year. The second period of the survey was considered as the dry season, with the highest temperatures recorded over this period of the year. Sampling of water and plants were carried out on a monthly basis during these two periods in each of the selected sites. The sediment samples were collected once in each of these sites in 2016 to estimate the composition and therefore the characteristic of the sediment, but also to quantify the amount of nutrient available for plants. Water temperature beneath water hyacinth mats were also recorded in 4 of the 10 sites.

2.6.2 Surface and below-water sampling

In order to determine the physico-chemical parameters of the water sampled from each of the ten water hyacinth monitoring sites, data were collected monthly, from June 2014 to October 2014 for the first survey, and from November 2015 to April 2016 for the second monitoring survey. Each month, sterile bottles of 1L, previously rinsed several times with the sample to be collected, were used to collect water sample from ±30cm below the water hyacinth surface. At each site, the bottle was immersed into water until it was full. Once the bottle was full, the rope was pulled and the container was closed, labeled and transferred into a cooler containing ice blocks pending further analysis. A total of three samples of water were collected per site at three different places (upstream, middle, and downstream) to serve as repetition for each site and per month. The collections were made every month to assess the change in the composition of water between the different seasons.

For each water sample the physical and chemical parameters were analyzed and measured. Physical parameters included pH, electrical conductivity (CND), water temperature, salinity and total dissolved solids (TDS) which were taken in situ using a multi-parameters PCSTestr^{TM} 35, while chemical parameters included nitrate ions, ammonium, and total nitrogen were measured using a Vernier Nitrate Ion-Selective Electrode, and Ammonium Ion-Selective Electrode, respectively.

Below water temperature was recorded using Thermochron iButtons (DS1922L#F5 and DS1921G#F5, Maxim/Dallas iButton Products) which were introduced into the water at approximately 1m for a period of 5 months from December 2015 to April 2016. The key features of the DS1922L#F5 have an operating temperature range from -40 °C to +85 °C, an accuracy of ±0.5 °C from -10 °C to +65 °C, and a sampling rate from 1s to 273 hours, while the key features of the DS1921G#F5 have an operating temperature range from -40 °C to +85 °C, an accuracy of ±1 °C from -30 °C to +70 °C, and an accuracy of ±1.3 outside of that range, and a sampling rate from 1minute to 255 minutes. The iButtons were wrapped in plastic bags to prevent them getting wet, a stone was added, and a string tied to the package. The package was immersed in the water and attached to a solid tree or bridge according to the area where the iButton was introduced. The areas were: Centre Equestre, Petit Bonanjo1, Grand Baobab 1 and Saint Richard.

2.6.3 Plant parameters

At each site, the condition of the water hyacinth plant was determined by using various plant parameters. The plant phenostage and site phenostage was evaluated using the tables presented in the data sheet (Table 2.3 and Table 2.4).

A quadrat of 0.5×0.5 (0.25 m^2) was placed randomly on the mature water hyacinth mats at three different places in each monitored site; a number of plants from each quadrat were removed and counted to obtain a density estimate (the number of individual plants per 0.25 m^2), after which they were divided in three parts and weighted to obtain the biomass above water for living material (kg) constituted of petioles and leaves (shoot), biomass below water or living material (kg) for roots, biomass of dead material (kg) present in the quadrat. The mean shoot/root wet biomass (kg) per 0.25 square metre was calculated per site and per month. As indicated by Coetzee & Hill (2012), a high shoot/root ratio would indicate greater allocation to above-water biomass, implying actively growing plants which are not limited by nutrient availability.

To evaluate the growth plant parameters per site, ten individual water hyacinth plants were also randomly collected each month from each site and, using a decameter. The following growth plant parameters for each of these plants were measured: longest petiole length (cm), which gives an indication of the height of the water hyacinth mat and therefore the maturity of the population per site; leaf of second petiole length (cm),which gives an idea of how old the leaf is; the number of ramets on each adult plant, which indicates the reproductive output of the population, and the maximum root length (cm), which indicates the availability of nutrients in the area. The surface area of the second leaf (cm^2), number of flowers, and the number of leaves were also assessed (Table 2.4). In 2014, due to increased precipitation in August and September, the plants in Bonassama Vallee and Grand Baobab 1 were washed out and lost; therefore no plant parameters were recorded at this time (Table 2.5, Figure 2.5), while in Château plants were still present at some places.

Table 2.4 Data sheet used during the survey to record the plant parameters and water samples

QUADRAT MEASURES:	**No. individual plants per quadrat:**	**1**	**2**	**3**
	Biomass above water – living material: (kg)			
	Biomass below water – living material: (kg)			
	Biomass – dead material: (kg)			

Plant	**Plant Phenostage**	**Longest petiole (cm)**	**Leaf 2 petiole (cm)**	**Leaf 2 area (cm^2)**	**Max root length (cm)**	**No. ramets**	**No. flowers**	**No. leaves**
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

QUADRAT PARAMETERS	**1**	**2**	**3**
Depth			
Temperature			
pH			
TDS			
Conductivity			
Salinity			
Nitrates			
Ammonium			

Table 2.5 Study sites sampled monthly during the two seasons of the study. The √ indicates that all the samples were collected, while an x indicates that plant parameters were not recorded because washed out and lost. ○ indicates that only water parameters were collected.

Sampling date	BV	CE	CH	FB	GB1	GB2	GH	PB1	PB2	SR
June 2014	√	√	√	√	√	√	√	√	√	√
July 2014	√	√	√	√	√	√	√	√	√	√
August 2014	○ x	√	√	√	○ x	√	√	√	√	√
September 2014	○ x	√	√	√	○ x	√	√	√	√	√
October 2014	√	√	√	√	√	√	√	√	√	√
November 2015	√	√	√	√	√	√	√	√	√	√
December 2015	√	√	√	√	√	√	√	√	√	√
January 2016	√	√	√	√	√	√	√	√	√	√
February 2016	√	√	√	√	√	√	√	√	√	√
March 2016	√	√	√	√	√	√	√	√	√	√
April 2016	√	√	√	√	√	√	√	√	√	√

2.6.4 Sediment samples

Soil samples were collected at each site in April 2016 and brought to South Africa, where they were sent to BemLab (16, Van Der Berg Crescent, Gant's Centre, Strand, 7140, RSA) for analysis. The following parameters were measured: Carbon (C), nitrate (NO_3^-), ammonium (NH_4^+), bulk density, phosphorus (P) and texture.

2.7 Statistical analysis

According to the Levene's test for homogeneity of variance and Kolmogorov-Smirnov test for normality, none of the parameters measured during this study fulfilled the requirements of parametric statistics. Therefore non-parametric statistics were performed. Data were analysed in Primer version 6.1.13 /Permanova (v.1.03), Statistica (v. 13), R (v. 3.2.2) and in Past (v.3.1). The different analyses used through these software were tests of differences (ANOVA, Permanova), CAP, correlations tests, BEST analyses, Distance Linear Based Models (DistLM) and Principal Coordinates Analysis (PCO).

Figure 2.5 Pictures of sites (Grand Baobab 1, Bonassama Vallee and Château respectively) before (a) and after (b) the flush out by water during the rainy season between August and September 2014.

Correlations tests were used in Statistica to confirm whether there was a correlation or a temporal variation between the number of individuals and the sum biomass per sites, and month in each of the seasons (rainy and dry season). Indeed, prior to investigationg the seasona effect on different parameters analysed, the whole time of observation period was divided into two fixed seasons: rainy (June to October) and dry (December to April). This was followed by another test in R called the Regression analysis, to obtain the p-value of the correlation to see if the relationship between these factors was significant through the regression model.

One-way ANOVA at 0.05% level of significance was used in Past to check for differences of means between the rainy and dry seasons both for the biological variables and for the environmental variables.

Similarity tests.

Before data were used in Primer/Permanova for the different tests which were performed, different transformation processes (Draftsman Plot, Euclidien distance ressemblance) were made both on the physico-chemical parameters (environmental variables) and on the biological data.

After their importation into the software Primer, a Draftsman Plot (a Scatter plot) was performed to check for variable pairs on the environmental variables, followed by a normalization of all data to give them the same weight as the parameters recorded were having different units. According to Ramette (2007), in multivariate data tables, measured variables can be binary, quantitative, qualitative, rank-ordered, classes, frequencies, or even a mixture of those types. If variables do not have a uniform scale (e.g. environmental parameters measured in different units or scales) or an adequate format, variables have to be transformed before performing further analyses. Each qualitative variable has to be recoded as a set of numerical variables that replace it in the numerical calculations. One way to do so is to create a series of 'dummy' variables that correspond to all the states of the qualitative variable. For instance, if the variable 'season' has to be recoded, four associated variables will be constructed, and for each object the value 1 will be given to the corresponding season when it occurs, and 0 for the three other season when it is absent. Many statistical packages automatically perform this recoding. The next step was to perform the Euclidian distance resemblance to assess the similarity in composition between sites. Data from the physico-chemical parameters which were considered for the analysis were: temperature, pH, conductivity, ammonium and nitrates. Salinity and TDS were not considered because they express basically the same pattern as conductivity.

As for the biological data (biomass, and density), the data were not transformed as they have the same unit, but a test of resemblance based on Bray-Curtis was performed to assess the similarity. Indeed, in ecological studies, Bray-Curtis similarity is recommended when using biological data (Clarke & Warwick 2001a, b).

Permanova and ANOSIM tests in Primer and a two-way ANOVA in Past, were used to check for differences in data among sites, between months and among sites x months for each of season (rainy, dry), and also to check for differences when the two seasons were combined; in another words, to check if data collected during the dry season were different from data collected during the rainy season; all this between sites, within seasons and between sites × seasons. The limitation of using ANOSIM was that it cannot check if there is a difference in the interaction between two factors (sites x months, for example). The Permanova test was shown to be better as it included both tests for difference for each factor, and the interaction of two factors. ANOVA and Permanova showed the same results for all the tests for difference, so, in order to be consistent in the writing of the results for this part, only the results from the Permanova test were used, although the p-value given in Permanova does not come from a F-distribution or any other distribution as in ANOVA test, but are generated by permutations. For this reason, the table summarizing the results, p (perm) is shown as well as unique perms, which indicate the number of times the values were generated.

The Principal Coordinates analysis (PCO) performed through the normalized data were used here to visualize patterns of relationship among the samples between the rainy and the dry season. PCO is an alternative procedure to PCA (Principal Component Analysis), in that it is more powerful than a PCA and therefore gives how much of the variation was explained in the set of data. When the environmental variables are plotted on the graph representing the biological data, the correlation between the patterns is calculated and the underlined environmental variables are put into the diagram.

The Canonical analysis of principal coordinates (CAP) helped to visualize the difference which appeared in the Permanova test, but which sometimes is not seen in a PCA or PCO.

The BEST analysis is used to check or confirm which environmental variables best explain the change in the biological data matrices (Clarke and Warwick 1994). When run, BEST analysis gives the best correlation or best set of correlations when there are more than two environmental variables involved between the biological data in the environment and the individual environmental variable. Although highly useful, the BEST analysis does not indicate how much of the variation was explained in the data, so the BEST analysis was therefore followed by the DistLM which described the pattern in the community, using the environmental variable through the Stepwise multivariate regression procedure and the AICc selection criterion (Akaike Information Criteria) which used the distance between two models through the actual fitted Kullback-Leibler information in the set of data. The AICc selection criterion is seen as the best model often used in practice and works with weight taken from the data (Anderson 2008, Hu 2007).

It is important to note that, when the data for the two seasons were analysed together to test whether there was a significant difference between sites and within sites, and also when other analyses were done, one month (November 2015) during the dry season was deleted so that each of the seasons had the same amount of data. November 2015 was deleted, because it was the closest month after the rainy season.

2.8 Results

2.8.1 Map of the distribution of water hyacinth in the Wouri Basin

According to the data provided by Azong & Afangang (2011), the Wouri River Basin is the river in Cameroon most severely invaded by water hyacinth of the ten rivers infested with the surface area coverts by water hyacinthvarying from high concentration to small patches. The total area covered by water hyacinth is 112.26 ha on about 14 290.57 ha of water (Figure 2.6, Table 2.6).

Table 2.6 Total surface area covered by water hyacinth in the Wouri Basin during the week of survey. Constructed from mapping record produced by Azong & Afangang (2011).

Days	Communities visited	Extent of infestation	Water hyacinth coverage
1	Pillar	High concentration	214 735 m^2
	Lobe		
	Bonendale	Small Patches and Spots	
	Tondo		
	Djebale		
	Sodiko		
	Bonamatoumbe		
2	Entrée Mbangue	Patches	53 971 m^2
	Bonaloka	More than 3 hectares	
	Bonamouang	Patches	
	Kong		
3	Mbangue	Very high concentration of water hyacinth recorded. This area could be described as the seat of water hyacinth in the Wouri-Basin. The Creek of Yabea is completely covered till near to Ile d'Abo	542 947 m^2
	Bonaloka		
	Etia Loka		
	Yassem		
	Bonangando		
	Yabea		
4	Bonangando	These areas could be considered as the second highest surface areas of water hyacinth but with lesser quantities compared to that of day 3. There are no mangroves, unlike other areas visited Water becomes shallower with many sand bars.	138 591 m^2
	Katanga		
	Bossamba		
	Etia Bossamba		
	Bonaloka		
	Bonamoumbe		
	Bonandolo		
	Bonepea		
	Bonamatoumbe		
5	Lakes of Bonamoussadi	Presence of lots of water hyacinth flourishing in the second lake visited	175 958 m^2
	Yassa	High concentration of water hyacinth	
	New Deido	Large quantity of water hyacinth recorded at Deido, Casablanca, Bonaloka area and the remaining areas showed small patches and spots	
	Akwa-Nord		
	Bonamouang		
	Mbanya		
	Bonangang		
	Bangue		
	Bonabeyike		
	Cassablanca		

	Bonaloka area		
6	Youpwe	No trace of water hyacinth in these areas due to high salinity of water	0 m^2
	Manoka		
	Dahomey		
	Sanje		
	Matanda Masidi		
	Bikoro fishing port		
7	Mbanga Pongo	No trace of water hyacinth	0 m^2
	Bafia		
	Ndogpassi I & II		
	Mabanda areas	Small concentration	4 m^2
Total surface area covered by water hyacinth			**1 122 620.2 m^2**
			Or 112.26 ha

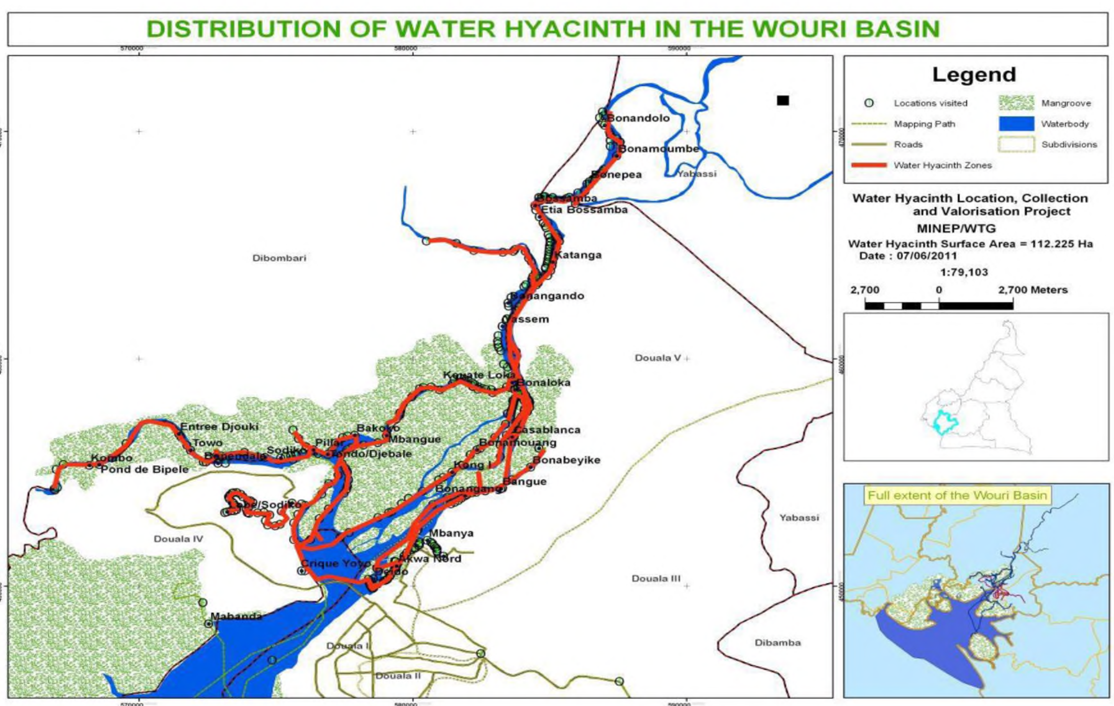


Figure 2.6 Map of the distribution of water hyacinth in the Wouri-Basin. Azong & Afangang (2011).

2.8.2 Plants parameters

Sites and plant phenostage

The plant samples at each site during the rainy and the dry seasons were taken from relatively permanent mature water hyacinth mats, except for Bonassama Vallée, Grand Baobab 1 after the wash-out of the plants in August and September 2014 during the rainy season, and in November 2015 at Bonassama Vallée, Grand Baobab1, Centre Equestre, Saint Richard and Grand Baobab 2 during the dry season. The height of plants encountered at these sites during the dry season in November could be explained by the same phenomenon as that which occurred in 2014 after the rainy season, given that heavy rains occur from July to September each year. The plant phenostage at Centre Equestre, Forêt Bar, Petit Bonanjo 1 and 2, Saint Richard, Château, Grand Hangar and Grand Baobab 2 were characterized by plants varying from medium to tall with attenuated petioles while at Bonassama Vallée and Grand Baobab1, the plants were small to moderate with inflated petioles (Figure 2.7). The height of the tall plants ranged from 80.3cm to 96.3cm during the rainy season for Château, Grand Baobab 2, Forêt Bar, Centre Equestre, Grand Hangar and Petit Bonanjo 2, while the shortest plants were recorded at Saint Richard (48.3cm). Plants of medium height were recorded most often at Petit Bonanjo 1, Grand Baobab 1and Bonassama Vallée (Figure 2.7).

Length of the second leaf petiole

During the dry season, a fluctuation in the length of the second leaf petiole was observed from short, medium and tall plants. The shortest petioles were observed at Bonassama Vallée (33.8cm) in November 2015; at Grand Baobab 1 (38.1cm) and Château (39.6cm) in December 2015. The tallest petioles were measured at Grand Hangar (92cm) and Saint Richard (83.7cm) in December 2015; Forêt Bar (88.2cm) in January 2016; Centre Equestre (86.1 and 86.7cm) in April and February 2016, respectively. A decline in the petiole length between January and March 2016 was observed at Petit Bonanjo 2, Saint Richard, Château, Grand Hangar, Forêt Bar and Center Equestre, while at Bonassama Vallee from January until April 2016 the plant height was constant (Figure 2.8).

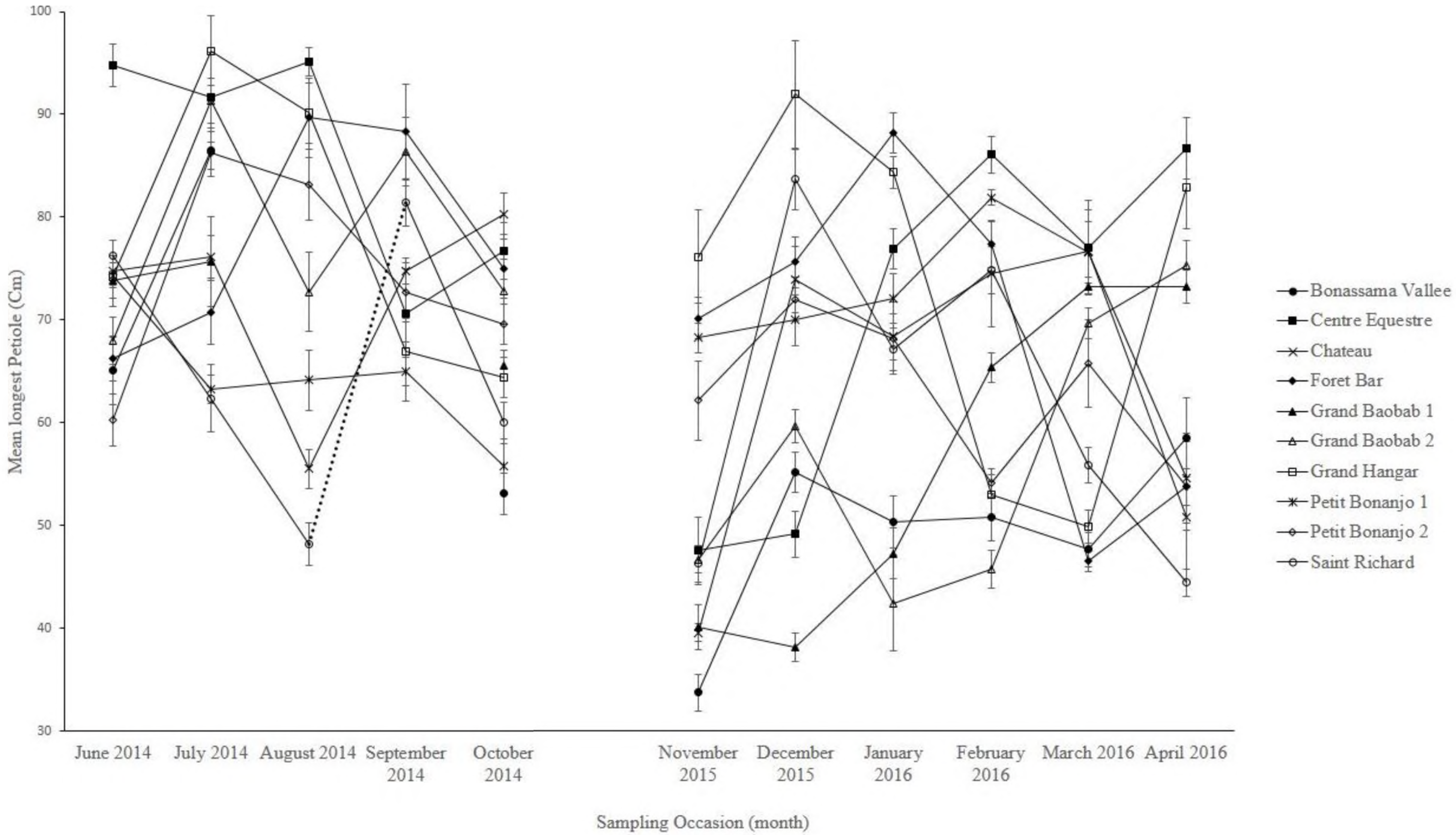


Figure 2.7 The mean length (cm) of the longest petiole of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

In fact, the length of the second petiole decreased from 69.4 cm (mean) during the rainy season to 52.5cm in the dry season, with a significant difference ($F_{(1, 958)}$=255, p=4.51E-51).

Number of leaves

The number of leaves was relatively consistent between sites during the rainy season, with the majority of plant having between 6 to 8 leaves. The pattern in the dry season is almost the same, with the lowest number of leaves observed at Foret Bar, Saint Richard and Grand Baobab 1, Grand Baobab 2 which contrasted with the highest number of leaves (10) in December 2015 (Figure 2.9). The number of flowers was almost zero for the two seasons, with the mean equivalent to 0.07 flowers with, however, a slight increase of during the dry season (Figure 2.10). In both the rainy and the dry seasons, obviously, no significant difference was noticed between the seasons ($F_{(1, 958)}$=0.80, p=0.37).

Number of ramet

The ramet production varied from 0 to 3.5 during the rainy season (with 0 ramets observed at Petit Bonanjo 1 in August 2014) and from 0 to 3 during the dry season, with 0 ramets at Château and Grand Hangar in January 2016 (Figure 2.11). Even if the ramets seem to be the same for the two seasons, a significant difference was noticed ($F_{(1, 958)}$=15.96, $p<0.05$).

Root length

In both the dry and rainy seasons, the root length was consistent at between 11 cm and 30cm. The shortest root was measured at Grand Baobab 2 during both the dry and rainy seasons. The longest root was observed at Petit Bonanjo 2 (32.2cm) during the rainy season, and at Saint Richard (36.9cm) and Centre Equestre (36.4cm) during the dry season (Figure 2.12). The mean root length during the rainy season was 20.2cm and 19.2cm for the dry season with no significant difference noted between the season ($F_{(1, 958)}$=1.451, p=0.23).

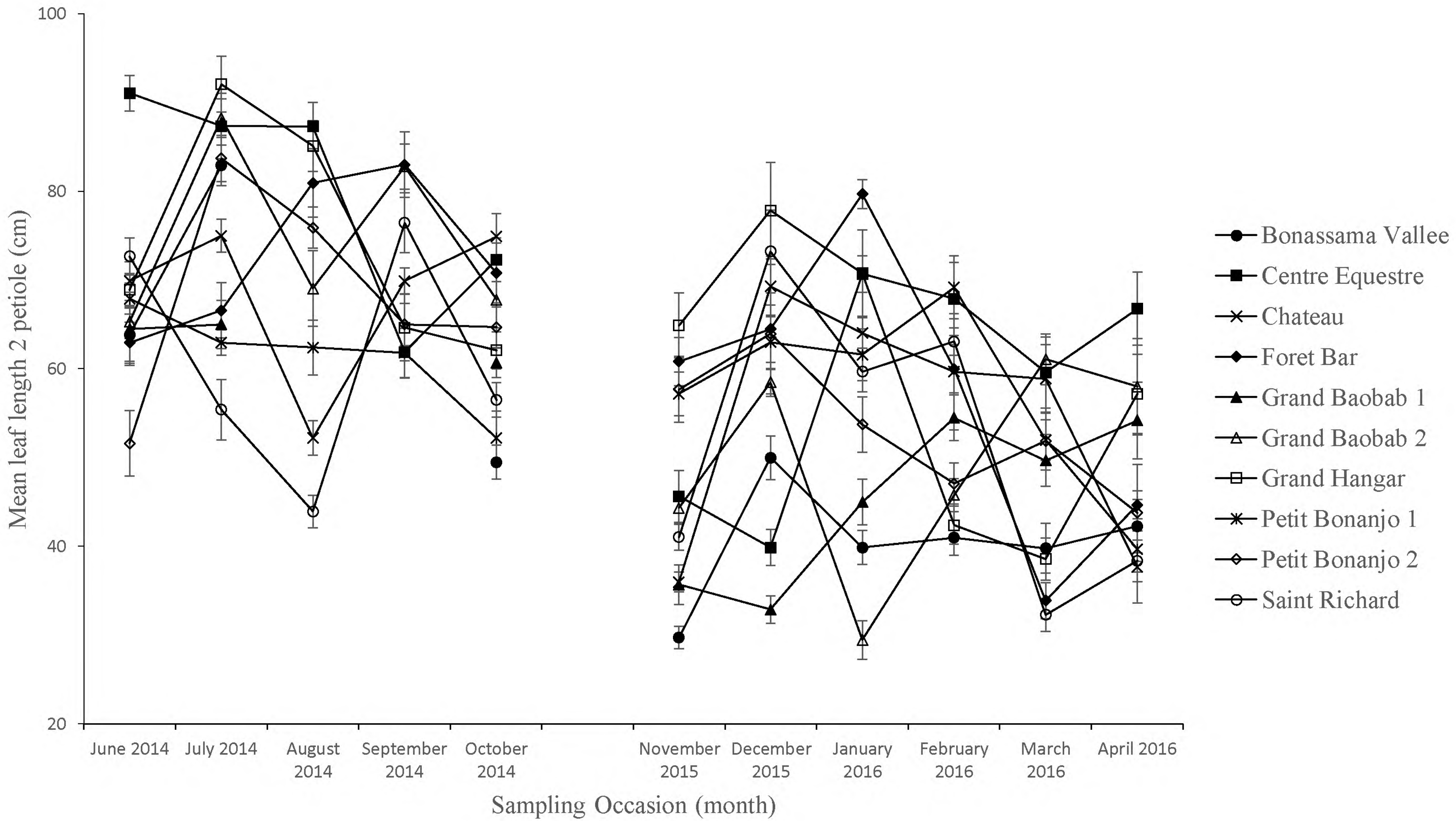


Figure 2.8 The average length (cm) of the second leaf petiole of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

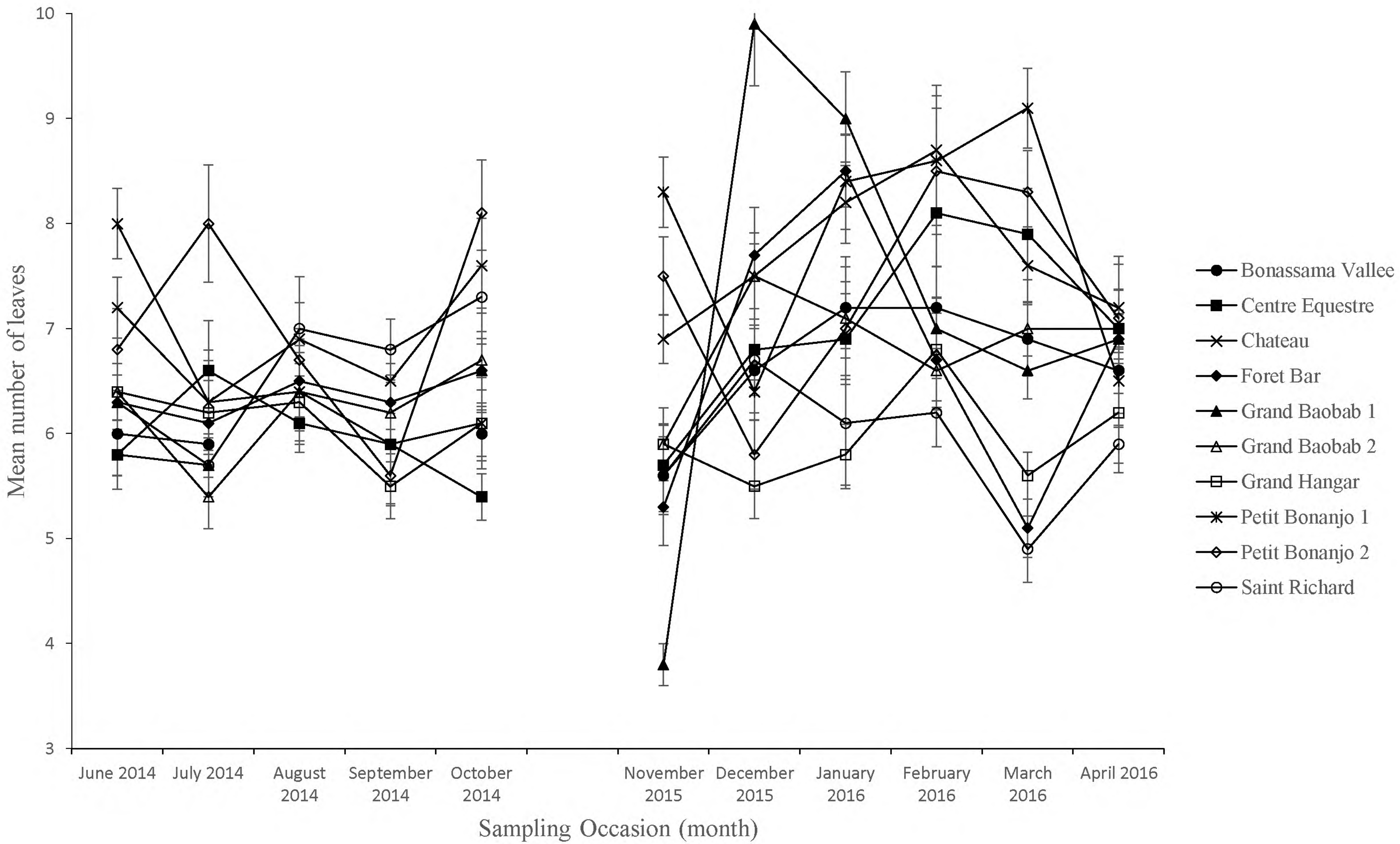


Figure 2.9 The average number of leaves of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

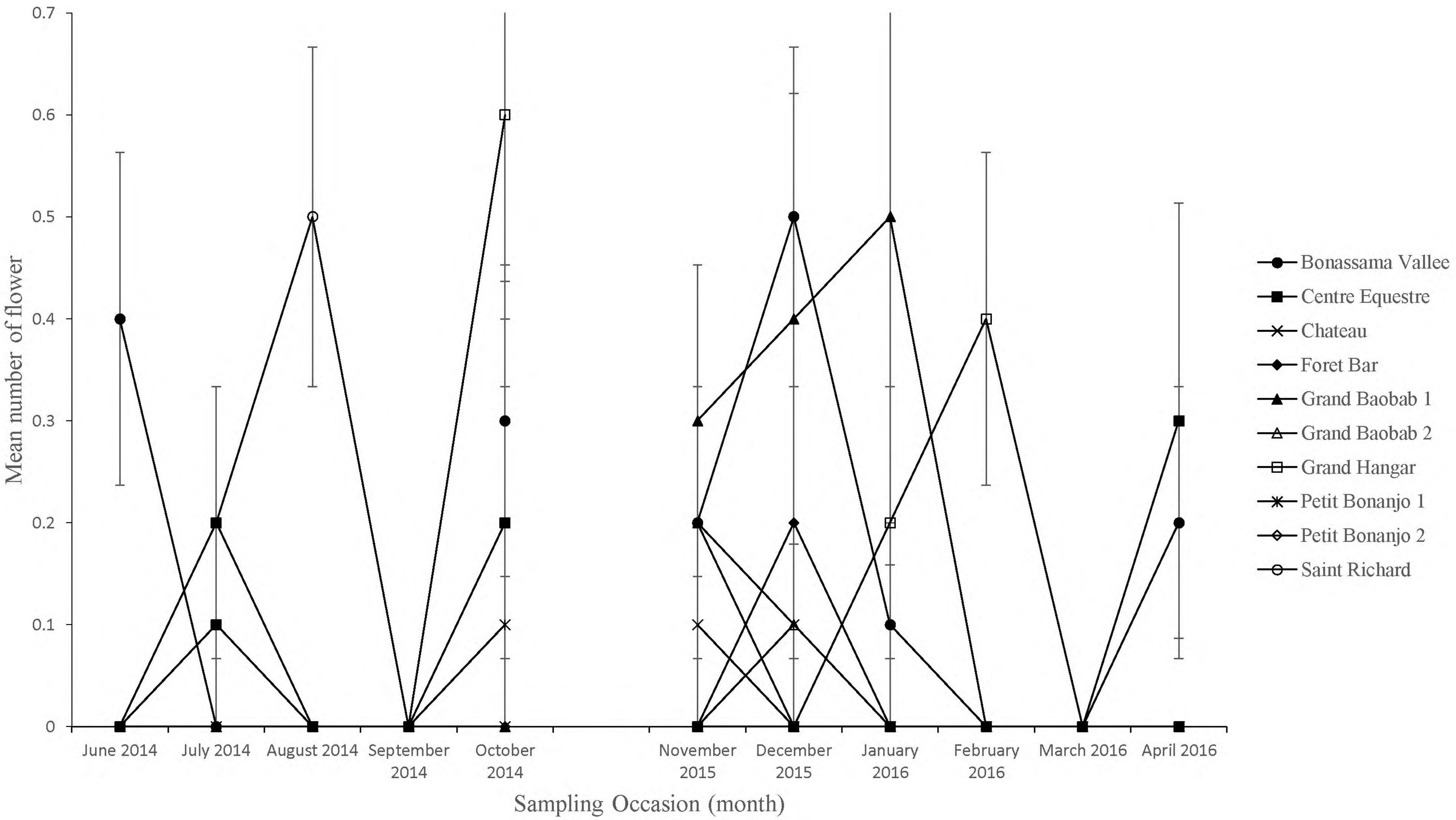


Figure 2.10 The mean number of flowers of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

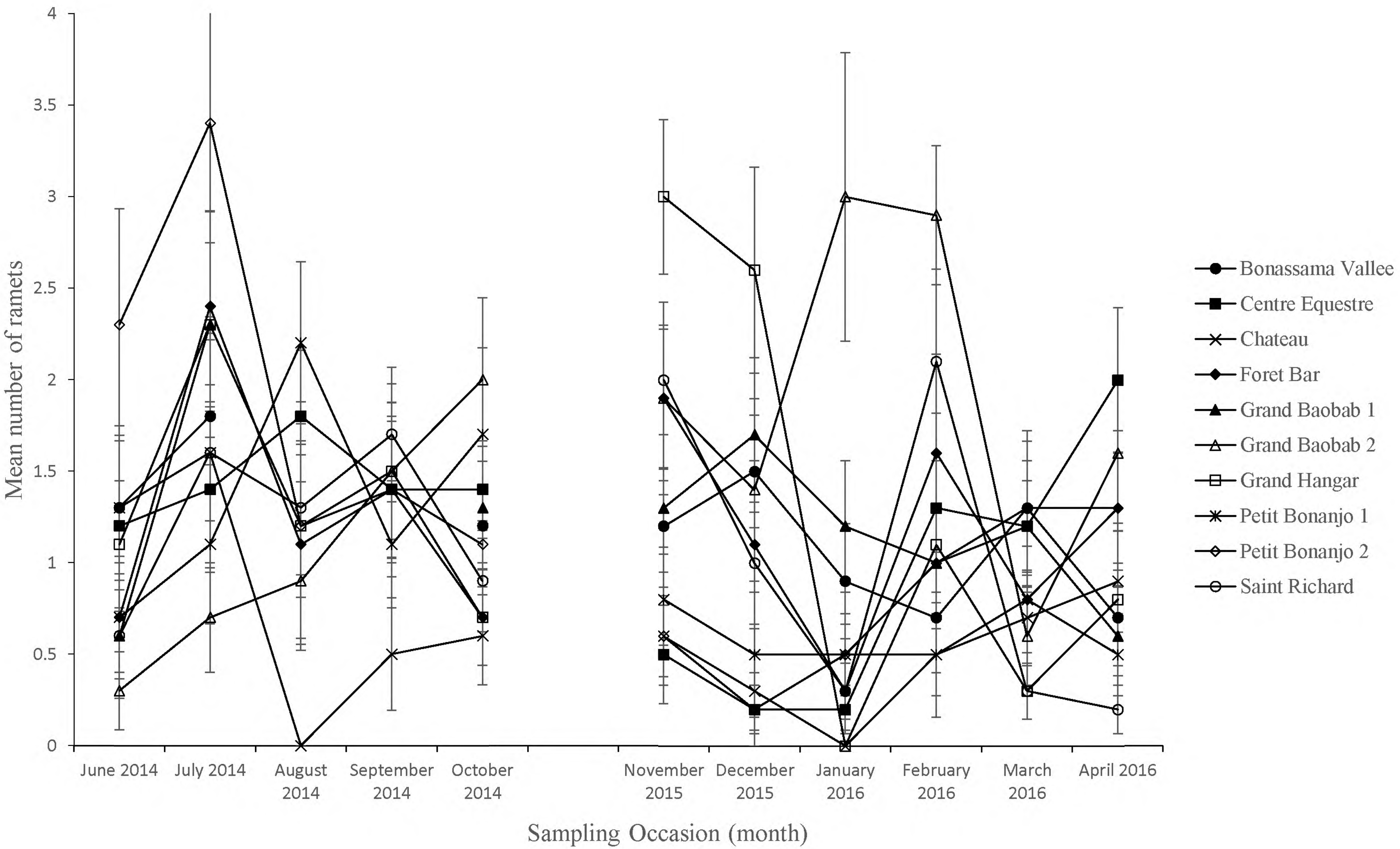


Figure 2.11 The average number of ramets of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

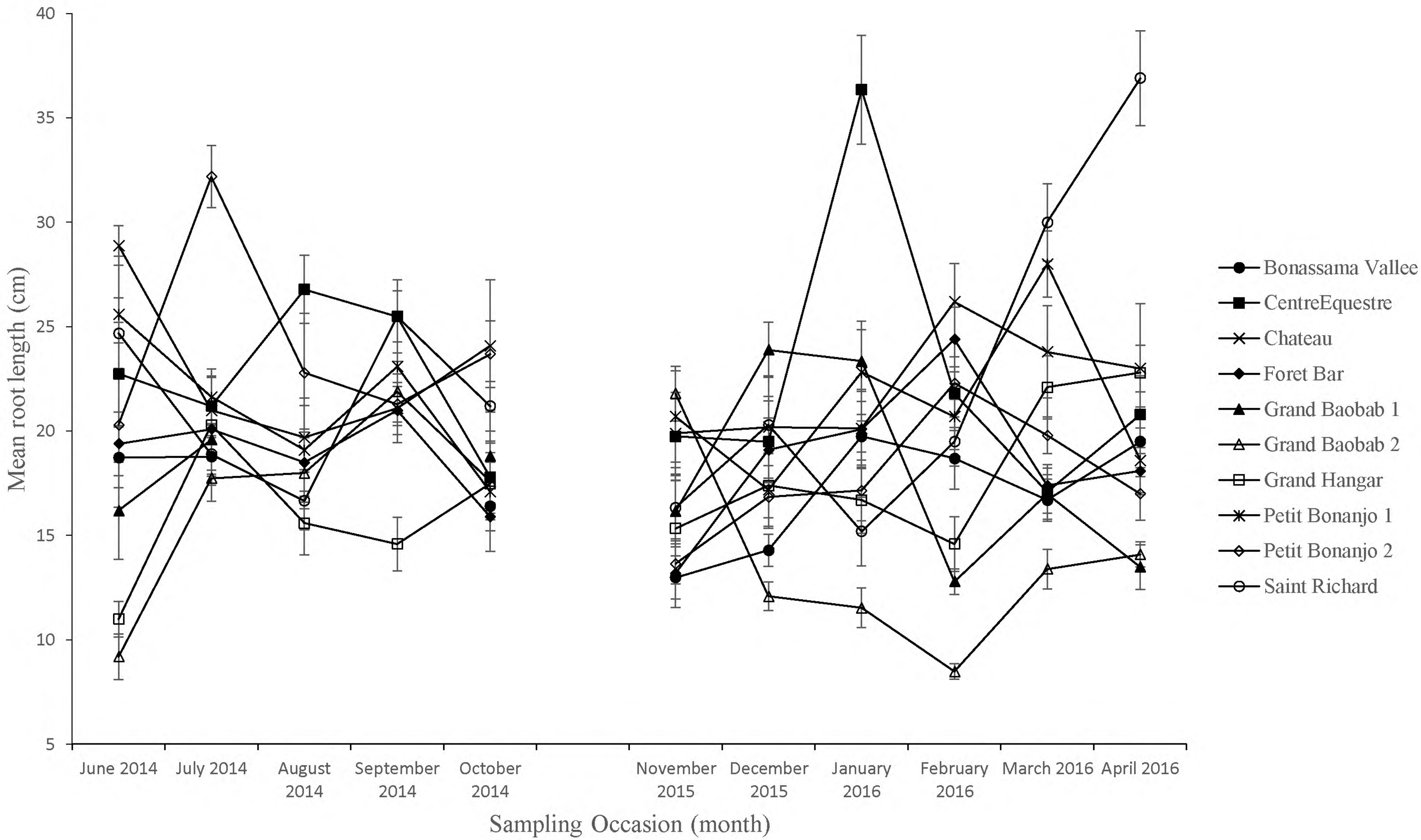


Figure 2.12 The mean root length (cm) of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

Surface area of the second leaf

The surface area of the second leaf was quite constant during the rainy season between 174.1 per square centimetre and 302.2 square per centimetre; however, a decline in the surface area was observed at almost all the sites from July to October 2014. During the dry season, the pattern was different, with the smallest surface area recorded at Saint Richard and Forêt Bar (64.1cm²) in March 2016, while the highest surface area was recorded at Centre Equestre (324.8cm²) in February 2016. In between the sampling month there was an increase and an increase of the surface area each month during the dry season, while at Bonassama Vallee and Chateau the surface area was almost constant (Figure 2.13). The mean surface area for leaf 2 for the rainy season for all the sites was ca. 250 cm² while it was 197 cm² during the dry season, with a highest leaf area of 303 cm² and 325 cm² for the rainy and dry season, respectively with a significant difference between the two season ($F_{(1, 958)}$=117.4, $p < 0.05$).

2.8.2.1 Permanova test

For each of these analysis, the results were presented between months and sites for each season (rainy and dry season) and after between sites and seasons to have an overview of the impact of month or season on the proliferation of water hyacinth in the Wouri River Basin.

2.8.2.1.1 Impact of sampling months and sites on growth paramters of water hyacinth during the rainy Season

The results from the Permanova test on the impact of the sampling months during the rainy season between sites on growth parameters of water hyacinth showed that there was significant difference among sites, and between sites and between sites × month with a p(perm) of 0.001 for each of them (Table 2.7).

Table 2.7 Summary table of the PERMANOVA test of significance for the effect of plant parameters between sites and months during the rainy season. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	8941.3	993.47	11.741	**0.001**	999
Months	4	3747.2	936.79	11.071	**0.001**	999
Sites * Months	32	13777	430.55	5.0882	**0.001**	999
Residuals	414	35032	84.617			
Total	459	61394				

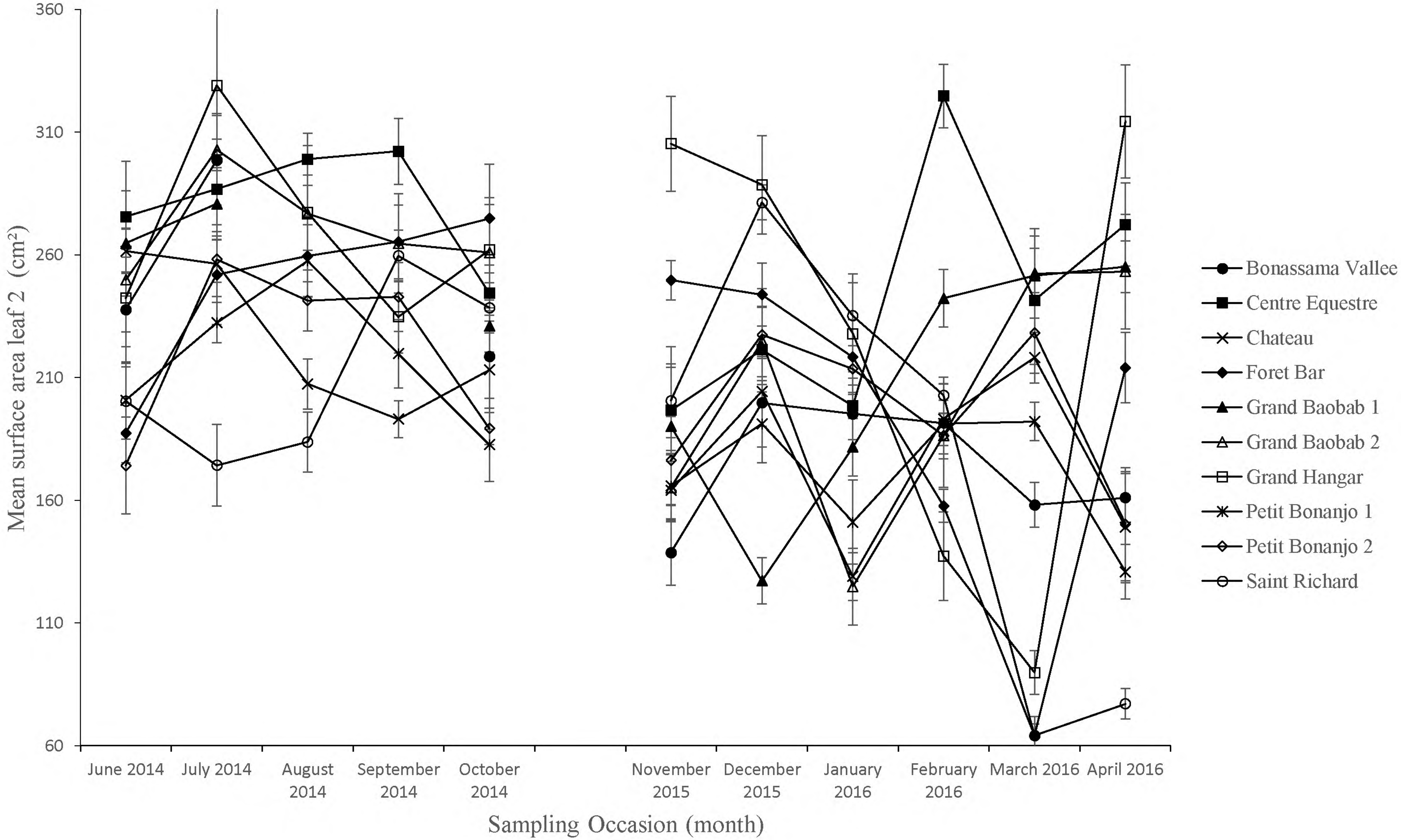


Figure 2.13 The average surface area (cm²) of the second leaf petiole of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

2.8.2.1.2 Impact of sampling months and sites on the groth parameters of water hyacinth during the dry season

The same results, when the Permanova test was done on the impact of the sampling months during the rainy season on growth parameters of water hyacinth showed that there was significant difference among sites, and between sites and between sites x month with a p(perm) of 0.001 for each of them (Table 2.8).

Table 2.8 Summary table of the PERMANOVA test of significance for the effect of plant parameters between sites and months during the dry season. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	16069	1785.5	15.88	**0.001**	997
Months	5	8864.9	1773	15.769	**0.001**	996
Sites * Months	45	73963	1643.6	14.618	**0.001**	996
Residuals	540	60715	112.44			
Total	599	1.5922E5				

2.8.2.1.3 Impacts of combined rainy and dry seasons on the growth pf water hyacinth

A Permanova test was done to test if whether the data collected during the rainy and dry seasons were different. The results obtained after this analysis showed that for the growth parameters of water hyacinth, when the data were analyzed according to sites and between seasons, there was a significant difference with a p(perm) value of 0.001, while the analysis done between sites × season showed a significant difference of 0.003 (Table 2.9).

Table 2.9 Summary table of the PERMANOVA test of significance for the effect of plant parameters between seasons. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	17590	1954.5	10.625	**0.001**	998
Seasons	1	23549	23549	128.01	**0.001**	998
Sites * Seasons	9	4499.3	499.92	2.7176	**0.003**	999
Residuals	940	1.7292E5	183.96			
Total	959	2.1951E5				

A Canonical Analysis of Principal Coordinates (CAP) was used to show the representation of these differences, especially during the season (Figure 2.14).

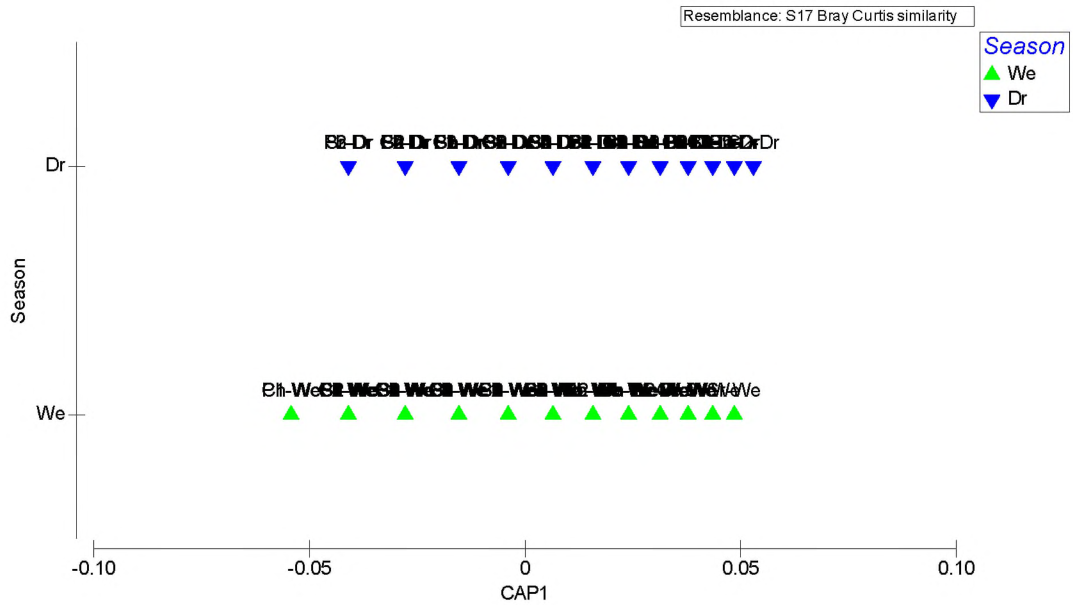


Figure 2.14 Canonical Analysis of Principal Coordinates (CAP) illustrating the significant difference for the plant parameters observed in the Permanova test of difference between seasons.

The figure (Fig. 2.14) showed that there is a clear separation between data recorded during the rainy and dry season for the plant parameters. The significant differences observed in each of these seasons (rainy and dry) and when both seasons were combined as seen after the PERMANOVA test could be explained by the different activities happening in each of the sites which sometimes differed, according to the season.

2.8.3 Density of water hyacinth per site and season

The number of plants per 0.25 m² was relatively constant during the rainy season: between six and 13 individuals (Figure 2.15), while during the dry season, the number of individuals increased slightly with a mean of 11 individuals, although Petit Bonanjo 2 showed the smallest number of individuals in January 2016 (6.3) (Figure 2.15).

2.8.3.1 Permanova test of the density of water hyacinth both during the dry and rainy seasons

The Permanova test for the density (number of individuals) showed that during the dry season, there was no significant difference within sampling months, neither was it significant between sites and among sites × months (Table 2.10).

Table 2.10 Summary table of the PERMANOVA test of significance for the density (number of individuals) between sites and months during the dry season. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	3546.7	394.08	5.4365	**0.001**	998
Months	5	626.15	125.23	1.7276	0.117	998
Sites * Months	45	11705	260.1	3.5883	**0.001**	998
Residuals	120	8698.5	72.487			
Total	179	24576				

The lack of significant difference in the number of individuals during the dry season is possibly due to the relationship between the number of individuals and the sum of biomass as both individuals and biomass were measured per 0.25 m^2. Effectively, a positive correlation with a significant difference between the number of individuals and the biomass was observed during the rainy season (Spearman rank correlation $r = 0.35$, $p = 3.272e-05 < 0.05$) while a negative correlation with no significant difference was found during the dry season between the number of individuals and the sum of biomass (Spearman rank correlation $r = -0.0011$, $p = 0.9883 > 0.05$).

The lack of correlation between the number of individuals and the biomass during the dry season could be explained by the fact that either the biomass during this season does not depend of the number of individuals, or that the biomass is correlated in this case to each individual and not to the total number of individuals, which means that when one individual is more productive it can influence the biomass of the plant taken alone, but not when the whole number of plants (recorded in the quadrat) are taken together. This can also be due to smaller plants weighing less even when taken together. Moreover, the negative correlation could also be the result of the fact that these individuals respond individually and differently during the dry season depending on the availability of water, especially when some plants do not receive the same amount of water as others.

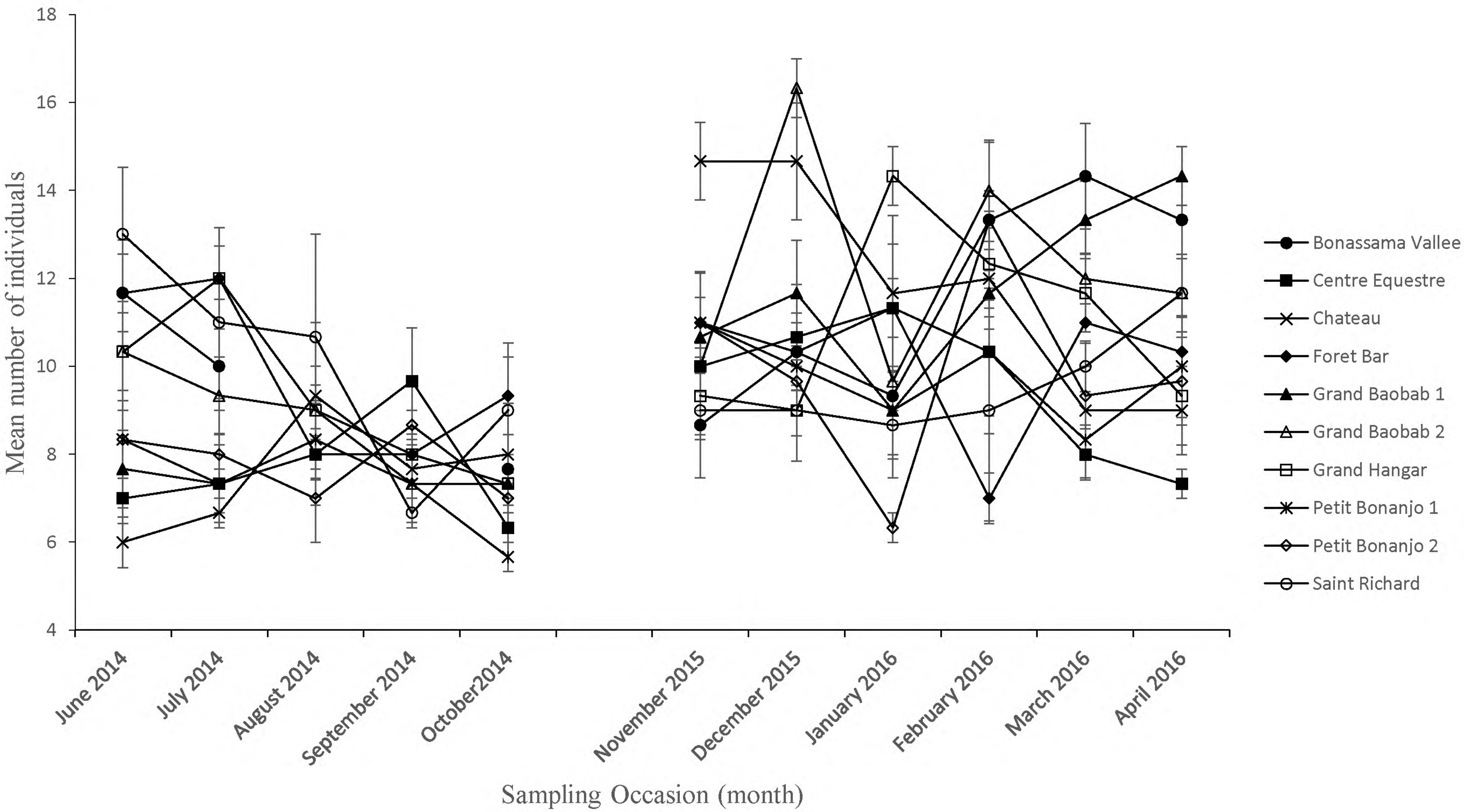


Figure 2.15 The mean density of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

In contrast, during the rainy season, there was a significant difference between sites, among months, and between sites × months (Table 2.11).

Table 2.11 Summary of the PERMANOVA test of significance for the density (number of individuals) between sites and months during the rainy season. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	4085.1	453.9	5.497	**0.001**	997
Months	4	2008.5	502.12	6.0809	**0.001**	997
Sites * Months	32	5513.7	172.3	2.0867	**0.003**	997
Residuals	92	7596.7	82.573			
Total	137	19205				

When both seasons were analysed together, the Permanova tests showed that there was a significant difference within seasons, sites and among sites × season (Table 2.12).

Table 2.12 Summary table of the PERMANOVA test of significance for the density (number of individuals) between seasons. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	4690.1	521.12	4.2749	**0.001**	999
Seasons	1	8636.5	8636.5	70.847	**0.001**	997
Sites * Seasons	9	3468.5	385.39	3.1614	**0.003**	999
Residuals	268	32670	121.9			
Total	287	49833				

A Canonical Analysis of Principal Coordinates (CAP) was used to show the representation of these differences, especially between months (Figure 2.16). The figure (Fig. 2.16) showed that the data recorded the same month no matter the site are gathered together, where the clear separation between data recorded during each month for the number of individuals.

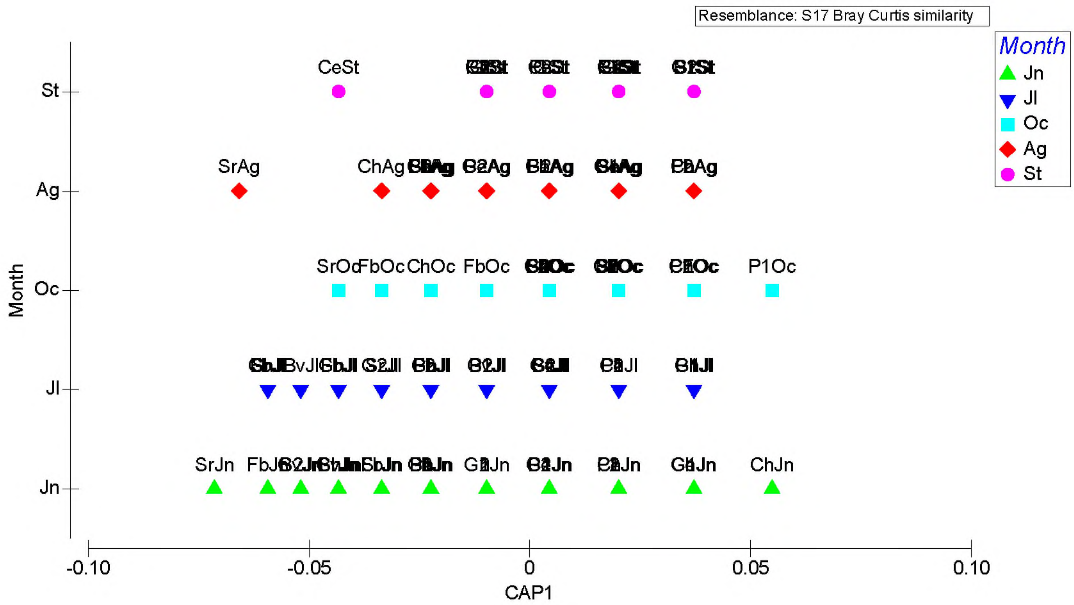


Figure 2.16 Canonical Analysis of Principal Coordinates illustrating the difference for the density observed in the Permanova test of difference between months during the rainy season.

2.8.4 Biomass (above, below and dead material) of water hyacinth for each of the sampling sites per season

During the rainy season, the biomass above water was almost constant during the sampling months except for Grand Hangar, Forêt Bar, Saint Richard and Château which was higher than at the other sites in July 2014. This biomass varied from 2.1kg to 4.83kg (Figure 2.17**)**. During the dry season, the lowest above biomass was measured at Forêt Bar (1.06kg) in March 2016 and the highest biomass at Centre Equestre (4.8kg) in February 2016, while most of the biomass measured between 2 to 4kg (Figure 2.17).

The below water biomass and dead material showed the same pattern as the above water biomass, with the highest below biomass recorded at Saint Richard (5.56kg) during the rainy season (in July) and the lowest below biomass at Grand Baobab 2 (0.66kg) in December 2015 during the dry season (Figure 2.18). The highest and lowest biomass for the dead material was recorded at Bonassama Vallée (4.23kg) in July and in October 2014 (0kg) during the rainy season, and in November 2015 during the dry season for Bonassama Vallée and Grand Baobab 1 (Figure 2.19).

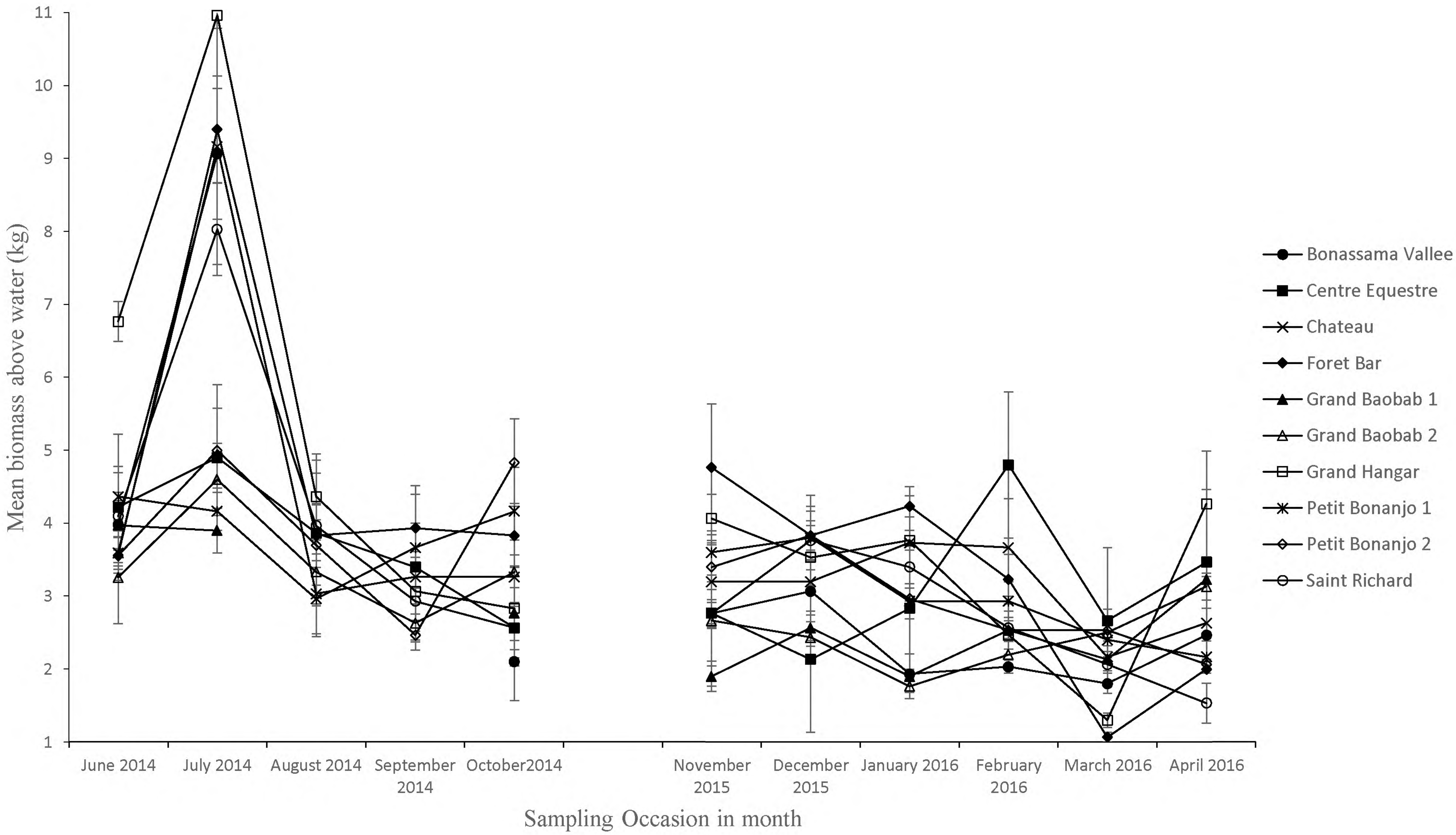


Figure 2.17 The mean above biomass (kg) of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014) and November 2015–April 2016. Error bars indicate standard errors around each mean.

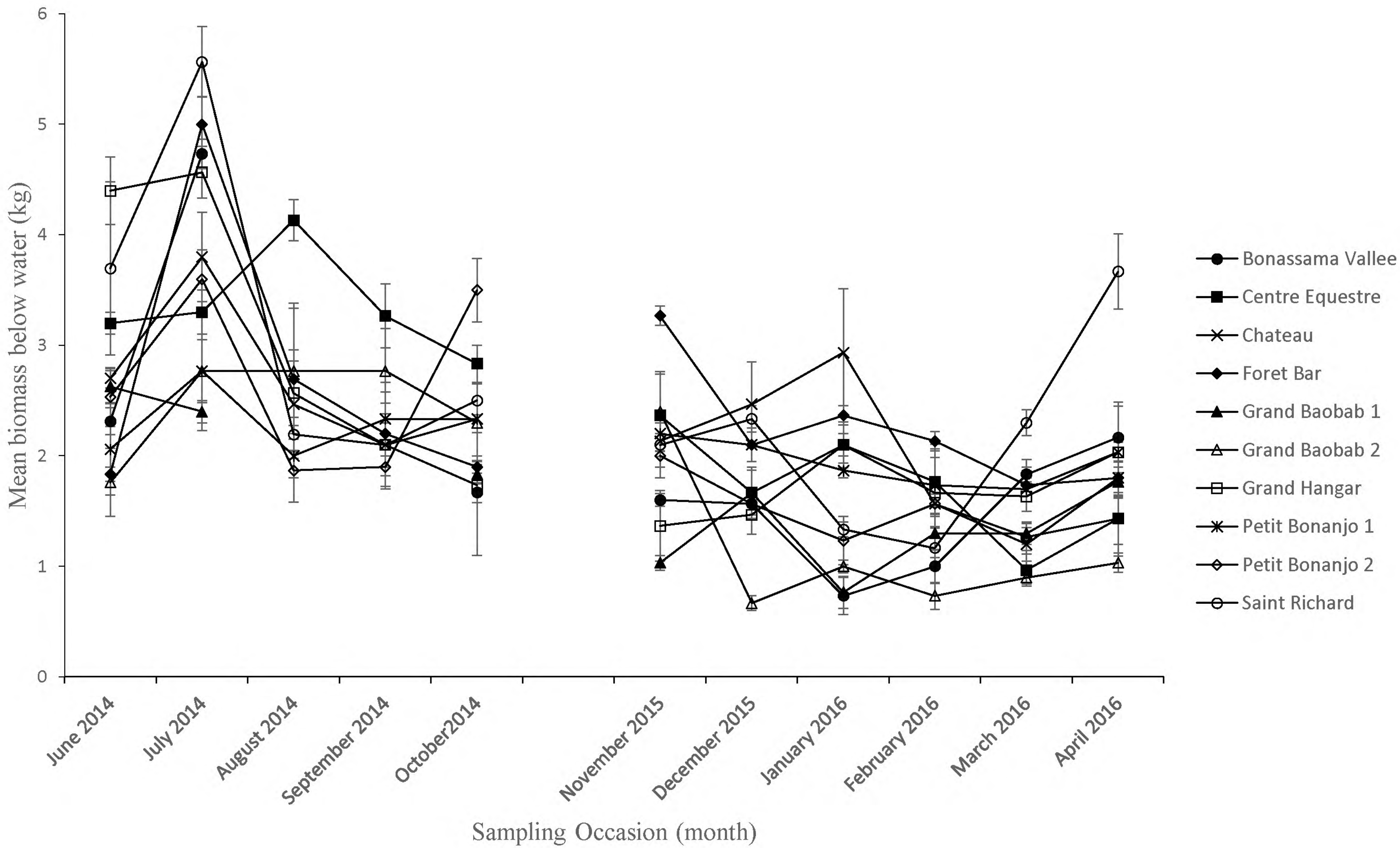


Figure 2.18 The mean below biomass (kg) of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

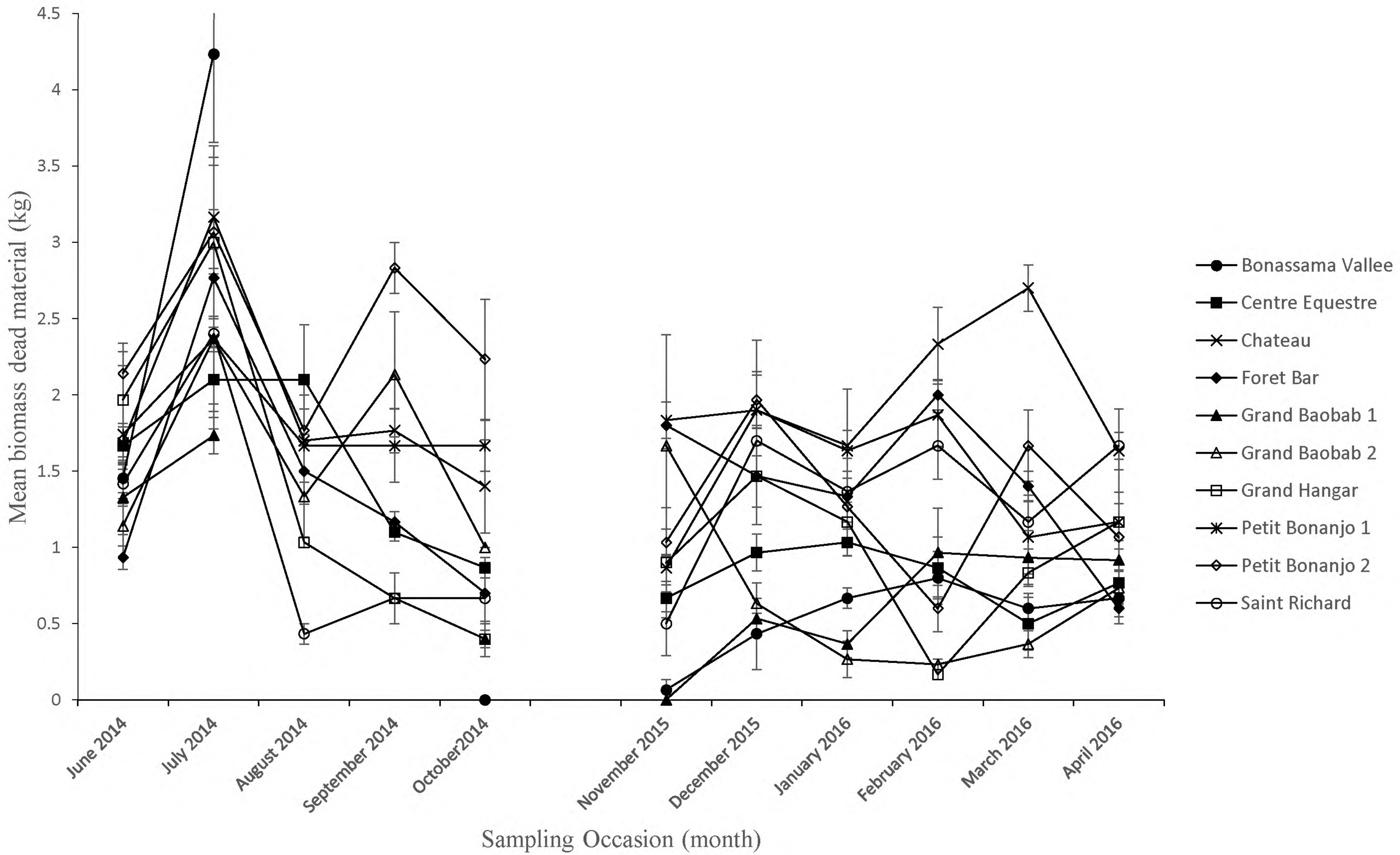


Figure 2.19 The mean biomass of dead material (kg) of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

The fact that there was no dead material at these sites could be explained by the regeneration of new water hyacinth plants after the flushing out of the system which happened during the rainy season in August and September 2014, which could also have happened before the beginning of the dry season in 2015. The results of the combined biomass (sum of biomass) showed the same pattern as with the biomass recorded separately, whether in the rainy or the dry season (Figure 2.20).

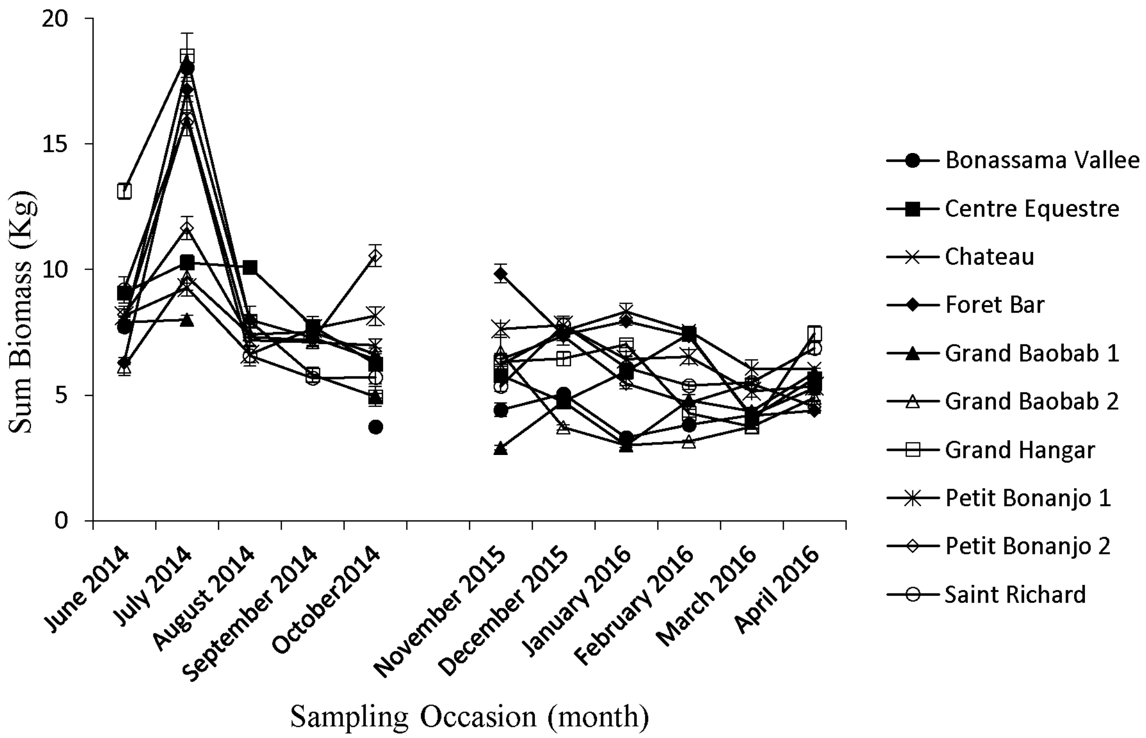


Figure 2.20 The mean sum of biomass of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

2.8.5 Mean shoot/root ratio wet biomass

The pattern of the mean shoot/root ratio for the wet biomass during the rainy season is almost the same for all sites, with exception of Centre Equestre and Grand Baobab 2 where this ratio decreased from July until October for Centre Equestre, and from July until September at Grand Baobab 2. Both these sites presented the lowest ratio, which was 0.9kg (Figure 2.21).

The dry season is characterized by a ratio which varied from 0.4kg at Saint Richard in April 2016 to 3.65kg at Grand Baobab 2 in December 2015, with a decrease which took place from January until March at Bonassama Vallée, Forêt Bar, Grand Baobab 1, Grand Hangar, Petit Bonanjo 1 and 2, and Saint Richard (Figure 2.21).

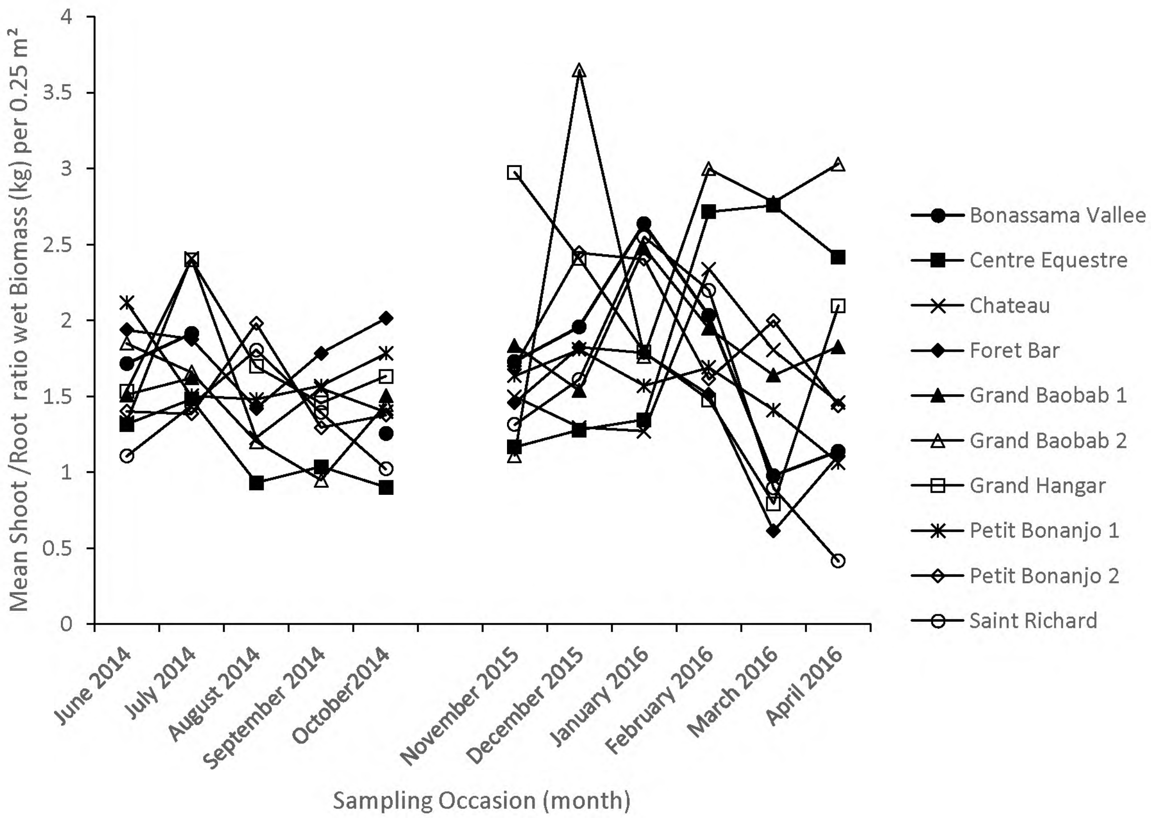


Figure 2.21 The mean shoot/root ratio (kg) of the wet biomass of water hyacinth at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016.

However, in this study, the results of the mean shoot/root ratio biomass during the dry season were higher than the shoot/root ratio during the rainy season (Figure 2.22) and somewhere followed the model of functional equilibrium. This functional equilibrum which according to Wilson (1988), states that under all growth conditions the roots and shoot have the same priority, either in the use of the nitrogen uptaken for the roots or for the products of photosynthesis.

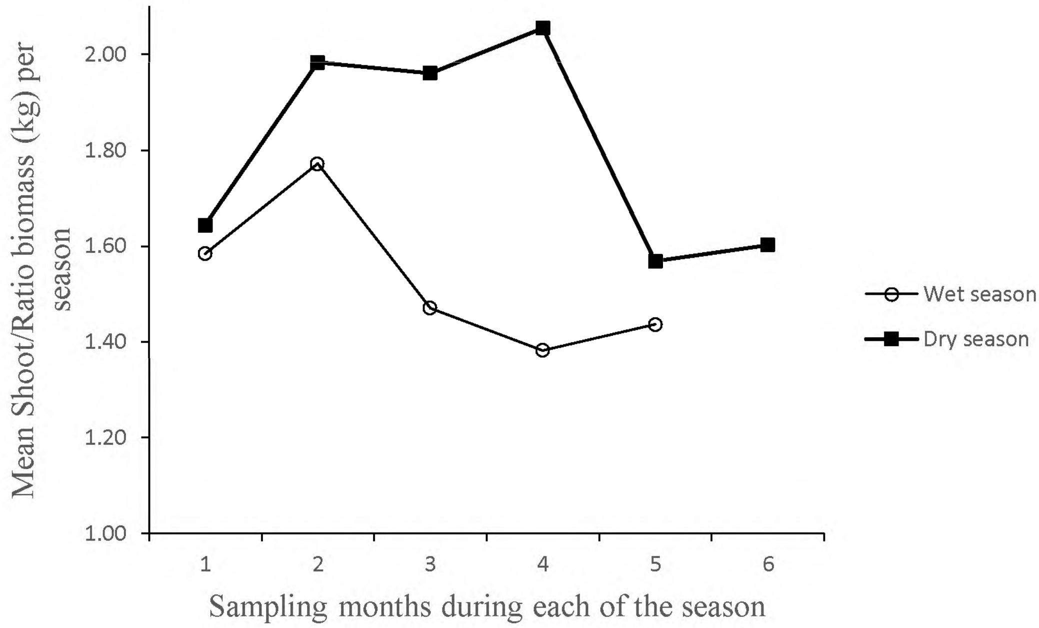


Figure 2.22 The mean shoot/root ratio (kg) of the wet biomass of water hyacinth during the two seasons, the numbers represent the numberof samplingmonthfor wach season, 5 months during the rainy season (June 2014–October 2014) and 6 months during the dry season (November 2015–April 2016).

2.8.6 Permanova analysis for plant biomass

2.8.6.1 Dry and Rainy season

The results from the Permanova test showed that regardless of the season (dry or rainy), there is a significant difference whether the data were analysed among months, between sites, or between sites × months with a p (perm) value of 0.001 respectively (Table 2.13 and Table 2.14).

Table 2.13 Summary table of the PERMANOVA test of significance for the plant biomass during the rainy season. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	5646	627.34	6.049	**0.001**	999
Months	4	19091	4772.7	46.02	**0.001**	999
Sites * Months	32	13799	431.21	4.1579	**0.001**	999
Residuals	92	9541.2	103.71			
Total	137	47399				

Table 2.14 Summary table of the PERMANOVA test of significance for the plant biomass during the dry season. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	16131	1792.3	18.819	**0.001**	999
Months	5	4902.7	980.55	10.295	**0.001**	999
Sites * Months	45	23136	514.14	5.3982	**0.001**	999
Residuals	120	11429	95.243			
Total	179	55599				

2.8.6.2 Combined dry and rainy season for plant biomass

When both the seasons were combined, a Permanova test showed that there was a significant difference among sites, between seasons and among sites × season with a p (perm) value of 0.001 respectively (Table 2.15). This could be explained by the constant variation in terms of water availability either during the rainy or dry season, but also by the movement of tides which happens daily every six hours. Indeed, during the rainy season, there is high water levels and nutrients are diluted. So, each of the season on his own has an effect on the plant biomass.

Table 2.15 Summary table of the PERMANOVA test of significance for the plant biomass between season and sites. Values in **bold** are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	12206	1356.3	5.0716	**0.001**	999
Seasons	1	22390	22390	83.726	**0.001**	999
Sites * Seasons	9	7765.5	862.84	3.2265	**0.001**	999
Residuals	268	71669	267.42			
Total	287	1.1576E5				

These differences are clearly represented in a graph obtained from the CAP for all the seasons (Figure 2.23).

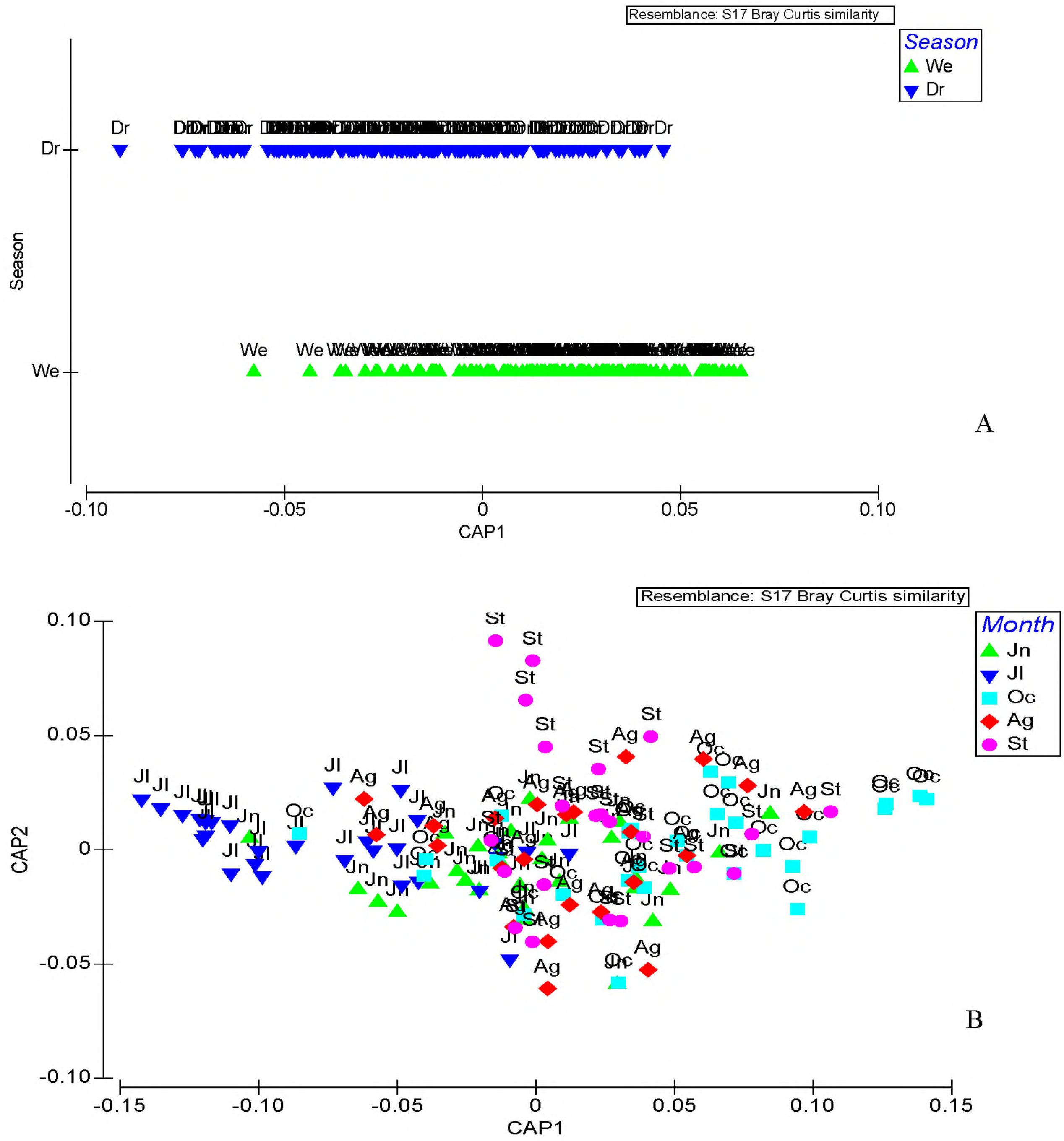


Figure 2.23 Canonical Analysis of Principal Coordinates illustrating the significant difference observed in the Permanova test of difference between seasons (A) and between months (B) during the rainy season for the plant biomass.

2.8.7 Sediment results

The results from the sediment samples are presented in the Table below (Table 2.16). The sediment was collected in each of the selected sites for the long-term study.

Table 2.16 Composition and classification of soil samples for each of the monitored sites collected in April 2016. Bonassama Vallée (BV), Centre Equestre (CE), Château (CH), Forêt Bar (FB), Grand Baobab 1 (GB1), Grand Baobab 2 (GB2), Grand Hangar (GH), Petit Bonanjo 1 and 2 (PB1, PB2), Saint Richard (SR), Ecomité (EC).

Sites	Bulk density Kg/l	NH_4-N Mg/kg	NO^3-N Mg/kg	C (%)	Clay %	Silt %	Sand %	Classification	Stone %	P Bray II mg/kg
BV	*	11.14	103.14	5.07	13	10	77	SaLm	0.00	75.28
CE	*	22.74	67.02	4.57	17	14	69	SaLm	10.08	47.12
CH	0.97	19.61	25.81	3.55	13	8	79	SaLm	50.42	21.03
FB	0.83	29.69	20.05	2.64	11	10	79	SaLm	40.82	72.29
GB1	1.20	5.79	0.38	1.21	5	4	91	Sa	1.92	39.43
GB2	0.96	45.98	4.63	1.94	13	10	77	SaLm	9.54	27.26
GH	0.83	4.7	40.57	2.46	11	10	79	SaLm	0.00	179.27
PB1	*	59.40	1.43	5.12	21	12	67	SaKLLm	63.71	8.38
PB2	1.09	3.81	14.47	1.12	11	8	81	SaLm	32.98	78.10
SR	0.90	49.96	13.87	2.73	17	12	71	SaLM	0.00	27.51
EC	1.41	3.50	2.59	1.43	9	8	83	LmSa	23.31	200.80

* Samples too small to determine bulk density

A further site, Ecomité (EC) without water hyacinth (see Chapter 3), was added to the 10 sites which were chosen for a long-term study for the purpose of this thesis, in order to look at the difference in composition between sites with water hyacinth and the site without water hyacinth. In general, the site without water hyacinth showed a relatively low concentration of other nutrients, except for phosphorus, which was very high compared to the sites with water hyacinth. In the sites with water hyacinth, the concentration of ammonium was relatively low at Grand Baobab 1, Grand Hangar and Petit Bonanjo 2, while the concentration of nitrates was high at Bonassama Vallée, Centre Equestre, Château, Forêt Bar, Grand Baobab 2, Petit Bonajo 2 and Saint Richard. The percentage of carbon (C %) was almost constant for the other sites, except for Grand Baobab 1 and 2, Petit Bonanjo 2 where it was relatively low. The same results were obtained for the percentage of clay and silt at Grand Baobab 1 while for the other sites, not too many changes were observed. Almost the same percentage of sand was observed in all the sites, but no stone was recorded at Bonassama Vallée, Grand Hangar and Saint Richard. The highest concentration of phosphorus was measured at Grand Hangar (179.27mg/kg), while the lowest concentration was measured at Petit Bonanjo 1 (8.38mg/kg).

Soil composition samples were classified into four categories, namely:

- Sandy loam (SaLm) soil at Bonassama Vallée, Centre Equestre, Château, Forêt Bar, Grand Baobab 2, Grand Hangar, Petit Bonanjo 2 and Saint Richard;
- Sandy (Sa) soil at Grand Baobab 1;
- Sandy clay loam (SaKLLm) soil at Petit Bonanjo 1, and
- Loam sand (LmSa) at Ecomité.

2.8.8 Water parameters

During the rainy season, temperature and pH were constant throughout the months with temperatures ranging between 25 and 28.3°C and pH between 6.52 and 7.63 (Figures 2.24 and 2.25). With regard to conductivity, salinity and total dissolved solids (TDS), the same patterns were observed, declining from June to August in all the sites except Saint Richard, Forêt Bar, and Grand Hangar where these parameters increased slightly in August (Figures 2.26, 2.27, 2.28).

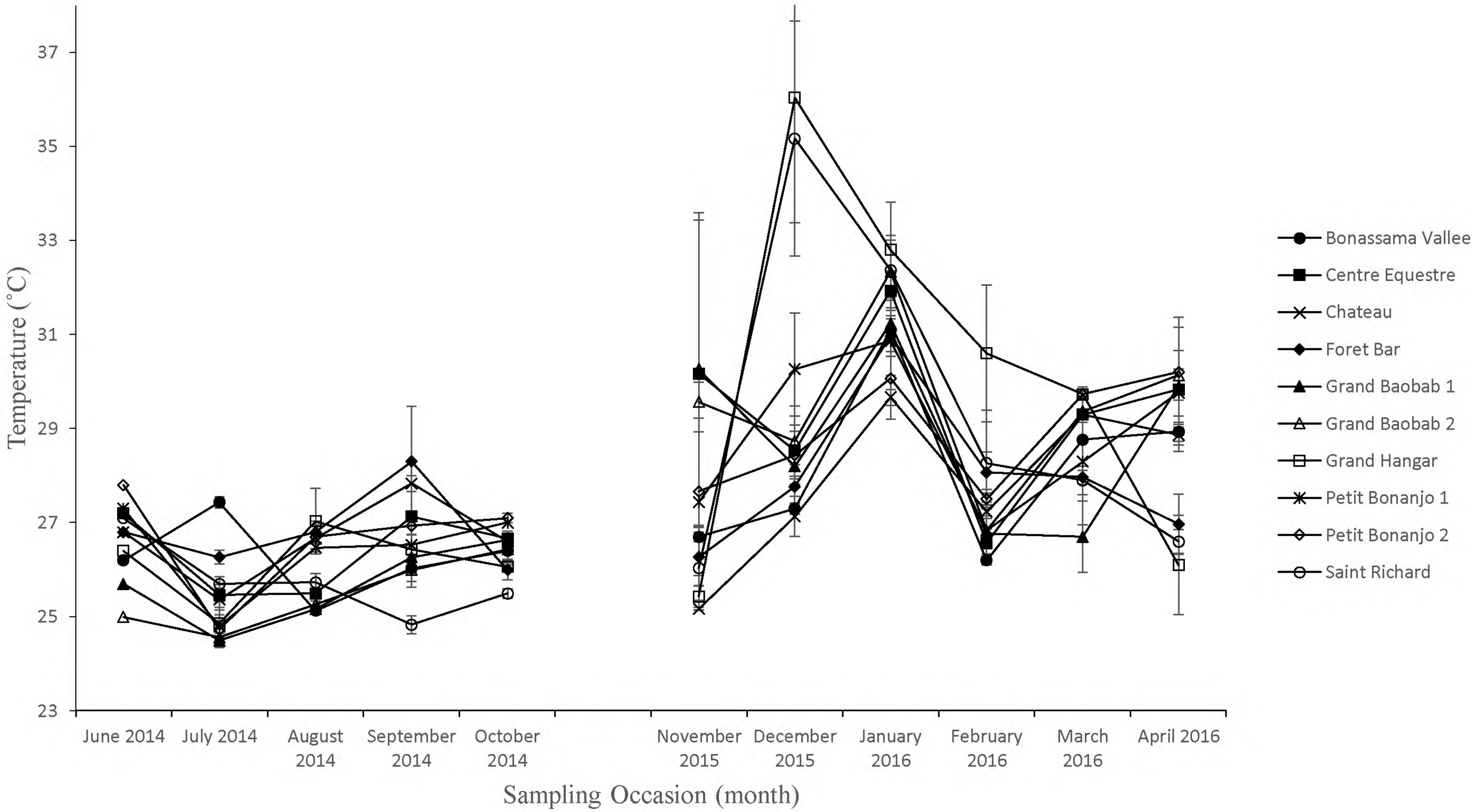


Figure 2.24 The mean temperature (°C) of water samples collected at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

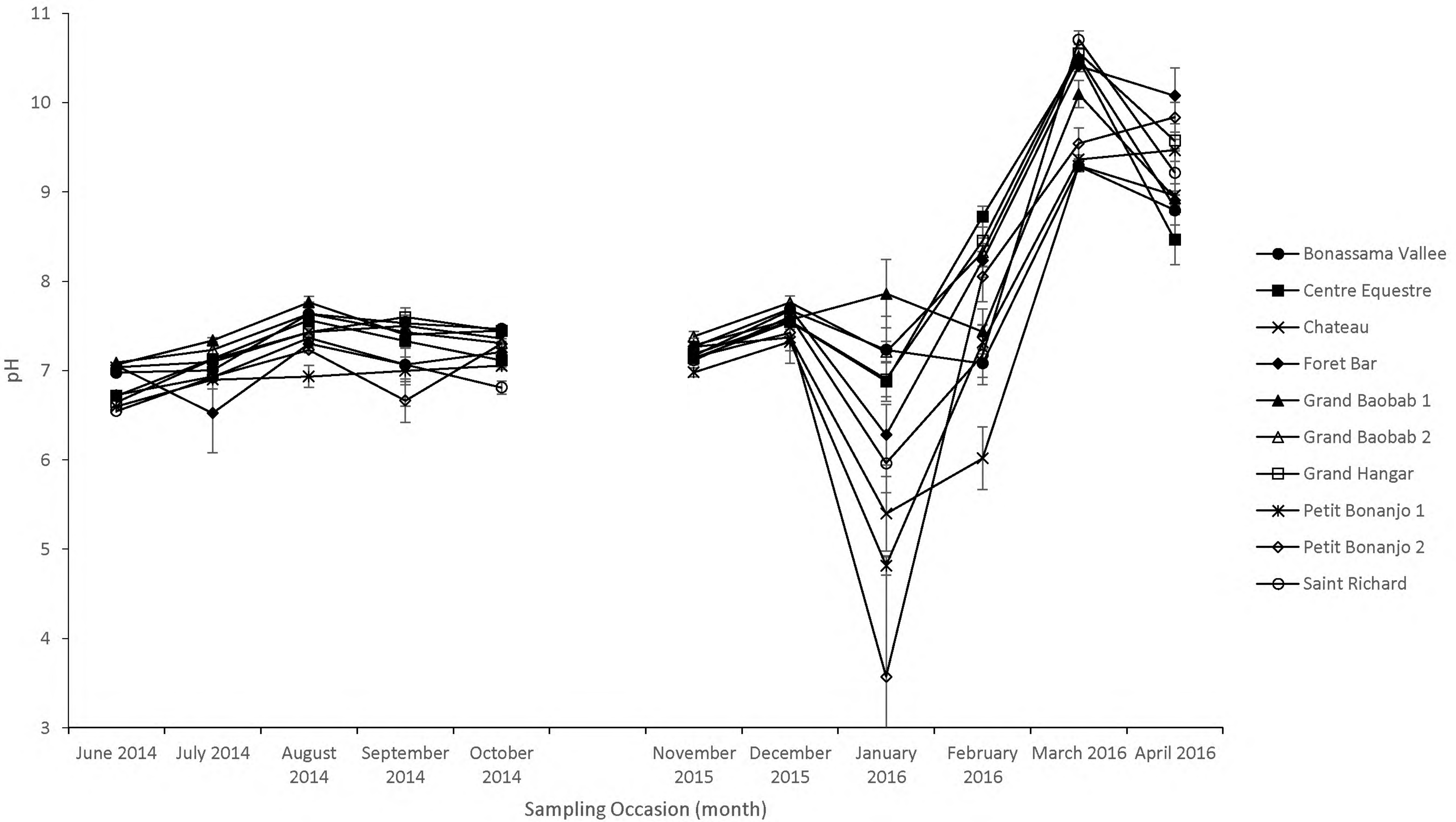


Figure 2.25 The mean pH of water sample collected at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

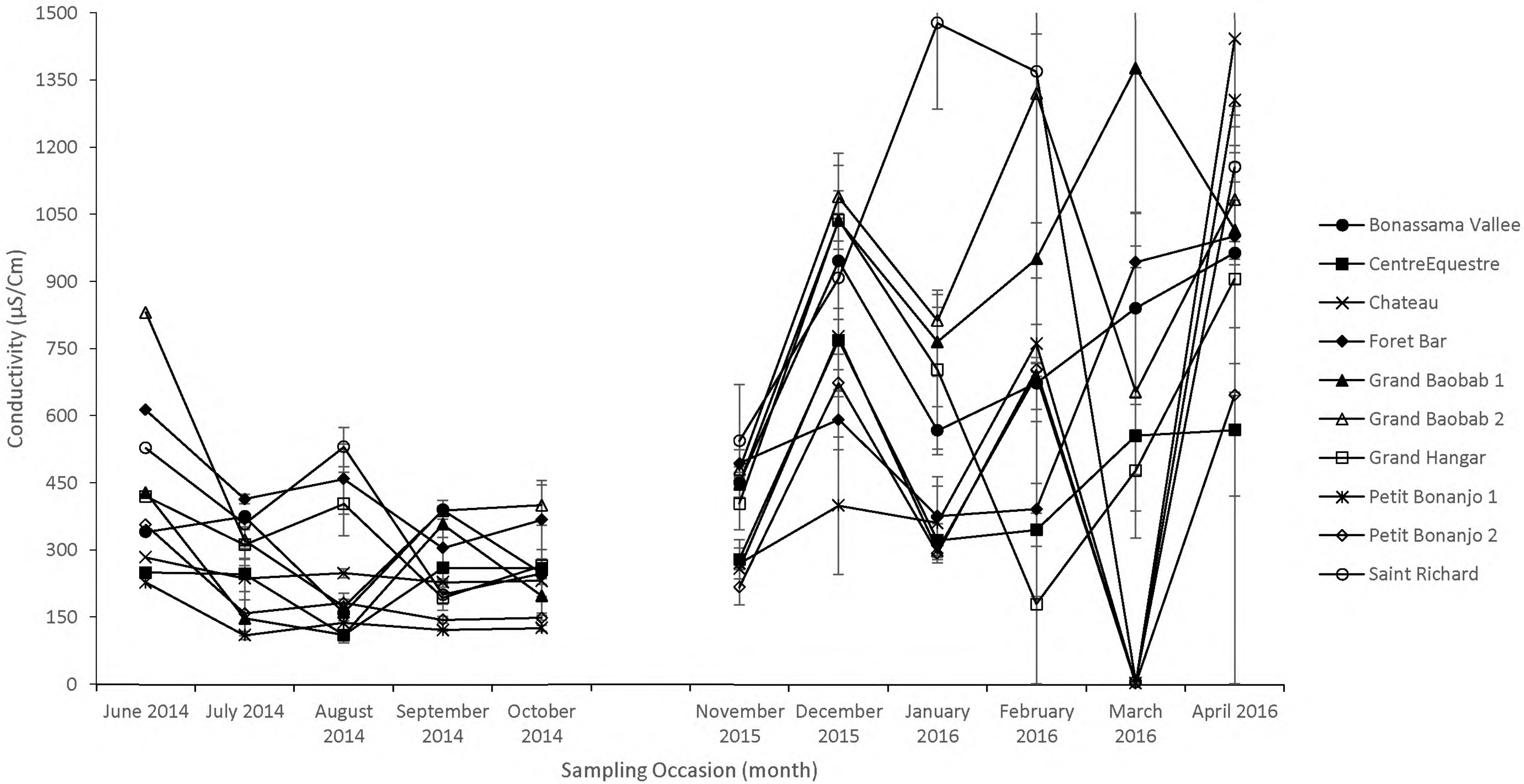


Figure 2.26 The mean conductivity (µS/cm) of water samples collected at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

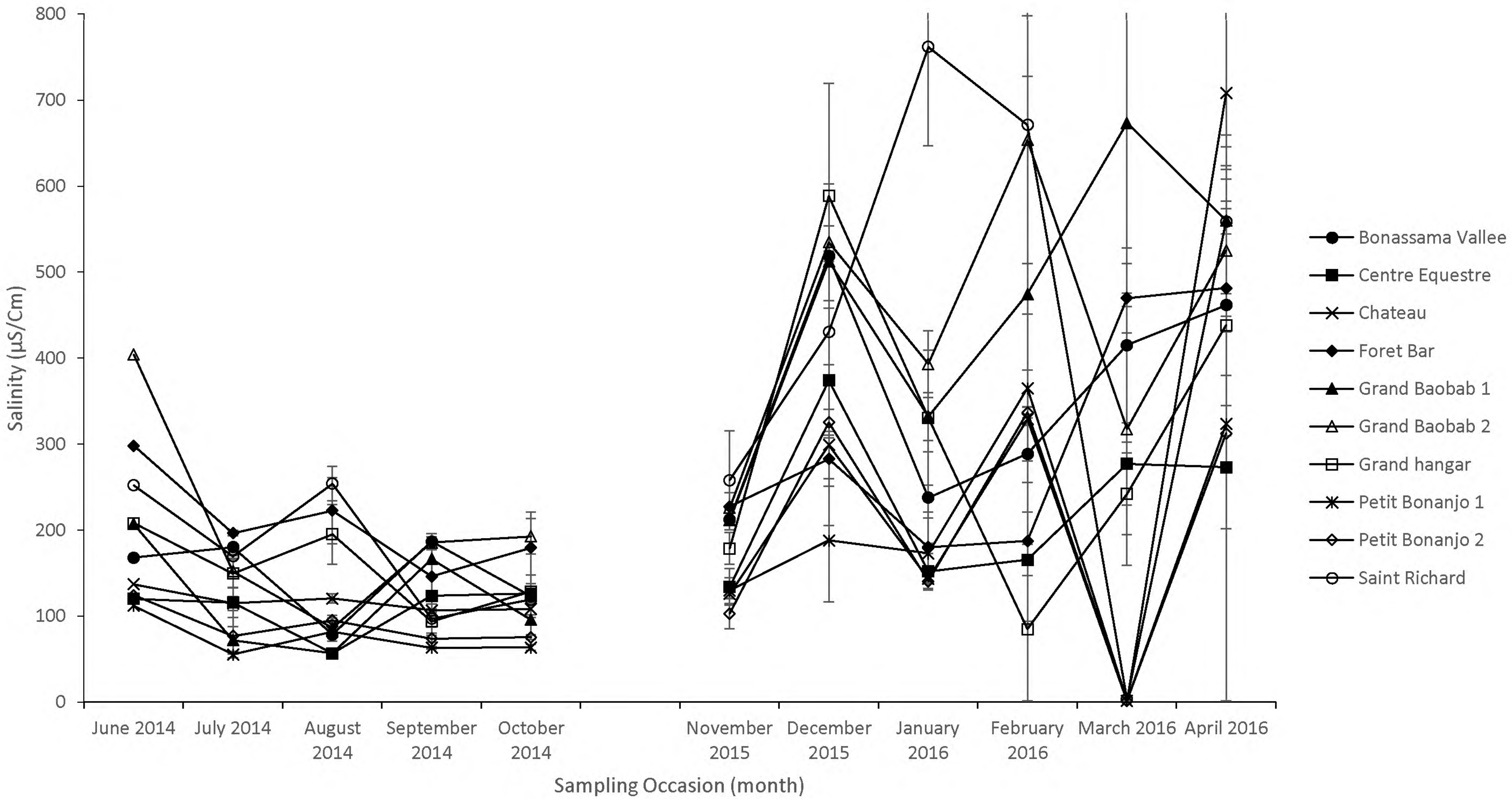


Figure 2.27 The mean salinity (µS/cm) of water sample collected at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard error around each mean.

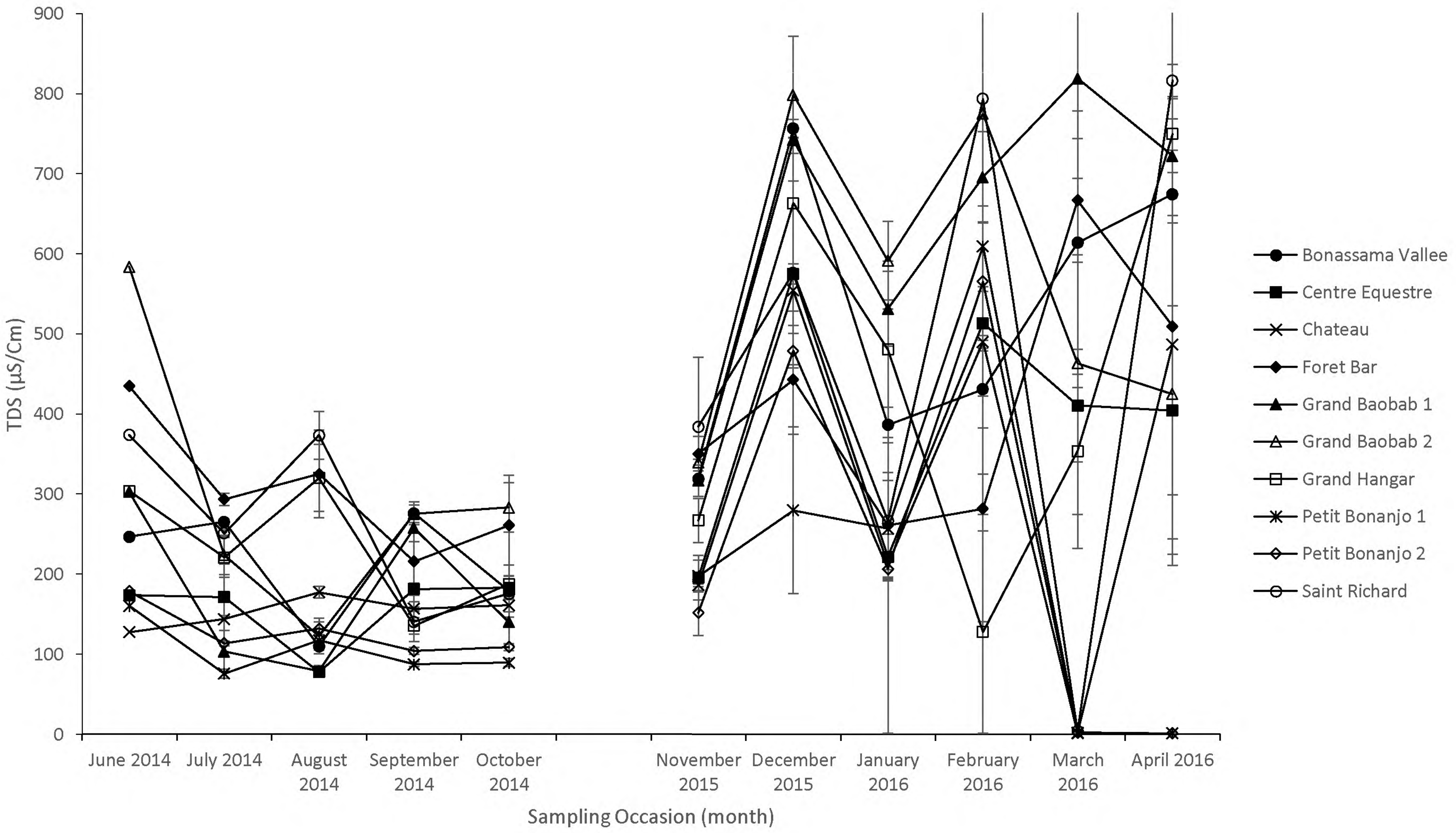


Figure 2.28 The mean Total Solids Dissolved (TDS) (µS/cm) of water sample collected at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

The concentration in nitrate was relatively low in all the sampling months during the rainy season compared to the dry season when high concentrations were measured with up to 57.7mg/l at Saint Richard in March 2016, the month in which the concentration of nitrate increased in all the sites (Figure 2.29). Similarly, the concentration of ammonium was low during the rainy season (between 0.4 and 16.4mg/l respectively in June and August at Saint Richard) compared to the concentration recorded during the dry season which varied from 2.5 to 35.1mg/l in November at Château and Grand Hangar respectively (Figure 2.30).

As with the concentration of nitrate and ammonium, the other parameters such as temperature, pH, CND, salinity and TDS were very high during the dry season with the exception of March 2016, when the values recorded were very low. This was attributed probably to the multi-parameters which might have been faulty that month, according to the big gap noted from the first sampling point to others. The change observed during the rainy and dry seasons could be explained by the process of eutrophication which is denser during the dry season, and also to the process of sedimentation which takes place during the same season.

2.8.8.1 Permanova test of physico-chemical parameters per season and between seasons

Whether in a rainy or dry season, or when data for the both season were combined, a significant difference was shown in data collected between sites, among months and season, and between sites × months, and sites × season (Tables 2.17, 18, 19).

Table 2.17 Summary of the PERMANOVA test of significance for the water parameters during the rainy season. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	176.61	19.623	11.255	**0.001**	999
Months	4	150.97	37.742	21.647	**0.001**	998
Sites * Months	32	201.4	6.2937	3.6098	**0.001**	997
Residuals	92	160.4	1.7435			
Total	137	685				

Table 2.18 Summary of the PERMANOVA test of significance for the water parameters during the dry season. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	116.53	12.947	6.0797	**0.001**	994
Months	5	248.86	49.772	23.371	**0.001**	998
Sites * Months	45	274.06	6.0902	2.8597	**0.001**	995
Residuals	120	255.56	2.1296			
Total	179	895				

Table 2.19 Summary of the PERMANOVA test of significance for the water parameters between seasons and sites. Values in bold are significant.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Sites	9	105.97	8.1514	2.6254	**0.001**	998
Seasons	1	415.03	415.03	133.67	**0.001**	999
Sites * Seasons	9	70.033	7.7814	2.5062	**0.001**	998
Residuals	264	819.68	3.1049			
Total	287	1435				

These differences may be explained by the characteristic of each site and by the different elements which are drained into the sites per month, all this varying according per season.

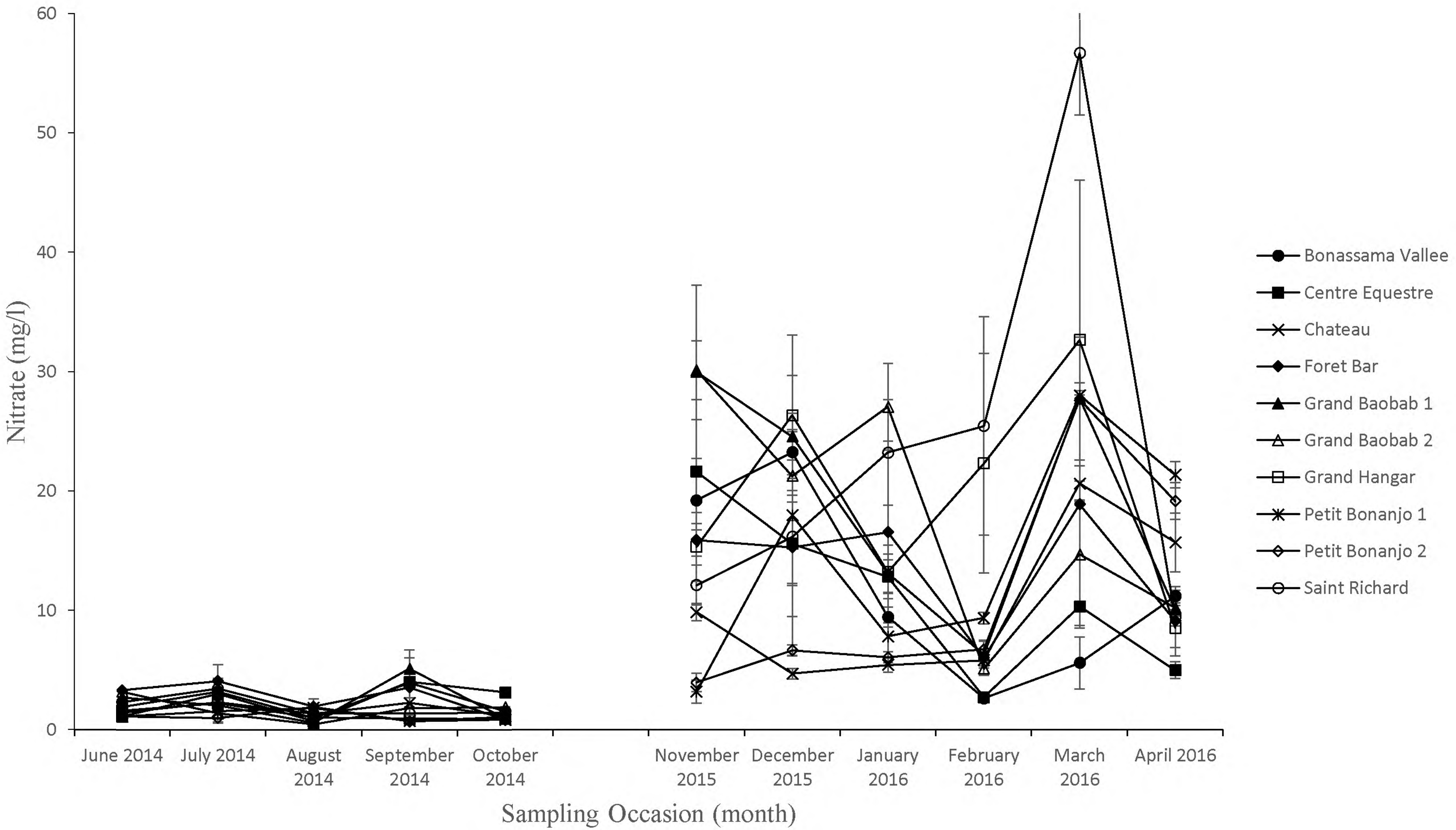


Figure 2.29 The mean nitrates (mg/l) of water samples collected at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

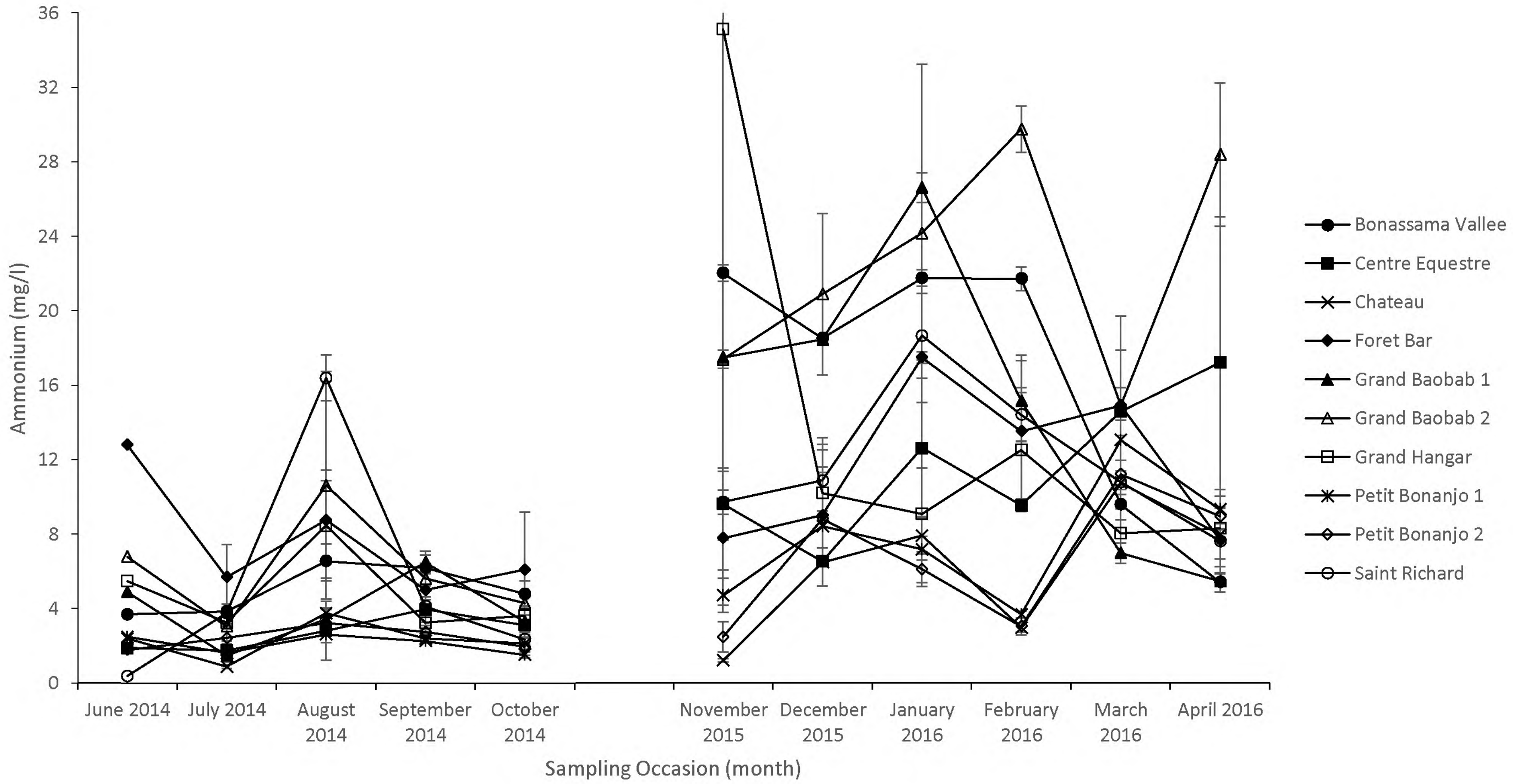


Figure 2.30 The mean ammonium (mg/l) of water samples collected at each of the ten sites during the two seasons, June 2014–October 2014 and November 2015–April 2016. Error bars indicate standard errors around each mean.

As with the abundance (number of individual) and the biomass, the CAP for environmental variables showed a clear separation between data collected per month during the dry season (A) and data collected between seasons (B) (Figure 2.31).

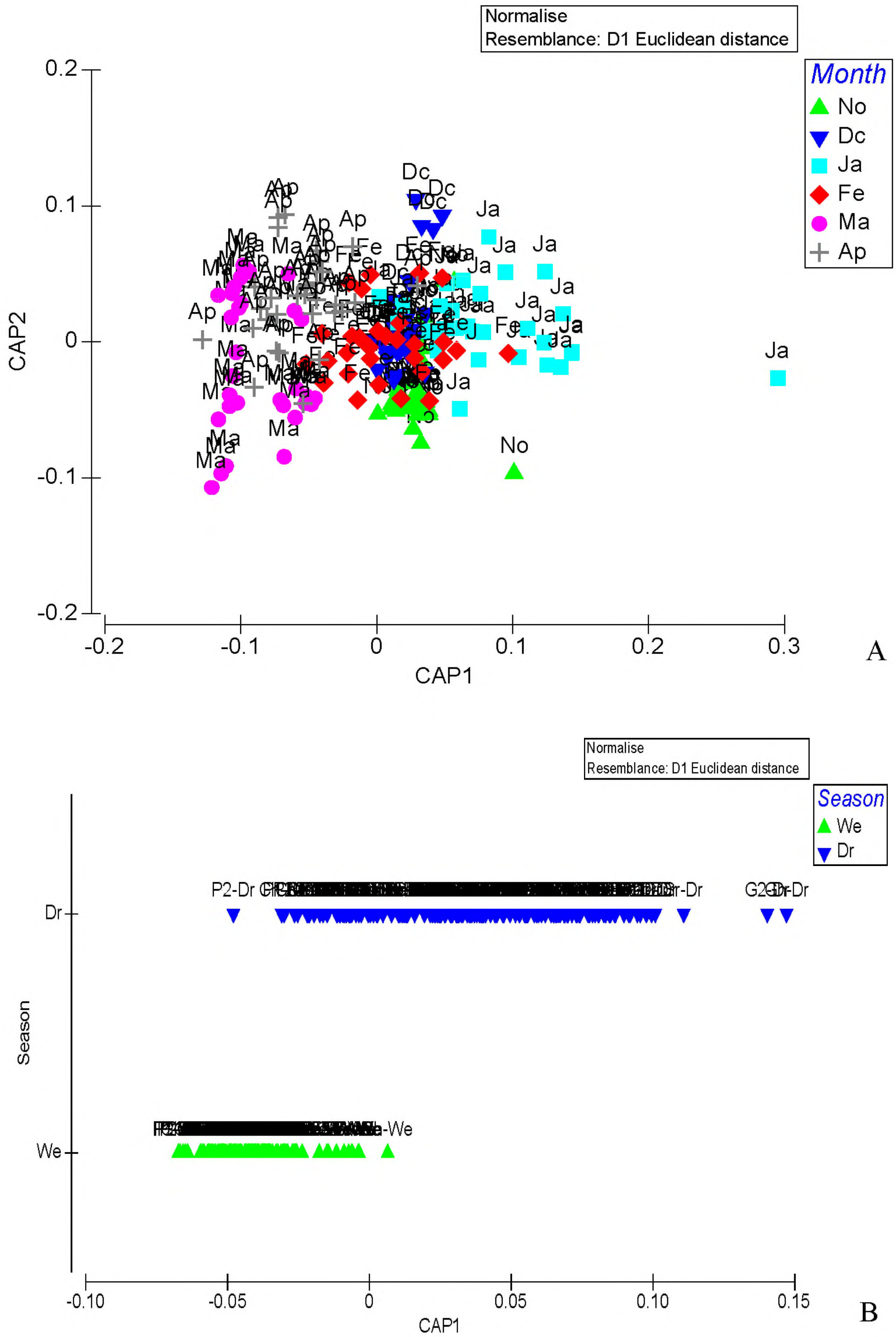


Figure 2.31 Canonical Analysis of Principal Coordinates illustrating the significant difference observed in the Permanova test of difference between months (A) during the dry season and between seasons (B) for the environmental variables.

2.8.9 Principal coordinates analyses for combined rainy and dry season

The principal coordinate analysis (PCO) of the combined physico-chemical data from the rainy and dry seasons showed a distinct separation between the data collected during the dry season and those collected during the rainy season, no matter in which sites they were collected. All these grouped together per season with the exception of Petit Bonanjo 2 which was an outlier (Figure 2.32). When plotted on the graph, the environmental variables (temperature, pH, CND, ammonium and nitrate) showed more correlation to the dry season than to the rainy season, where all the parameters were low. The loading of temperature, CND, and nutrients (Ammonium and Nitrate) were positive on PCO1 (Figure 2.32) and the loading of pH was positive on the PCO2 (Figure 2.32). The environmental variables represented by the horizontal axis PCO1 contributed 46.5 % of total variation and was t called the 'nutrients or polluted' component while the vertical axis, PCO2, contributed 19% of total variation and was called the 'pH' component. In this graph, Saint Richard, Grand Hangar and Grand Baobab 2 presented the highest value for temperature, conductivity and ammonium, while Petit Bonanjo 1 was influenced by nitrate; Saint Richard, Grand Baobab 1, Foret Bar and Grand Baobab 2 had a high value of pH.

2.8.10 Results from the iButton data logger

The temperature data recorded during the dry season using the iButton were illustrated in Figure 2.33. The three sites where the data were gathered showed the same pattern with the minimum temperatures recorded on the 7th December 2015 as 28.22°C, 27.86°C and 28.03°C) at Petit Bonanjo 1, Centre Equestre and Saint Richard, respectively, while the maximum temperatures were recorded on the 29th February as 30.39°C, 29.99°C at Petit Bonanjo 1 and Centre Equestre respectively. However, on a different day in February, the 22nd, the maximum temperature at Saint Richard was recorded as 32.05°C. The average temperature for all three sites varied from 28.04°C on the 7th December 2015 to 30.66°C on the 29th February 2016 (Figure 2.33).

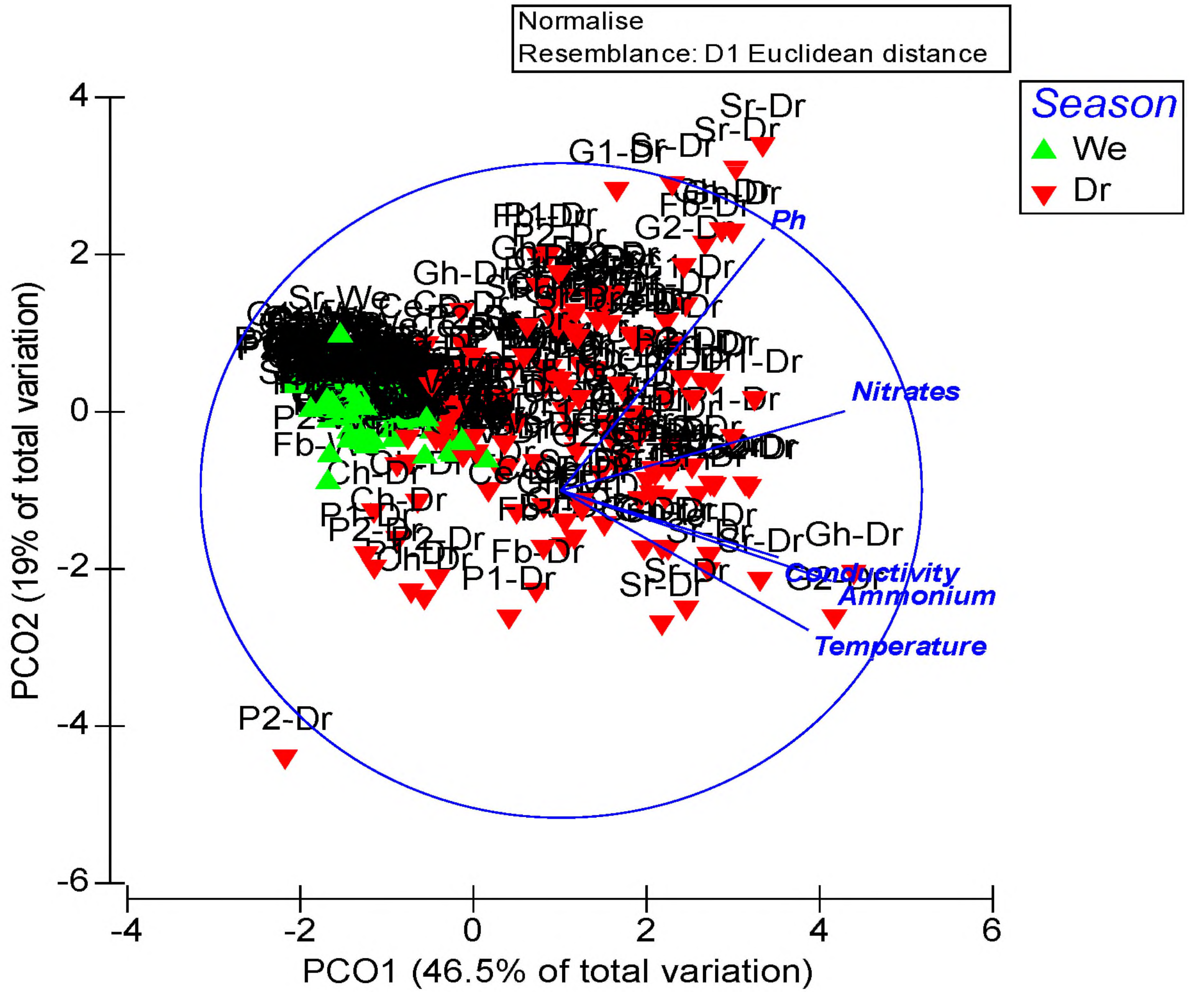


Figure 2.32 Principal Coordinates Analysis (PCO) bi-plot based on resemblance matrix using Euclidian distance, illustrating the relationship between the seasons and the environmental variables explained by each axis, and the representation of different seasons and sites with regard to which variables there are most closely related.

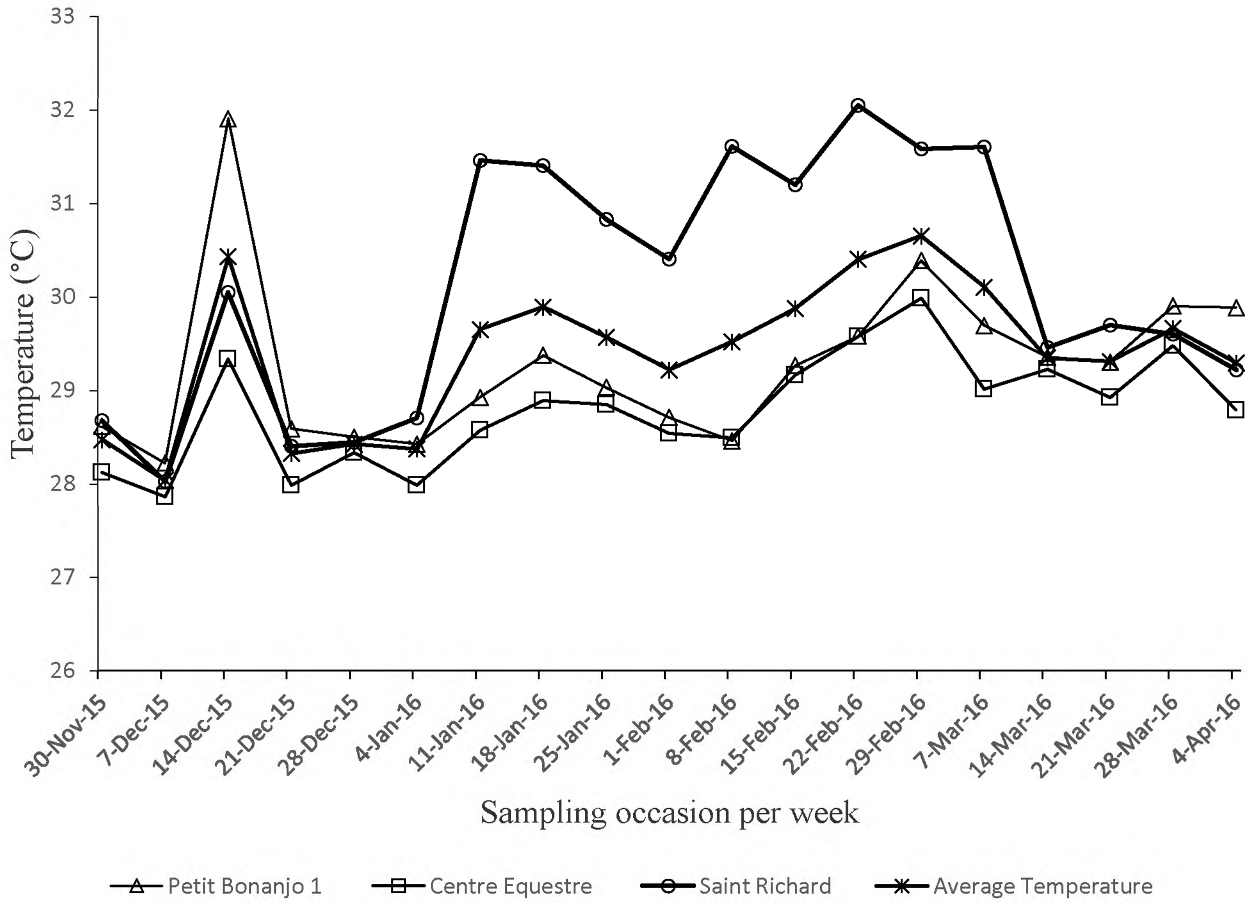


Figure 2.33 The mean water temperature (°C) recorded at Petit Bonanjo 1, Centre Equestre and Saint Richard from November 2015–April 2016 and the mean temperature (°C) for the three sites.

2.8.11 Relationship between environmental variables (water samples) and biological data (plant biomass and number of individual)

To understand the relationship between environmental variables and biological data, the BEST analysis, as well as the Distance Based Linear Models (DistLm) for the rainy and dry season, was analyzed separately and then the combined data from the dry and rainy season were used.

2.8.11.1 Rainy season

Density/Number of individuals

Concerning the abundance (number of individuals), conductivity was the factor which best explained the change in the number of individuals per site (ρ = 0.154, slss = 0.1%). When the DistLm was run, pH and conductivity appeared to be more significant with both of the factors explaining 20.89 % of the variation, although conductivity alone explained 20.85% of the variation. The graph representing only conductivity was chosen as pH added nothing to the total variation (Figure 2.34).

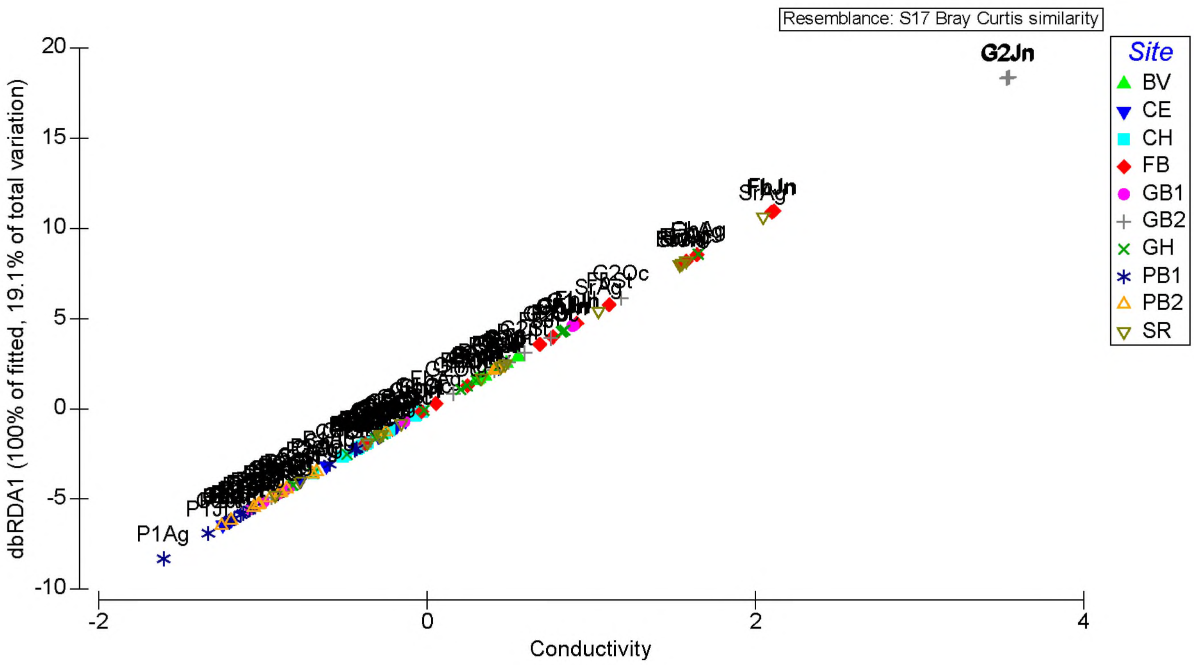


Figure 2.34 Distance-based linear models (DistLM) showing the specific environmental variable Conductivity for all sites and months which best explained the change in the density of water hyacinth during the rainy season. The first axis (dbRDA 1) explains the amount of variation for conductivity: 19.1%.

Biomass

The results from the BEST analysis showed that during the rainy season, the changes in the biomass were more closely correlated with the increase of pH and nitrates with a sample statistic Rho of 0.118 and a significant level of sample statistic (slss) of 3.4 % (ρ = 0.118, slss

= 3.5%). The DistLm showed that both factors explained 12.6 % of the variation in the models which means that even if there are factors which best explained the changes in biomass, there is still a number of unexplained variations in the data (Figure 2.35).

2.8.11.2 Dry season

Density/Number of individual

Temperature, conductivity and ammonium were the three best factors which explained the changes in the number of individuals (ρ= 0.023, *slss*= 74.9%). However, when the DistLM was used, it showed that ammonium added nothing in this variation with 0% of % explained out of total variation individual. So, the graph with only temperature and conductivity was viewed as the best representation of the change in pattern in the data, with conductivity alone explaining 5% of the variation (Figure 2.36).

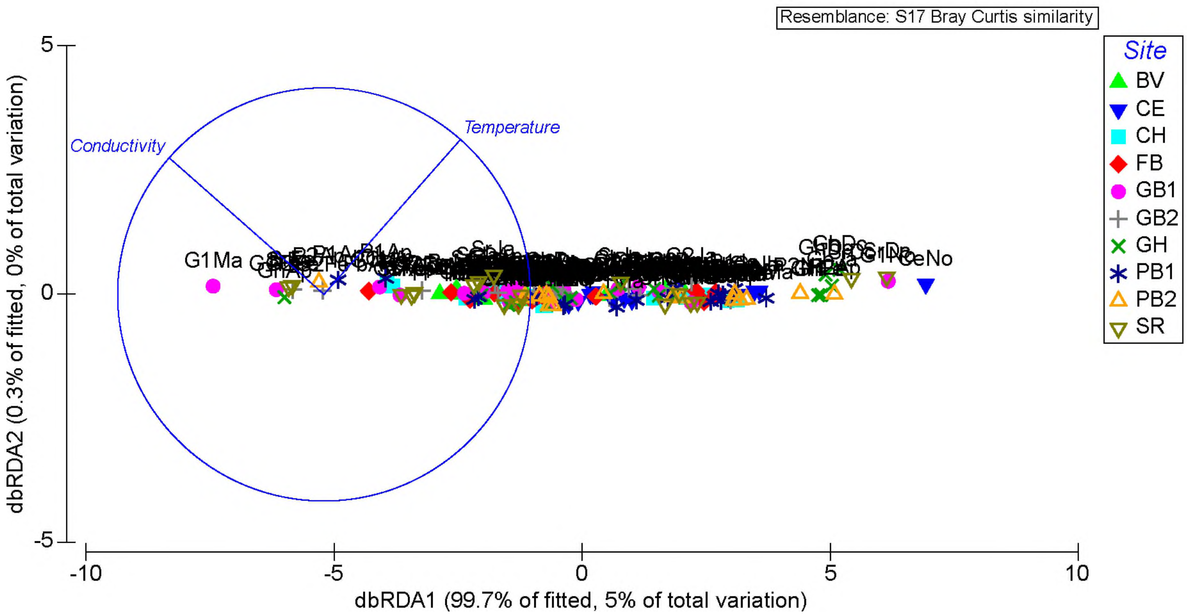


Figure 2.35 Distance-based linear models (DistLM) showing the specific environmental variable temperature and conductivity for all sites and months which best explained the change in the density of water hyacinth during the dry season. The first axis (dbRDA 1) and second axis (dbRDA 2) explain the amount of variation for both factors: 5% and 0.3%, respectively.

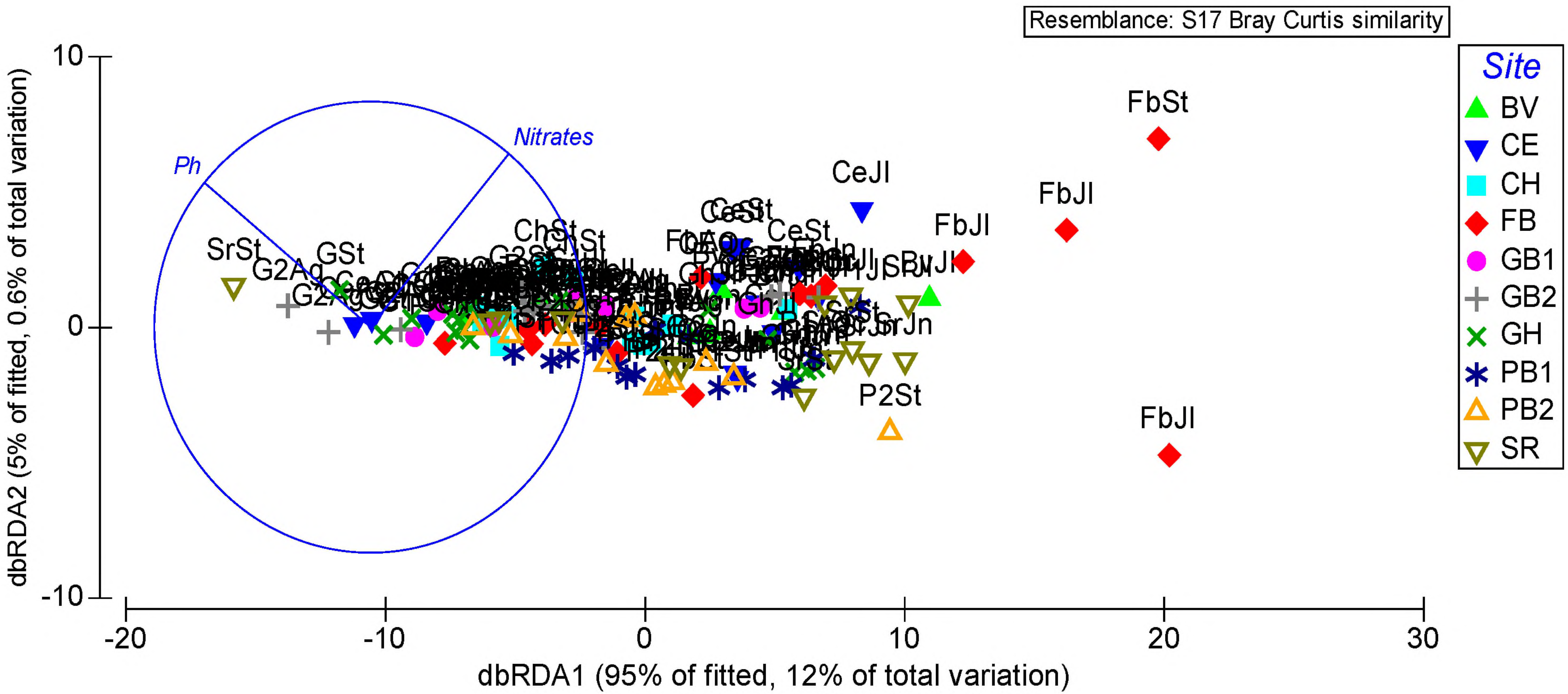


Figure 2.36 Distance-based linear models (DistLM) showing the specific environmental variable nitrate and pH for all sites and months which best explained the change in the biomass of water hyacinth during the rainy season. The first axis (dbRDA 1) and second axis (dbRDA 2) explain the amount of variation for both factors: 12% and 0.6%, respectively.

Biomass

The BEST function used showed that the combination of environmental variables which best explained variation in the biomass, were ammonium and nitrate (ρ=0.166, *slss*=0.1%). However, the DistLm showed that pH and ammonium were more significant that ammonium and nitrate together, and indeed the variation when pH and ammonium (13.9%) were combined was higher than when ammonium and nitrate were combined (10.6%), so pH and ammonium were the factors which best explained the change in the biomass during the dry season (Figure 2.37).

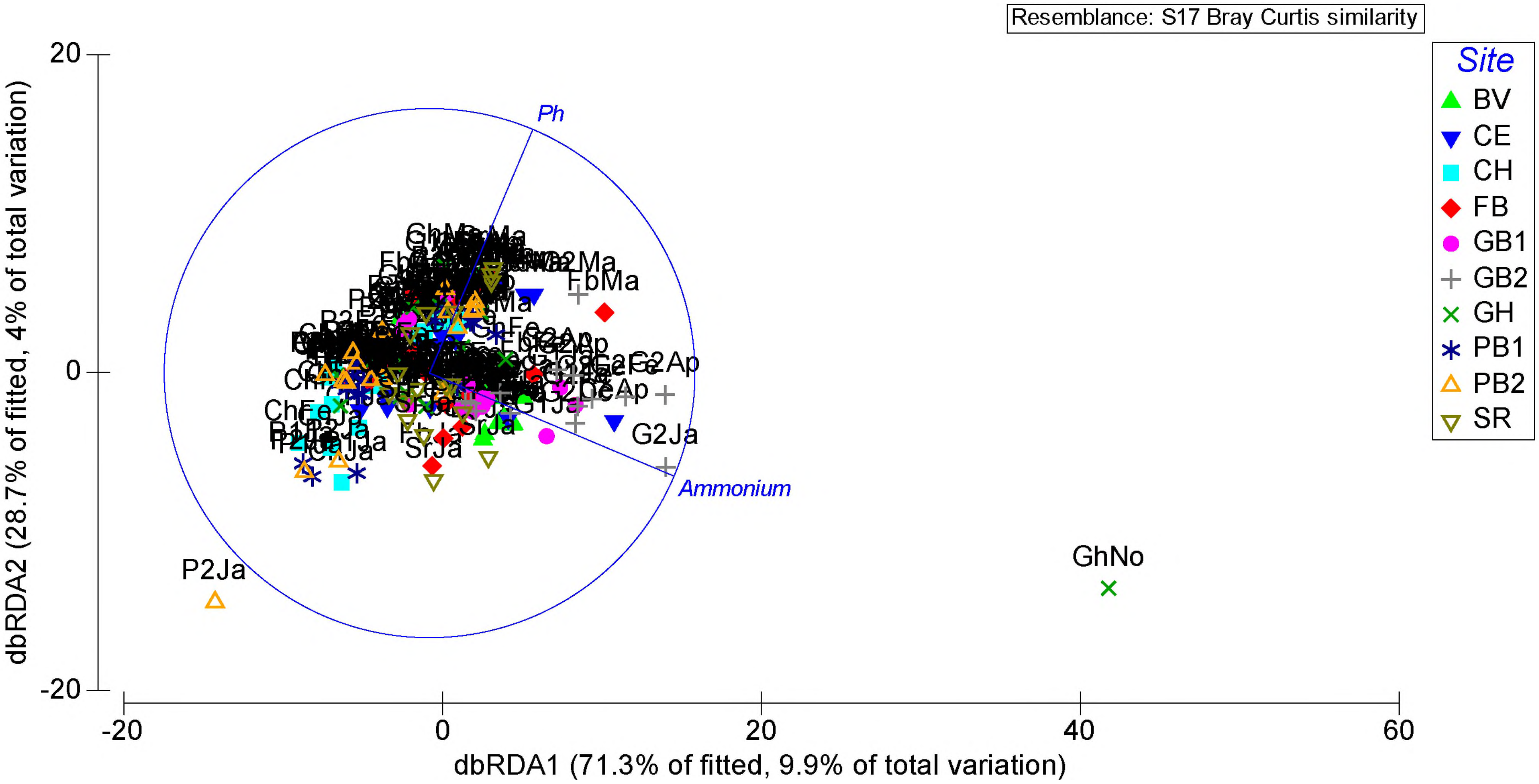


Figure 2.37 Distance-based linear models (DistLM) showing the specific environmental variable ammonium and pH for all sites and months which best explained the change in the biomass of water hyacinth during the dry season. The first axis (dbRDA 1) and second axis (dbRDA 2) explain the amount of variation for both factors: 9.9% and 4%, respectively.

2.8.11.2.1 Combined wet and dry season for the density and the biomass

Density of water hyacinth

The DistLm for the abundance showed that conductivity, nitrate and ammonium were significant, with conductivity explaining 17 % out of total individual, nitrate (0.08%) and ammonium (0%). So the Best environmental variable which explained most of the change in abundance both during the wet and dry season was conductivity, as previously found when the BEST analysis was done (ρ=0.122, slss=0.1%); conductivity taken alone explained 14.9% (Figure 2.38).

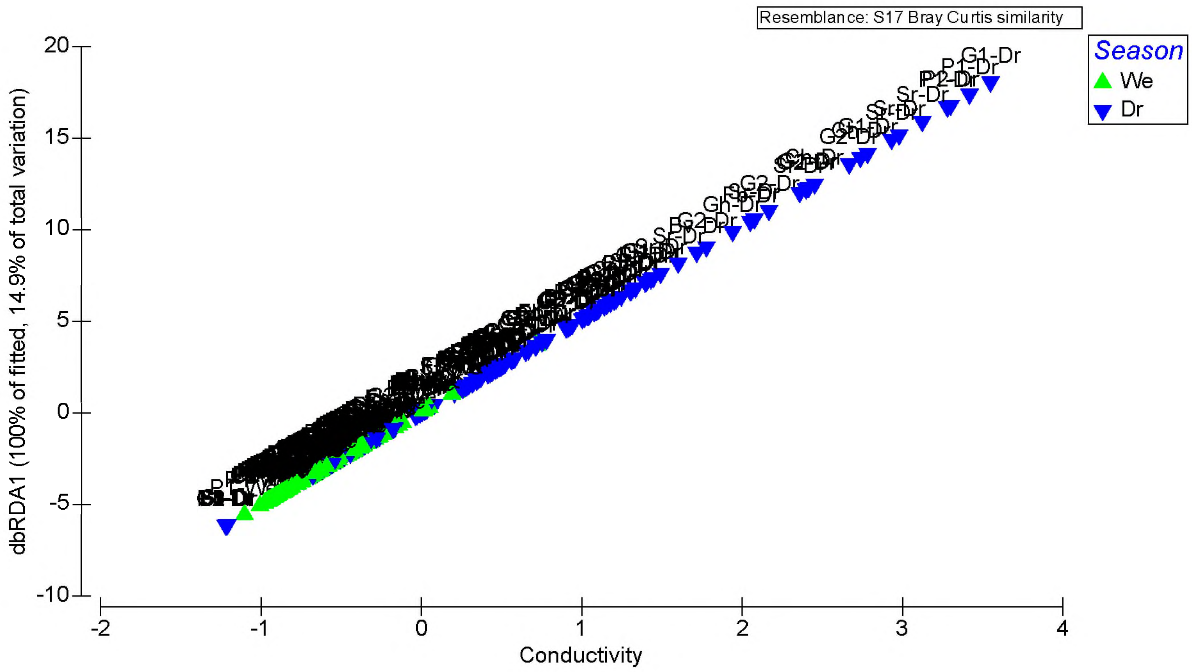


Figure 2.38 Distance-based linear models (DistLM) showing the specific environmental variable conductivity for all sites and seasons which best explained the change in the biomass of water hyacinth independently of seasons. The only axis (dbRDA 1) explains the amount of variation for conductivity: 14.9%.

Biomass of water hyacinth

Ph and ammonium were the two factors found together in the BEST analysis and DistLM which best explained the change in the biomass when the rainy and dry season were combined together. Together they explained 24 % of variation in the change of biomass (ρ=0.219, slss=0.1%) (Figure 2.39).

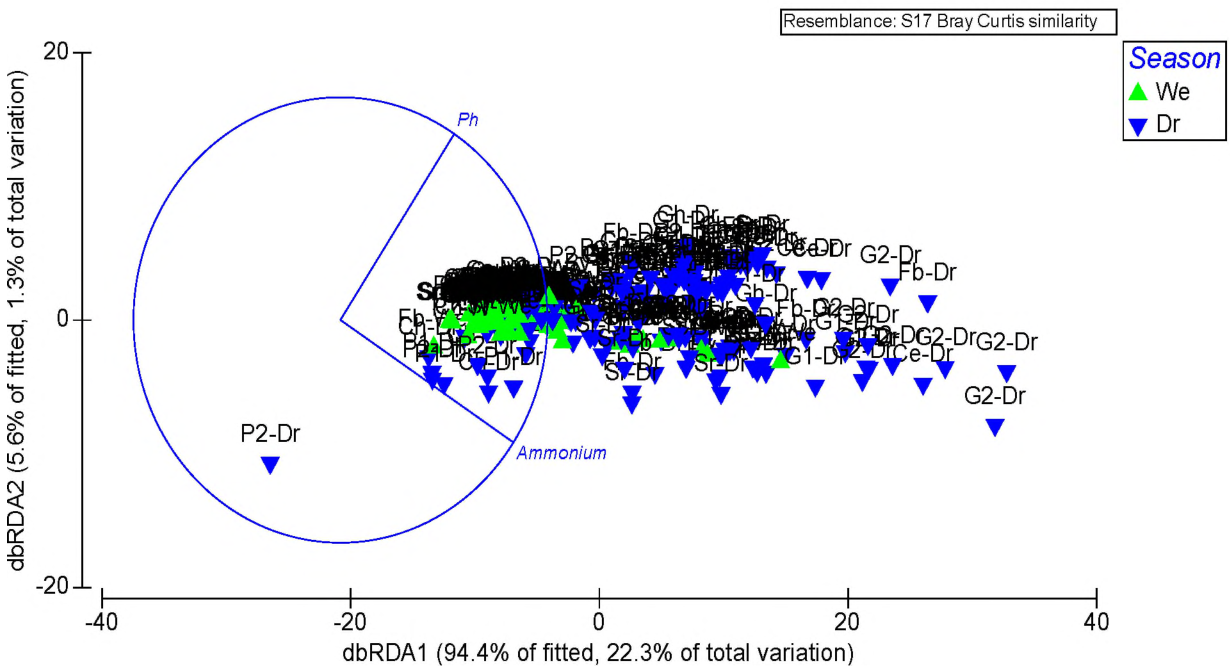


Figure 2.39 Distance-based linear models (DistLM) showing the specific environmental variables pH and ammonium for all sites and seasons which best explained the change in the density of water hyacinth between the two seasons. The first axis (dbRDA 1) and second axis (dbRDA 2) explain the amount of variation for both factors: 22.3% and 1.3%, respectively.

2.9 Discussion

The main objectives of this chapter were to quantify the impact of abiotic factors which promote the proliferation of water hyacinth in the Wouri-Basin, and especially in the selected areas. Different factors appear to play an important role in the spread of water hyacinth; among those factors affecting the growth and therefore the proliferation of water hyacinth are seasonal effects (rainy/dry season) and environmental variables, which include nutrients, conductivity and pH. The results are discussed with an emphasis on the changes in season.

Growth parameters of water hyacinth

The number of individual plants was slightly lower during the rainy season with a mean of 8.54 individuals per 0.25 m^2, compared to the dry season where a mean of 10.75 individuals per 0.25 m^2 were found for a total of 34.16 individuals per square metre during the rainy season and 43 individuals per square metre for the dry season. Almost the same number of individuals were obtained by Weyl (2011) where he counted 8 to 15 individuals at sites with tall plants (60–80 Cm) and between 18–25 individuals at sites with small plants (below 50 cm) per 0.25 m^2. Similar to this study, Hassane (2010) in his study in the Niamey River (Niger) found 47, 37 and 33 individuals per square metre on the left shore, Tondibiah, and Saga on the Niamey River, respectively. The lower number of individual recorded in sites where the plant are tall can be explained by the intra-species competition for more light, in which case, the plants exhibit their leaves, which thereby occupy the space.

The number of individuals found in this study differed from the number of individuals found by Center & Spencer (1981) where, in the summer, numbers ranged between 60–90 plants/m^2 with an overall average for the period of ca. 73 plants/m^2. The difference in the number of individuals recorded between their study and the current could be explained by the fact that, in the current study an individual a mature plant was counted as having roots, petioles and leaves, including ramets, which were not counted as individuals by Center & Spencer (1981). Moreover, most of the plants measured during this study were tall, and when the plants are tall, there is intra-species competition for more light, in which case, the plants exhibit their leaves, which thereby occupy the space.

The consistency in the number of leaves during the two seasons is noticeable, with a distribution of between six and eight leaves, although the highest number of leaves was counted during the dry season (10). A similar number of leaves was noted both by Center & Spencer (1981), with a maximum of 13 leaves, and by Weyl (2011), who found that the majority of plants had six to eight leaves, although up to 10 leaves was not uncommon. He found that the number of leaves counted could be the normal standard for a mature water hyacinth shoot and that an equilibrium was reached when the leaf production and senescence resulted in the retention of a nearly constant leaf complement. Although in an experimental conditions, which are different from the field, Marlin *et al.* (2013) found the number of leaves varied from seven to a plant can get up to 11 from a low to high nutrient concentration.

The values of leaf area found during this study were below the value of lamina area index found by Center & Spencer (1981), which was 270 cm^2 but nevertheless within the range. The decrease in the leaf area from the rainy season to the dry season could be explained by the decrease of leaf size or the leaf 2 petiole length during the dry season, as the leaf area was measured on the second petiole. In fact, the length of the second petiole decreased from 69.39 cm (mean) during the rainy season to 52.53 cm in the dry season. Center & Spencer (1981) explained that the changes in the leaf area was due to the changes in the length of leaf, indeed, more the longer leaves length, small the surface area of the lamina. In some sites, or within a season, the longest petiole length appeared to be the leaf 2 length, which could be explained by the fact that after the production of five to six leaves, the senescence of the oldest leaves begins as new ones appears, and therefore the new leaves progressively show a long and elongate petiole as result of larger relative gains in lamina area, inducing a decrease of the leaf area ratio (Center & Spencer 1981).

In both the rainy and the dry seasons, the mean number of flowers was the same, with 0.07 flowers. The quasi-absence of flowers during the study period, can be explained by firstly the sampling month which was not the flowering season of the plant, or secondly by the area where the plants were sampled which was not necessarily where the plants presented flowers.

The mean number of ramets obtained for the rainy season was 1.32 while for those collected during the dry season it was 1.0. This number of ramets was fairly similar to those found by Weyl (2011) in the different experiments he carried out where he found approximately two ramets per plant, and between 0.3–3.5 ramets based on the data collected on the field. However, he noted that the ramet production was low at sites characterized by large tall plants in dense mats (0.3–1.5), while higher ramet counts were found in sites with small plants in sparse mats. These results confirmed those obtained in the current study, firstly, because water hyacinth mat in almost all the study sites was dense, and secondly, because during all the sampling months in each site, except for Bonassama Vallée and Grand Baobab 1, the remaining sites showed plants that moderate to tall in height.

The results obtained for the mean root length were very different from those found by Weyl (2011) where the root length was up to 120 cm. The difference in the root length in these two studies could be explained by the continuous availability of nutrients in the current study, which was not the case in Weyl's study. The roots, therefore, had to extend their surface area to find the nutrients necessary for the plant's survival. Indeed, roots are the major organ of the plant which play an active role in the uptake of water as well as nutrients (Nye & Tinker 1977), especially nitrogen and phosphorus, given that in the sediment-poor water, the absorbable nutrient concentration is higher than in the water column (Carr & Chambers 1998, Chambers *et al.* 1989).

Plant biomass

The nutrient value in the water where water hyacinth plants grow is high compared to the low value of biomass recorded during the dry season, which could be explained by the increase of light irradiance during the dry season. Poorter & Nagel (1999) assert that higher irradiance implied not only a higher rate of photosynthesis or unit leaf mass, but also a higher rate of water uptake because of increased transpiration and an increased need for nutrient uptake because this stimulated growth. In higher intensity light (dry season), the observed shoot/root ratio value should decrease as the biomass allocation to leaves decreases, while the allocation biomass to root increases (Poorter & Nagel 1999). Therefore, the increase in the shoot/root ratio biomass during the dry season could be explained by an increase in the value of nitrogen, as noticed in the data collected. Furthermore, the mean biomass was higher during the rainy season than during the dry season, which could be explained by the fact that, even if the sites are subjected to tidal fluctuation of freshwater during the day, the water availability is low during the dry season, and consequently a reduced uptake of nutrients is noted, as the delivery of nutrients by mass flow is hampered in dry soil (Marschner 1995). Another reason could be that, before the plant has dispatched all the nutrients uptake into its cells, a dry day occurs and hampers the growth of the plant. However, although this ratio was higher during the dry season than during the rainy season, both seasons had a constantly high shoot/root ratio, which means that the growth of water hyacinth was not limited by the nutrient, as these were always available in both seasons.

Nevertheless, it is important to note that a limitation in water availability in the soil leads to the decrease of soil water movement which reduces the mass flow of nutrients to the root. This is especially true in that, sometimes during the dry season, the plants at several sites were dried out, especiallyat Saint Richard and Foret Bar, as if they were burned (Figure 2.40). The availability of carbon or nutrients can be assessed by the shoot/root ratio which is an important strategy for resource acquisition for plants (Xie & Yu 2003). The weed utilizes the nutrients in its metabolic processes, such as protein and nucleic acid synthesis for its growth and other functions (Xie & Yu 2003).

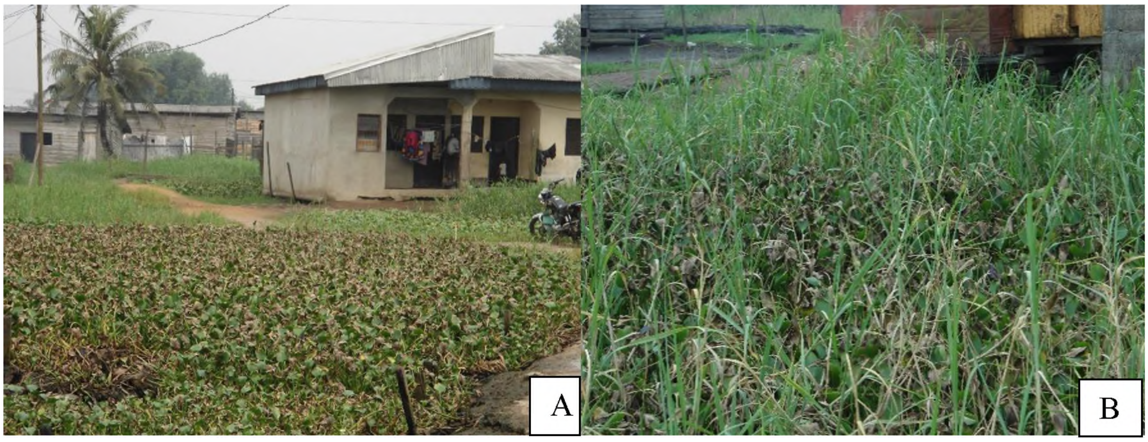


Figure 2.40 Water hyacinth mat dried out at Forêt Bar (A) and Saint Richard (B) during the dry season.

Physico-chemical parameters

Measurements using the multiparameter or the iButton showed that the temperatures recorded during the study (between 24–37 °C) were always within the limits of the temperature for optimum growth for water hyacinth, as determined by Knipling *et al.* (1970) at about 12–38 °C. These temperature values were similar to those found by Center & Spencer (1981), which ranged from 22–35 °C, and Hassane (2010) which were between 28.4 and 29.23 °C. This agrees with other estimates: for example, Wilson *et al.* (2005) found during their study on “Determinants and patterns of population growth in water hyacinth” that the minimum temperature for growth according to different experiments carried out were approximately 8.08 °C with 25–27.5 °C the optimal and 40 °C the maximum.

The value of pH obtained during this study for both seasons were similar to those found by Tening *et al.* (2013) in their study on “Nitrate and ammonium levels of some water bodies and their interaction with some selected properties of soils in Douala metropolis, Cameroon” carried out during the dry season in February 2010 which ranged between 7.2 and 7.6, although, during the dry season in the current study, values of pH in some sites were up to 10.70; values which are near optimal to the value of pH for optimum growth of water hyacinth which are between 6 and 8 (Tellez *et al*. 2008; Berg 1961). However, Moyo *et al.* (2013) in the Shagashe River in Masvingo, Zimbabwe, found during the rainy season in October a pH varying between 6.8 and 6.9 which was less than the value of pH found in the Wouri River. This difference can be explained by the fact that, in their study, they did not do a follow up of water parameters during several months as it was done in the current study, but they did the sampling during one month in October.

The value of conductivity (43-15000 µS/cm) found by Tening *et al.* (2013) in the Wouri Basin, although very high in some areas were still in the ranged of those found during the current study. Mean values of conductivity recorded during the dry season (673.16 µS/Cm) were three times higher than the mean value recorded during the rainy season (294.6 µS/Cm). These values were similar to the range of conductivity found by Moyo & Mapira (2012) which were between 200 and 673 µS/Cm. This difference in conductivity during the two seasons could be explained by the fact that, during the dry season, given that water availability is not as constant in some sites as during the rainy season, water becomes more turbid and the concentration of nutrients and other parameters in the water increases. Electrical conductivity provides an estimated measure of salt or ion concentration in water and is directly proportional to the total solids and salinity (Uka & Chukwuka 2007). Indeed, the conductivity especially during the dry season, were higher than the 1000 µS/cm maximum allowable (WHO 2008). In the meantime, the value of ammonium (18.2-39.0mg/l) and nitrates (15.4-30.8mg/l) were similar to the values of ammonium (2.5-35.13mg/l) and nitrates (3.2-56.7 mg/l) measured during the current study in the same season (dry season), while concerning ammonium, there were high compared to the values found by Hassane (2010) which were ranged between 0.7 and5.67mg/l. However, concerning the value of nitrate (NO_3^-), for all the sites and seasons, there were below the 45 mg/l advocated by WHO (2008), whilst the value of ammonium (NH_4^+) were astronomically above the 0.5 mg/l maximum proposed by WHO (2008) in the guideline for drinking water. The high value of ammonium could be associated first to the decomposition of plants from the river and agricultural left-overs which are thrown into the river, but also secondly by all the other wastes and refuse dumps close to the river (Figure 2.41).

Figure 2.41 Refuse dumps, toilet and other wastes present around and in the water courses invaded by water hyacinth.

As well as with the concentration of ammonium, the high concentration of nitrates might be the consequences of waste water disposal, oxidation of nitrogenous waste products in human and animal excreta, septic tanks, and deposition from industrial establishments. The variation and higher values of nitrate and ammonium measured in the water of all the rivers result from different human activities around the monitored sites (industries, slaughterhouses, garage, and toilets on stilt) which contributed to the increase of these elements in the concerned tributaries. Moreover, Tening *et al.* (2013) also explained the very high levels of NH_4^+ by the fishing activity from the neighboring villages that brings in a lot of nitrogenous organic materials, the mineralization of the latter increasing the NH_4^+ level.

This study showed that temperature and ammonium influence the changes in biomass in water hyacinth mats in both the dry and rainy seasons, while conductivity and, to a lesser extent, pH were the factors which influenced the changes in density (number of individuals).

These findings support the study carried out by Reddy & Tucker (1983) on "Productivity and Nutrient Uptake of Water Hyacinth, *Eichhornia crassipes* I. Effect of Nitrogen Source" who showed that water hyacinth was more efficient in utilizing ammonia than nitrate even when both the nitrogen sources were supplied in equal proportion. Almost the same results was obtained by Moyo & Mapira (2012) in their study on the bioremediation with water hyacinth who found that water hyacinth may not have removed nitrates from the river between the two sample points but preferentially removed ammonia over nitrates as a nitrogen source.

Soil samples

The value of phosphorus measured in the soil sample collected during this study was far lower than that measured by Hassane (2010) which ranged from 273mg/kg to 615mg/kg at Tondibia and Saga respectively. Water hyacinth growth, nitrogen and phosphorus content are strongly related to the nitrogen and phosphorus level of the water (Taheruzzaman & Kushari 1989). Our results also showed that water hyacinth is able to grow in different soils, from sandy loam soil to loam sand soil, and simultaneously increase its biomass. To do that, water hyacinth must possess a good root system which allows it to absorb all the necessary nutrients and water available that are important to its growth. As stated by Hussner *et al.* (2009), a root system that enables an aquatic plant to absorb nutrients and water under different conditions will allow it to survive dry periods successfully.

Although the soil samples of the monitored selected sites were low in clay, the values are still slightly above those found by Tening *et al.* (2013) which ranged between 4.0 and 4.8%. However, the percentage of sand were the same in both studies, while the percentage of silt in some areas in their study (Tening *et al.* 2013) were the double (between 17.8-30.8%) of the percentage of silt found in the current study which were ranged between 4-14% in sites with water hyacinth and 8% in the site without water hyacinth. Despite these slight differences, the textural classification (sandy loam and loamy loam) of the soil found by these authors were the same found during the current study. Indeed, as stated by Takem *et al.* (2010), and Tening *et al.* (2013), the textural classification of these soils are just the resultant of the characteristic of the soil in the Wouri Division which is alluvial, resulting from the weathering and sedimentary rocks of this area, and therefore highly permeable to industrial and agricultural discharges.

2.10 Conclusion

The observation of a frequent, stable population of water hyacinth all along the Wouri Basin and especially in the sites investigated, together with the data gathered during this study, showed that water hyacinth found optimum conditions for its fast growth, both in the rainy and dry seasons, and in all the sites. During these seasons, in each of these sites, nutrients were very high and readily available to be stored by the plant; these nutrients come from agricultural activities (excess application of inorganic nitrogenous fertilizers), waste water disposal, oxidation of nitrogenous waste products in human and animal excreta from septic tanks, and deposition from industrial establishments. Indeed, in each of these sites according to different activities prevailing around, water from the river is highly polluted with values sometimes above the recommended values of WHO for waste water. This availability is enhanced by the constant fluctuation of freshwater which occurs every day, providing the water hyacinth with enough water necessary for easy uptake of nutrients through the roots, even during the dry season. Moreover, this study has shown that, whatever the type of soil where water hyacinth is present, as long as all the conditions (temperature, salinity, conductivity, pH, nutrient) are fulfilled, the plant will prosper. So, if nothing is done, the plant is able to extend its invasions into other regions or areas in Cameroon as the climatic conditions are favourable for the growth of water hyacinth, thus confirming its status as the most invasive in the world

Other external factors were not measured during this study, but are also correlated with the growth pattern of water hyacinth in an environment (Center & Spencer 1981). These include: external environmental factors such as solar radiation, and air temperature on top of water hyacinth mat; a competitive interaction (i.e. intraspecific competition), and intrinsic morphological limitations (i.e. size limitation).

Further studies therefore should investigate more intensively the Wouri River, in order to get as much data possible to understand the proliferation of water hyacinth there; moreover, other studies should take into account the concentration of nitrogen and phosphorus in water hyacinth plant tissue and the implication of factors mentioned above in the proliferation of water hyacinth in the Wouri Basin; but also look at the impact of water hyacinth on the plant communities in the infested areas.

3 Chapter 3. Impact of water hyacinth on aquatic plant communities in the Wouri River Basin (Douala-Cameroon)

3.1 Introduction

Aquatic and terrestrial ecosystems comprise several species which play an important role in the environment in which they grow. The increase of travel and global mobility has resulted in the degradation of the biodiversity and bio-geochemistry and therefore impacted economic uses of several of these habitats (Strayer 2010). The main changes in the aquatic environment are due to eutrophication which offers suitable conditions for the establishment of IAS (Invasive Alien Species). Eutrophication can be defined by the process by which a body of water becomes enriched in dissolved nutrients (as phosphates) that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen. Invasion occurs when species are transported out of their natural habitat, grow and reproduce rapidly in the absence of natural ennemies, invade new areas and finally out-compete the native species. They then become invasive and disrupt the equilibrium of the new ecosystems in which they find themselves (William & Hecky 2005). Several studies have shown that IAS are the most significant driver of species population decline and extinctions in aquatic ecosystems (McNeely *et al.* 2001; Resear *et al.* 2007), influencing species diversity, richness, composition, abundance and interactions (including mutualism) (Resear *et al.* 2007).

Alien aquatic weeds are mostly invasive: in the United States, approximately 700 000 ha per year are invaded by alien aquatic weeds (Pimentel *et al.* 2005).Indeed, the most dangerous one is European purple loosestrife (*Lythrum salicaria* L.), which was introduced as an ornamental plant in the early 19th century (Malecki *et al.* 1993). It spread an estimated 115 000 ha per year and caused a change in the structure of most of the wetlands it invaded (Thompson *et al.* 1987). The biomass of 44 native plants species decreased because of this plant, and the bog turtle and several ducks species which depend on these native plants are now endangered (Gaudet & Keddy 1988 in Pimentel *et al.* 2005).

In Florida, exotic aquatic weeds such as hydrilla (*Hydrilla verticillata* (L.f.) Royle), water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) are cited as causing the most damage,and about US$14.5 millions is spent each year to control the spread of hydrilla alone (Center *et al.* 1997). Wherever it has been introduced, *E. crassipes* has become a nuisance both in the environment that it colonizes and for the riparian communities.

Originally perceived as a problem only for fishing and navigation, *E. crassipes* is now considered as a threat to biodiversity, affecting fish fauna, plant diversity and other freshwater life and the food chains which depend upon the river (Luken & Thieret 1997). The success of its invasion is due mainly to polluted waters and the absence of natural enemies and competitors (Tellez *et al.* 2008). Once established, *E. crassipes* co-exists with the native species, but because of oxygen depletion, and high evapotranspiration of the aquatic ecosystem which it colonizes, water hyacinth can often completely eliminate the associated aquatic species from the habitat (Tellez *et al.* 2008). Although the economic losses and impacts caused by water hyacinth can be measured, the impact on the biodiversity of aquatic ecosystems is less well known and, consequently, is more difficult to quantify (Midgley *et al.* 2006). However, a few studies have been carried out around the world to determine the impact of water hyacinth on the abundance and diversity of associated fauna and flora (e.g. Gopal 1987; Toft 2000; Massifwa *et al*. 2001; Midgley *et al.* 2006; Villamagna & Murphy 2006; Coetzee *et al.* 2014). All these studies found that water hyacinth resulted in decreased diversity of some micro-organisms and plants while it appeared to enhance the abundance and diversity of other aquatic macro-invertebrates and detritivorous animals at the interface with the open water (de Marco *et al.* 2001; Masifwa *et al.* 2001; Brendock *et al.* 2003).

Midgley *et al.* (2006) found that water hyacinth mats had a detrimental effect on both abundance and diversity of benthic invertebrates and algal biomass on the New Year's River in South Africa, and Brendock *et al.* (2003) found that the diversity indices in phytoplankton and zooplankton were significantly higher in the unvegetated zones without water hyacinth than the vegetated littoral sites with water hyacinth. However, the water hyacinth mats seem to have a positive effect on diversity of fish, but only for a limited number of groups and small size classes. This apparent habitat preference differs depending on fish biology. Brendock *et al.* (2003) also found that, before the expansion of water hyacinth on Lake Chivero in Zimbabwe, submerged and rooted floating-leaved macrophytes which had been common in shallow water were scarce or absent, while floating species dominated the macrophyte community in the littoral zones of the lake (Brendock *et al.*2003). Finally, an experimental study carried out in USA showed that a 10–25% cover of water hyacinth reduced population of the fish *Tilapia aurea* by 50% (Howard & Harley 1998).

3.2 Aims and objectives

Whilst all of the above studies have shown the impact of water hyacinth on the diversity of some components of the aquatic environment invaded, there are few studies on its impact on plant diversity.

3.2.1 Aim

The aim of this study was therefore to investigate the impact of water hyacinth on the abundance and diversity of plant communities of the Wouri River Basin, Cameroon associated with the water physico-chemical parameters of these ecosystems.

3.2.2 Specific objective

The specific objective consisted to make comparisons between the plant diversity of sites invaded by water hyacinth and those without water hyacinth.

3.3 Material and methods

3.3.1 Material

Eleven sites located within the Wouri River Basin were chosen for the purpose of this study. Of these sites, ten were identified at the beginning of the survey of the Wouri Basin for a long-term study with water hyacinth (Chapter 2): Bonassama Vallée, Centre Equestre, Château, Forêt Bar, Grand Baobab 1, Grand Baobab 2, Grand Hangar, Petit Bonanjo 1, Petit Bonanjo 2 and Saint Richard. The eleventh site, Ecomité has no record of water hyacinth. All these sites are located at Bonaberi (Douala IV) on the western side of the harbour across the Wouri River from the larger port of Douala, at the coordinates 4.08° north, 9.68° east and at an elevation of 1 metre above sea level.

Daily tide movements, with an average difference of at least 6.5 hours between each high and low tide and which vary according to the day, influence the sites. Weather conditions are the same as those in the Littoral Region with a higher temperature (29 °C) recorded during the dry season in February, and an average rainfall of 750.5 mm in August during the rainy season (Figure 3.1). Because of their low elevation above sea level, almost all the areas are flooded during the rainy season. All weather data (temperature, precipitation) for the period between 1982 and February 2016 were collected at the Ministry of Transport (see appendices).

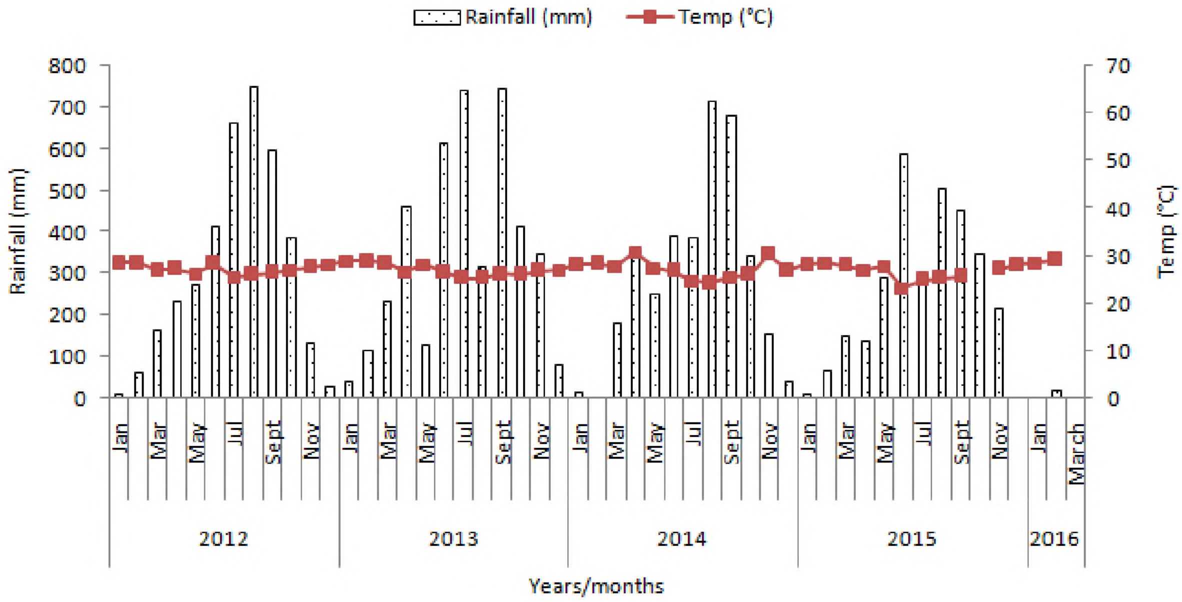


Figure 3.1 Bagnouls-Gaussen's ombro-thermal diagram of the Wouri Division (Douala, Cameroon) between 2012 and 2014 representing the average of temperature (°C) and precipitation (mm) per month (Source: Ministry of Transport, Regional Delegation of Littoral, Service of meteorology).

3.3.1.1 Characterization of the sites sampled

To compare the diversity of sites with water hyacinth and sites without water hyacinth, the ten sites selected at the beginning of the survey for a long term-study were used as sites with water hyacinth, while only one site without water hyacinth was located in the same sub-division (Figure 3.2). The descriptions of the 10 sites with water hyacinth were presented in Chapter 2.

3.3.1.2 Ecomité

Almost all the tributaries along the Wouri River, and especially in Douala IV (Bonaberi) (as it was the sub-division selected for the purpose of this study), have been invaded by water hyacinth. It was therefore not easy to identify one without water hyacinth. To qualify, the site had to meet the criteria for the selection of sites, i.e. it should be connected to the hydrographical network in such a way that any plant species would have the same likelihood of being found in all the sites. Considered a swampy area, this site is situated at the coordinates

N: 04.10127° and E: 009.61002°. It covers an area of about 3000 m^2 and is influenced by pollution from the houses surrounding it. The depth of the river varies from one point to another one, and with the tide from 0.5 m to 1.5 m.

Table 3.1 Details of the different studied sites, including site name, sampling site abbreviation, site co-ordinates, surface area of the whole site, and percentage cover of water hyacinth

Sites	Abbreviation	Locality	Coordinates	Presence or no of water hyacinth	Water hyacinth Cover (%)	surface area (m^2)
Bonassama Vallée	BV	Douala IV (Bonaberi, old road)	N: 04.07722° E:009.68184°	Water hyacinth	70	3000
Centre Equestre	CE	Douala IV (Bonaberi, old road)	N: 04.08482° E:009.67486°	Water hyacinth	60	2000
Château	CH	Douala IV (Bonaberi, New Road)	N: 04.09967° E:009.65998°	Water hyacinth	75	3000
Forêt Bar	FB	Douala IV (Bonaberi, New Road)	N: 04.04261° E:009.39297°	Water hyacinth	80	5000
Grand Baobab 1	GB 1	Douala IV (Bonaberi, old road)	N: 04.07520° E:009.68221°	Water hyacinth	75	5000
Grand Baobab 2	GB 2	Douala IV (Bonaberi, old road)	N: 04.07719° E:009.68171°	Water hyacinth	65	1000
Grand Hangar	GH	Douala IV (Bonaberi, New Road)	N:04°08’59.1’’ E: 009°65645	Water hyacinth	80	5000
Petit Bonanjo 1	PB 1	Douala IV (Bonaberi, New Road)	N: 04.06230° E:009.38511°	Water hyacinth	95	6000
Petit Bonanjo 2	PB 2	Douala IV (Bonaberi, New Road)	N: 04.10561° E:009.64744°	Water hyacinth	90	4000
Saint Richard	SR	Douala IV (Bonaberi, New Road)	N: 04.07463° E:009.65756°	Water hyacinth	85	8000
Ecomité	EC	Douala IV(Bonaberi, Carrefour Mutzig)	N: 04.10127° E: 009.61002°	Not present	0	3000

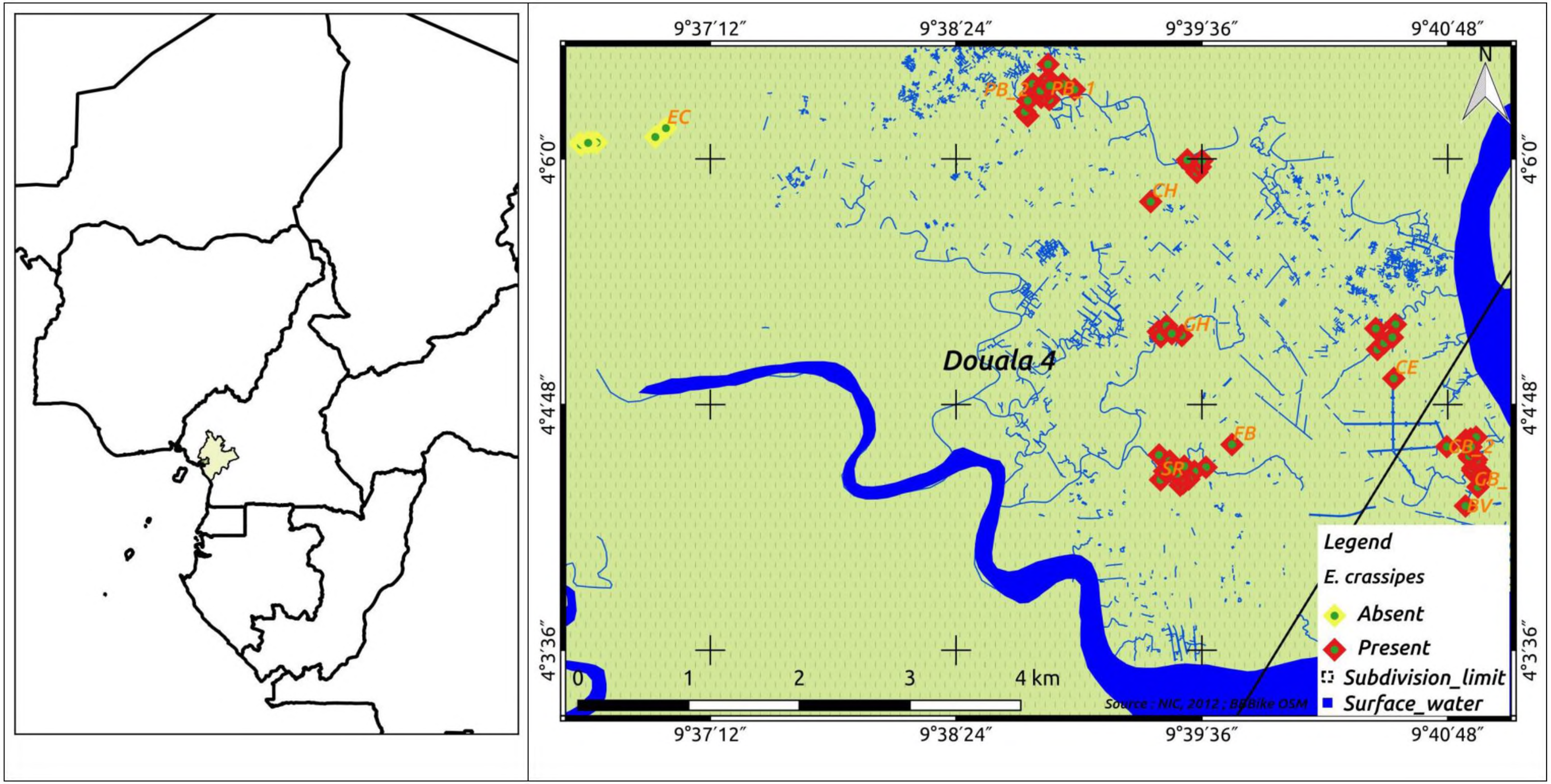


Figure 3.2 Ten sampling sites with water hyacinth in red (present), and site without water hyacinth (Ecomite) (Absent), all located in the Wouri Basin.

3.3.2 Methods

3.3.2.1 Survey on the abundance and density of aquatic plants

In order to evaluate abundance and density of the plants found in each selected site, a quadrat was used. In each selected site, a quadrat of 10 m x 10 m (100 m^2) was randomly set up in the river. All the species present within the quadrat were identified and associated with the coefficient abundance–dominance corresponding to the area covered by each species according to the classical scale of Daubermire (1957). The following scale was used: 1–No occurrence (0 plants/m^2); 2–Rare (1–5 plants/m^2); 3–Common (6–14 plants/m^2); 4–Common (15–29 plants/m^2); 5–Abundant (30–99plants/m^2); 6–Very Abundant (>100 plants/m^2).

During the survey, the number of macrophytes species (expressed as percentage) was determined by estimating their percentage cover. This was expressed on an ACFOR abundance scale which was modified (Kent and Cokera, b 2012): 5–Abundant (75–100%); 4–Common (50–75%); 3–Frequent (25–50%); 2–Occasional (5–25%); 1–Rare (0–5%).

According to De Foucault (1980), the following classification was made as shown in Table 3.2 below. For example, for a species to be attributed the abundance-dominance of 5, its percentage cover should range between 75% and 100%, and therefore, the average will be (75 + 100) / 2 = 87.50%. This classification was relevant to the study especially during the survey as it helped to classify the recorded species in the specific abundance-dominance scale, and also to estimate the percentage cover of each species. An example can be taken with water hyacinth, to be classified with an abundance-dominance of 5, the surface cover of the plant comparatively to the whole water course, or to the target quadrat may be comprised between 75 and 100.

Table 3.2 Class recovery of Abundance-Dominance coefficients.

Abundance-Dominance	Class recovery (%)	Average recovery (%)
5	75–100	87.5
4	50–75	62.5
3	25–50	37.5
2	5–25	15
1	1–5	2.5
+	<1	0.5

3.3.2.2 Identification of species

In each quadrat, species were identified using their scientific names, and sometimes the vernacular names. Those plants which were not identified in the field were collected and taken to the National Herbarium (Yaoundé-Cameroon) where they were identified.

3.3.2.3 Water sampling

In order to determine the physico-chemical parameters of water from each selected site, parameters which could not be analysed on sites such as nitrate ions and ammonium ions, samples were collected in sterile bottles of 1litre from the different rivers which feed the Wouri River Basin. At each site, the bottle was immersed in water until it was full. Once the bottle was full, it was pulled up by rope, the container was closed, labeled and transferred into a cooler containing ice blocks, pending further analysis. A total of three samples of water were collected per site at three different places (upstream, middle, and downstream).once in the laboratory, these chemical paraeters were measured using a Nitrate Ion-Selective Electrode and Ammonium Ion-Selective Electrode respectively.

However, physical parameters such as pH, electrical conductivity (CND), water temperature, salinity and total dissolved solids (TDS) were taken in situ, using a multiparameter. The probe of the multiparameter was immersed at the surface of water exactly where the three samplings to analyse the chemical parameters were collected. The collections were made during the two months (September and October 2014) during which the floristic inventory was done to assess the change in the composition of water between the different seasons.

3.3.2.4 Data analysis

3.3.2.4.1 Quantitative analysis

The important quantitative analysis of tree species, shrubs and herbs species were determined as per Curtis and McIntosh (1950).

Density

Density is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrats is divided by the total number of quadrats studied. Density is recorded per unit area (plant per square meter).

Frequency (%)

This term refers to the degree of dispersion of individual species in an area and is usually expressed in terms of percentage occurrence. The study area was sampled at several places at random and the names of the species that occurred in each sampling unit were recorded. It was calculated as the number of quadrat in which the species occurred divided by the total number of quadrat studied times 100.

Abundance

This is the number of individuals of different species in the community per unit area. Using the quadrat method, samplings were made at random in several places and the number of individuals of each species was summed up for all the quadrats, divided by the total number of quadrats in which the species occurred.

3.3.2.4.1.1 Importance Value Index

This index is used to determine the overall importance of each species in the community structure. In calculating this index, the percentage values of the relative frequency, relative density and relative dominance are summed up together and this value is designated as the Importance Value Index or IVI of the species (Curtis, 1959). It includes:

Relative density (%)

Relative density gives the numerical strength of a species in relation to the total number of individuals of all the species.

Relative frequency (%)

This is the degree of dispersion of individual species in an area in relation to the number of all the species occurred.

3.3.2.4.1.2 Similarity and dissimilarity indices

Indices of similarity and dissimilarity were calculated by using formulae as per Misra (1989) and Sorensen (1948) as follows:

Index of similarity (S) = 2C/A+B

Where, A = Number of species in the community A; B = Number of species in the community B; C = Number of common species in both the communities.

Index of dissimilarity (S') = 1-S

3.3.2.4.1.3 Species richness, diversity and dominance indices

The species richness of the vascular plants was calculated by using the method 'Margalef index of richness' (Dmg) (Magurran, 1988)

Dmg = (S-1)/ ln N

Where, S = Total number of species. N = Total number of individuals.

3.3.2.4.1.4 Shannon-Weaver (1963) index of diversity, and Evenness (equitability)

The formula for calculating the Shannon diversity index (H') and the Evenness (E) (Pielou 1975, Smith & Wilson 1996) are:

$$H' = -\Sigma\, pi \ln pi \qquad \text{(Shannon-Weaver)}$$

$$E = H'/\ln(N) \qquad \text{(Evennes)}$$

Where, H' = Shannon index of diversity

*p*i = the proportion of important value of the i^{th} species (*p*i = *n*i / N, *n*i is the important value index of i^{th} species and N is the important value index of all the species).

Simpson (1949) Index of Dominance

Simpson's diversity index is a measure of diversity which takes into accounts both richness and evenness. The equation used to calculate Simpson's index was

$$D = \Sigma (pi)2$$

Where, D = Simpson index of dominance

*p*i = the proportion of important value of the i^{th} species (*p*i = *n*i / N, *n*i is the important value index of i^{th} species and N is the important value index of all the species).

As D increases, diversity decreases and Simpson's index of diversity (D') was therefore usually expressed as: **D' = 1 – D or 1/ D**

3.3.2.4.2 Statistical analysis

The software packages Primer6, version 6.1.13 and Permanova Version 1.0.3 (Clarke & Warwick 2001a, b) were used to perform analysis. The different functions used through this software were the Similarity test, Relate Analysis, Principal Components Analysis (PCA), Cluster Analysis, Non-metric Multi-Dimensional Scaling (MDS) and Best Analysis.

Similarity tests

As the abiotic data (physico-chemical) parameters were collected at three different places per site and per month, the data sets were first averaged to give the average concentration per site and per month. Then, they were Log(X+1) transformed and normalized. The Euclidian distance resemblance was performed to assess the similarity in composition between sites.

At the same time, similarity based on Bray-Curtis was also performed for biological data to assess the similarity between sites after an overall transformation based on Presence-Absence for each species per site. Indeed, in ecological studies, Bray-Curtis similarity is recommended as it is not affected by absences and gives more weight to abundance in comparing species (Clarke & Warwick 2001b).

Relate Analysis

To understand the relationships between the biological variables and environmental data, the Relate function was conducted. The Relate function in Primer is the comparison of two different sets of multivariate data of a sample on a matching set of samples, by calculating a rank correlation between all the elements of their similarity matrices (Clarke & Warwick 2001b).

Cluster Analysis

The objective of cluster analysis is to assign observations to small groups called "cluster dendogram" so that observations within each group are similar to one another with respect to variables or attributes of interest and the groups themselves stand apart from one another. In other words, the objective of the Cluster Analysis is to divide the observations into homogeneous, smaller and distinct groups based on their similarity (Tryfos 1997).

Cluster analysis is performed after computation of similarity between samples using the triangular matrix generated through the Bray-Curtis similarity index for biological data and through the Euclidian distances for environmental data. In Cluster Analysis, the closer a group of observations is to a similarity value of 100, the more the group is similar for biological data, while for environmental variables, the closer a Distance value to 0.5 a group of observation is, the more similar the group is, and the result is illustrated by a dendogram (tree diagram).

Principal Component Analysis

PCA (also called singular value decomposition) is a mathematical technique that exploits factors to pick out patterns in the data, while reducing the effective dimensionality of parameter space without significant loss of information (Quackenbush 2001). The Principal Component Analysis (PCA) performed through the normalized data were used here to visualize patterns of relationship among the samples. PCA is one of a family of related techniques that include 'factor analysis' and 'principal coordinate analysis' that provide a 'projection of complex data set onto a reduced, easily visualized space' (Quackenbush 2001). As PCA is not a test but a representation which allows interpretation of the data, complementary analyses were done using Principal Coordinate analysis and the Permanova test to identify hidden patterns in the data, and classify them according to how much closely the environmental variables relate to the site.

The PCA is entirely dependent on the nature of data and the relationship between variables that are being considered, the validity of the variables included, and their reliability (Vyas & Kumaranayake 2006).

Best Analysis

Best Analysis was also used to find which environmental variable best explains the pattern in the biological data for each site. Given that the floristic inventory was done in September, only the environmental variables recorded during this month were used to find the best variables to explain the pattern in biological data.

Permanova test

The Kruskal-Wallis test was used through Permanova to determine differences in concentration between each site per month for water analyses, and also to determine whether there was any difference between each site and month. A probability value of $p(perm) < 0.05$ was considered as statistically significant.

3.4 Results

3.4.1 Diversity and abundance of taxa

A total of 76 plant species representing 65 genera and 39 families were found at the 11 sites sampled along the Wouri-Basin. Of these species, 66 were identified to the species level and 10 to the generic level. It was not possible to give a name to one of the species found and it was classified as 'undetermined'. From the 10 sites with water hyacinth, a total of 66 species were identified representing 57 genera distributed into 34 families. At Ecomité (EC), which is the site without water hyacinth, 29 species were found and identified while one species was not identified and was classified as 'undetermined'. All these species are distributed in 25 genera and 21 families.

The distribution patterns for each site i.e. the Density, Relative Density, the Frequency, Relative Frequency, and Abundance of each species per site were measured and are represented in Table 3.3 together with the Shannon-Wiener (H'), the Equitability of Pielou (E), species richness, and Simpson's indices. The total number of species, including the number of invasive species per site, are represented in the Table 3.3.

The lowest values of species richness were found in Centre Equestre (CE) (1.19), Bonassama Vallée (BV) (1.5) and Grand Baobab 1 (GB 1) (1.56) (Table 3.3). The highest value of the species richness were found in Petit Bonanjo 1 (PB 1)(5.57), Petit Bonanjo 2 (PB 2)

(4.62), EC (4.03) and Saint Richard (SR) (3.84), while for Grand Baobab 2 (GB 2), Château (CH), Forêt Bar (FB) and Grand Hangar (GH) the species richness varies from Dmg = 1.70 to Dmg = 3.22. This could be explained by the number of species found in each of this site which varies from 8 at CE to 41 at PB 1, and therefore the highest value of species diversity (H') was found at PB1 (2.56) and the lowest at CE. These results are the opposite of those for the Evenness where the highest value of Evenness was found at GB 2 (0.79), followed by BV (0.76), SR (0.70), PB1 and EC (0.69). The rest of the sites presented values varying between 0.56 and 0.68. These values of Evenness could be explained by the fact that, the less variation in communities between species, the higher the Evenness (Mulder *et al.* 2004). For the Simpson's Diversity index, the results showed that EC presents the lowest value (0.18), followed by PB1 (0.19) and GB2, while GH has the highest value of D (0.38) (Table 3.3).

3.4.1.1 Invasive species found during our inventory

According to the list of invasive species provided by the Global Invasive Species Database (GISD), and a recent work published by the Ministry of Environment, Protection of Nature and Sustainable Development (MINEPDED 2014), 35 species in Cameroon are found to be invasive. In this case, an invasive species is a species that moves beyond its intended location and causes a negative impact according to some people, but not necessarily everyone, somewhere, but not necessarily everywhere and at some point in time, but not necessarily always (MINEPDED 2014). Of the 76 species which were identified during the current study, 12 are considered invasive species; they are: *Acrosticum aureum*, *Cecropia peltata, Chromolaena odorata, Echinochloa pyramidalis, Eichhornia crassipes, Elaïs guineensis, Ipomoea aquatica, Lasiomorpha senegalensis*, *Lemna paucicostata, Nymphaea lotus, Nypa* sp., and *Pistia stratiotes*.

Table 3.3 Distribution patterns of plant species sampled along the eleven sites chosen along the Wouri Basin (Douala, Cameroon). Species in bold are species which are considered as invasive in Cameroon according to the report published by the MINEPDED (2014).

% WH = Percentage cover of water hyacinth per site; **RD (%)** = Relative Density; **F (%)** = Frequency; **RF (%)** = Relative Frequency; **A**= Abundance; **Dmg** = Species richness; **H'**= Shannon Wiener index of diversity; **E** = Evenness; **D and D'** = Simpson's Diversity index; **TS** = Total number of species; **TF** = Total number of family; * **Name of species**= Invasive species

Sites	Species	% WH	Density	RD (%)	F (%)	RF (%)	A	Dmg	H'	E	D	D'
Bonassama Vallée	*Althernanthera maritima*	70	5.67	8.27	66.67	12.12	8.5	1.50	1.75	0.76	0.25	0.75
	Althernanthera nodiflora		1.17	1.70	33.33	6.06	3.5					
	Aspilia Africana		2.33	3.41	33.33	6.06	7					
	***Commelina benghalensis**		6.83	9.98	100	18.18	6.83					
	***Echinochloa pyramidalis**		13.50	19.71	100	18.18	13.5					
	***Eichhornia crassipes**		29.17	42.58	100	18.18	29.17					
	Eleusine indica		2.33	3.41	33.33	6.06	7					
	***Ipomoea aquatica**		3.50	5.11	33.33	6.06	10.5					
	Ipomoea cairica		3.67	5.35	33.33	6.06	11					
	Ipomoea carnea		0.33	0.49	16.67	3.03	2					
TS/ TF	**10 / 6**											
Centre Equestre	***Eichhornia crassipes**	60	28.83	49.15	100	20.69	28.83	1.19	1.41	0.68	0.32	0.68
	***Echinochloa pyramidalis**		13.67	23.30	100	20.69	13.67					
	***Commelina benghalensis**		7.67	13.07	100	20.69	7.67					
	***Ipomoea aquatica**		3.17	5.40	50	10.34	6.33					
	Alchornea cordifolia		3.00	5.11	50	10.34	6					
	***Chromolaena odorata**		2.00	3.41	33.33	10.34	4					
	***Lasiomorpha senegalensis**		0.17	0.28	16.67	3.45	1					
	***Elaies guineensis**		0.17	0.28	16.67	3.45	1					
TS/ TF	**8 / 8**											

Sites	Species	% WH	Density	RD (%)	F (%)	RF (%)	A	Dmg	H'	E	D	D'
Château	***Eichhornia crassipes**	75	53.00	56.28	100	17.65	53	2.37	1.63	0.59	0.35	0.65
	***Echinochloa pyramidalis**		14.83	15.75	100	17.65	14.83					
	***Commelina benghalensis**		3.67	3.89	50	8.82	7.33					
	Mussaenda arcuata		1.50	1.59	33.33	5.88	4.50					
	Alchornea cordifolia		3.17	3.36	33.33	5.88	9.50					
	Clerodendron dusenii		4.83	5.13	33.33	5.88	14.50					
	Avicennia germinans		2.67	2.83	33.33	5.88	8					
	Rhynchospora corymbosa		0.50	0.53	33.33	5.88	1.50					
	Aeschynomene crassicaulis		0.50	0.53	33.33	5.88	1.50					
	Mussaenda angolensis		1	1.06	16.67	2.94	6					
	Millettia sanagana		2.67	2.83	16.67	2.94	16					
	Clerodendron sp.		1.33	1.42	16.67	2.94	8					
	Heteropterys leona		3	3.19	16.67	2.94	18					
	Anthocleista djalonensis		0.33	0.35	16.67	2.94	2					
	***Elaies guineensis**		1	1.06	16.67	2.94	6					
	***Acrosticum aureum**		0.17	0.18	16.67	2.94	1					
TS/ TF	**16**											
Forêt Bar	***Eichhornia crassipes**	80	50.33	44.74	100	10.91	50.33	3.22	2.06	0.67	0.24	0.76
	Heliconia latispatha		2	1.78	33.33	3.64	6					
	Rhizophora harrisonii		1.50	1.33	33.33	3.64	4.50					
	Althernanthera nodiflora		2.33	2.07	33.33	3.64	7					
	Althernanthera repens		3	2.67	33.33	3.64	9					
	Avicennia germinans		2.50	2.22	33.33	3.64	7.50					
	Jussiaea suffruticosa		1.17	1.04	33.33	3.64	3.50					
	Althernanthera maritima		6.50	5.78	66.67	7.27	9.75					
	Cyperus mannii		0.33	0.30	16.67	1.82	2					
	***Ipomoea aquatica**		2	1.78	33.33	3.64	6					
	***Commelina benghalensis**		9.33	8.30	83.33	9.09	11.20					
	***Echinochloa pyramidalis**		17.50	15.56	100	10.91	17.50					
	***Lemna paucicostata**		3	2.67	33.33	3.64	9					

Sites	Species	% WH	Density	RD (%)	F (%)	RF (%)	A	Dmg	H’	E	D	D’
Forêt Bar	**_*Nymphaea lotus_**	80	1.33	1.19	16.67	1.82	8	3.22	2.06	0.67	0.24	0.76
	*Acrosticum aureum		1	0.89	16.67	1.82	6					
	Rhynchospora corymbosa		1.83	1.63	50	5.45	3.67					
	Pandanus baptistii		0.33	0.30	33.33	3.64	1					
	Alchornea cordifolia		3.67	3.26	66.67	7.27	5.50					
	Cyperus difformis		0.83	0.74	33.33	3.64	2.50					
	Brachiaria stigmatisata		0.33	0.30	16.67	1.82	2					
	Ludwigia leptocarpa		1.33	1.19	33.33	3.64	4					
	Pandanus candelabrum		0.33	0.30	16.67	1.82	2					
TS/ TF	**22 / 15**											
Grand Baobab 1	**_*Eichhornia crassipes_**	75	26.67	50.79	100	20	26.67	1.56	1.51	0.66	0.32	0.68
	Althernanthera nodiflora		1.33	2.54	50	10	2.67					
	Althernanthera maritima		1.50	2.86	33.33	6.67	4.50					
	Rhynchospora corymbosa		0.50	0.95	33.33	6.67	1.50					
	Cyperus difformis		2.17	4.13	33.33	6.67	6.50					
	*Echinochloa pyramidalis		11.67	22.22	100	20	11.67					
	*Commelina benghalensis		4.17	7.94	66.67	13.33	6.25					
	*Ipomoea aquatica		3.67	6.98	50	10	7.33					
	Aspilia africana		0.50	0.95	16.67	3.33	3					
	Ipomoea cairica		0.33	0.63	16.67	3.33	2					
TS/ TF	**10 / 7**											
Grand Baobab 2	**_*Eichhornia crassipes_**	65	20.17	34.08	100	17.65	20.17	1.70	1.9	0.79	0.19	0.81
	*Echinochloa pyramidalis		10.50	17.75	100	17.65	10.50					
	*Pistia stratiotes		7.83	13.24	66.67	11.76	11.75					
	*Lemna paucicostata		5.67	9.58	66.67	11.76	8.50					
	Ipomoea cairica		5.67	9.58	33.33	5.88	17					
	Rhynchospora corymbosa		0.17	0.28	16.67	2.94	1					
	*Commelina benghalensis		5	8.45	83.33	14.71	6					
	Brachiaria stigmatisata		1	1.69	16.67	2.94	6					
	Aspilia africana		0.83	1.41	33.33	5.88	2.50					

Sites	Species	% WH	Density	RD (%)	F (%)	RF (%)	A	Dmg	H’	E	D	D’
Grand Baobab 2	*Rhynchosia mannii*	65	1	1.69	16.67	2.94	6	1.70	1.9	0.79	0.19	0.81
	Rhizophora harrisonii		1.33	2.25	33.33	5.88	4					
TS/ TF	**11 / 10**											
Grand Hangar	***Eichhornia crassipes***	80	81.17	59.46	100	12	81.17	2.53	1.58	0.55	0.38	0.62
	Leersia hexandra		2.67	1.95	50	6	5.33					
	Clerodendron dusenii		0.33	0.24	16.67	2	2					
	Lasiomorpha senegalensis		0.33	0.24	16.67	2	2					
	Rhynchospora corymbosa		2.33	1.71	50	6	4.67					
	Aspilia africana		0.83	0.61	16.67	2	5					
	Brachiaria stigmatisata		1.33	0.98	33.33	4	4					
	Ipomoea aquatica		5.50	4.03	83.33	10	6.60					
	Commelina benghalensis		10.83	7.94	100	12	10.83					
	Senna alata		10.33	7.57	100	12	10.33					
	Echinochloa pyramidalis		11.33	8.30	100	12	11.33					
	Lemna paucicostata		4.67	3.42	33.33	4	14					
	Ludwigia leptocarpa		0.33	0.24	16.67	2	2					
	Elaies guineensis		0.33	0.24	16.67	2	2					
	Althernanthera maritima		1.17	0.85	33.33	4	3.50					
	Acrosticum aureum		1.83	1.34	33.33	4	5.50					
	Nymphaea lotus		0.83	0.61	16.67	2	5					
	Cocos nucifera		0.33	0.24	16.67	2	2					
TS/ TF	**18 / 15**											
Petit Bonanjo 1	***Eichhornia crassipes***	95	89.67	40.73	100	6.32	89.67	5.57	2.56	0.69	0.19	0.81
	Echinochloa pyramidalis		21.17	9.61	100	6.32	21.17					
	Coccinia grandis		2.33	1.06	33.33	2.11	7					
	Pentodon pentandrus		1.17	0.53	16.67	1.05	7					
	Mussaenda angolensis		1.50	0.68	33.33	2.11	4.50					
	Adenia gracilis		1.17	0.53	16.67	1.05	7					
	Heliconia latispatha		1.50	0.68	33.33	2.11	4.50					
	Acrosticum aureum		1.67	0.76	33.33	2.11	5					

Sites	Species	% WH	Density	RD (%)	F (%)	RF (%)	A	Dmg	H'	E	D	D'
Petit Bonanjo 1	*Anthocleista djalonensis*	95	1	0.45	33.33	2.11	3	5.57	2.56	0.69	0.19	0.81
	Ipomoea carnea		0.67	0.30	16.67	1.05	4					
	Brachiaria stigmatisata		1.00	0.45	16.67	1.05	6					
	Heteropterys Leona		2.33	1.06	33.33	2.11	7					
	Millettia sanagana		1.17	0.53	16.67	1.05	7					
	Dalbergia sp.		1.83	0.83	33.33	2.11	5.50					
	Clerodendron dusenii		2.33	1.06	33.33	2.11	7					
	Crudea klainei		2.83	1.29	33.33	2.11	8.50					
	Ludwigia leptocarpa		2.33	1.06	33.33	2.11	7					
	Rhynchosia mannii		4	1.82	66.67	4.21	6					
	Ipomoea aquatica		3	1.36	50	3.16	6					
	Cyperus compressus		2.50	1.14	33.33	2.11	7.50					
	Leersia hexandra		2.17	0.98	16.67	1.05	13					
	Solenostemon latifolius		0.33	0.15	16.67	1.05	2					
	Mussaenda arcuata		2	0.91	50	3.16	4					
	Rhynchospora corymbosa		4.50	2.04	33.33	2.11	13.50					
	Elaeis guineensis		1	0.45	16.67	1.05	6					
	Alchornea cordifolia		4.67	2.12	100	6.32	4.67					
	Raphia sp.		0.33	0.15	16.67	1.05	2					
	Cola sp.		0.17	0.08	16.67	1.05	1					
	Agauria salicifolia		1	0.45	16.67	1.05	6					
	Alstonia boonei		1.67	0.76	33.33	2.11	5					
	Althernanthera maritima		4.50	2.04	66.67	4.21	6.75					
	Althernanthera nodiflora		5	2.27	66.67	4.21	7.50					
	Althernanthera repens		4.33	1.97	50	3.16	8.67					
	Canna indica		0.33	0.15	16.67	1.05	2					
	Nymphaea lotus		4.67	2.12	50	3.16	9.33					
	Pandanus candelabrum		0.17	0.08	16.67	1.05	1					
	Commelina benghalensis		12.50	5.68	100	6.32	12.50					
	Pistia stratiotes		14.17	6.43	16.67	1.05	85					

Sites	Species	% WH	Density	RD (%)	F (%)	RF (%)	A	Dmg	H'	E	D	D'
Petit Bonanjo 1	***Lemna paucicostata***	95	6.50	2.95	50	3.16	13	5.57	2.56	0.69	0.19	0.81
	Jussiaea suffruticosa		1.50	0.68	33.33	2.11	4.50					
	Oldenlandia lancifolia		3.50	1.59	33.33	2.11	10.50					
TS/ TF	**41 / 27**											
Petit Bonanjo 2	***Eichhornia crassipes***	90	74.50	54.31	100	9.23	74.50	4.62	1.94	0.56	0.32	0.68
	Echinochloa pyramidalis		17.67	12.88	100	9.23	17.67					
	Eulophia alta		0.17	0.12	16.67	1.54	1					
	Mussaenda angolensis		0.33	0.24	16.67	1.54	2					
	Adenia gracilis		0.50	0.36	16.67	1.54	3					
	Acrosticum aureum		0.33	0.24	16.67	1.54	2					
	Lygodium microphyllum		1.67	1.22	16.67	1.54	10					
	Anthocleista djolonensis		1.17	0.85	16.67	1.54	7					
	Ipomoea carnea		0.50	0.36	16.67	1.54	3					
	Heteropterys leona		0.83	0.61	16.67	1.54	5					
	Millettia sanagana		1.67	1.22	16.67	1.54	10					
	Dalbergia sp.		0.50	0.36	50	4.62	1					
	Ludwigia leptocarpa		0.50	0.36	33.33	3.08	1.50					
	Rhynchosia mannii		0.83	0.61	16.67	1.54	5					
	Ipomoea aquatica		0.83	0.61	16.67	1.54	5					
	Heterosis prostrata		1.33	0.97	16.67	1.54	8					
	Cyperus compressus		2	1.46	33.33	3.08	6					
	Mussaenda arcuata		0.33	0.24	16.67	1.54	2					
	Rhynchospora corymbosa		1.50	1.09	50.00	4.62	3					
	Alchornea cordifolia		567	4.13	83.33	7.69	6.80					
	Agauria salicifolia		1	0.73	16.67	1.54	6					
	Alstonia boonei		0.83	0.61	33.33	3.08	2.50					
	Althernanthera maritima		1.67	1.22	33.33	3.08	5					
	Althernanthera nodiflora		1.67	1.22	33.33	3.08	5					
	Althernanthera repens		3.83	2.79	50	4.62	7.67					
	Nymphaea lotus		3.17	2.31	33.33	3.08	9.50					

Sites	Species	% WH	Density	RD (%)	F (%)	RF (%)	A	Dmg	H'	E	D	D'
Petit Bonanjo 2	***Commelina benghalensis***	90	6.83	4.98	100	9.23	6.83	4.62	1.94	0.56	0.32	0.68
	Lemna paucicostata		3.17	2.31	33.33	3.08	9.50					
	Psychotria sp.		0.67	0.49	33.33	3.08	2					
	Cayponia sp.		0.33	0.24	16.67	1.54	2					
	Jussiaea suffruticosa		0.83	0.61	16.67	1.54	5					
	Scleria sp.		0.33	0.24	16.67	1.54	2					
TS/ TF	**32 / 22**											
Saint Richard	***Eichhornia crassipes***	85	60.67	42.08	100	9.52	60.67	3.84	2.31	0.70	0.21	0.79
	Leersia hexandra		2.50	1.73	50	4.76	5					
	Sterculia tragacantha		1.33	0.92	16.67	1.59	8					
	Scoparia dulcis		1	0.69	16.67	1.59	6					
	Ormocarpum megaphyllum		1	0.69	16.67	1.59	6					
	Drepanocarpus lunatus		1	0.69	16.67	1.59	6					
	Fuirena umbellata		3	2.08	50	4.76	6					
	Cyperus difformis		3.67	2.54	33.33	3.17	11					
	Cyperus compressus		4.67	3.24	50	4.76	9.33					
	Acrosticum aureum		2.50	1.73	50	4.76	5					
	Avicennia germinans		2	1.39	33.33	3.17	6					
	Echinochloa pyramidalis		1633	11.33	100	9.52	16.33					
	Brachiaria stigmatisata		1.33	0.92	33.33	3.17	4					
	Commelina benghalensis		9.33	6.47	100	9.52	9.33					
	Ludwigia leptocarpa		1.67	1.16	33.33	3.17	5					
	Heteropterys leona		1.67	1.16	16.67	1.59	10					
	Clerodendron dusenii		0.33	0.23	16.67	1.59	2					
	Elaeis guineensis		1.67	1.16	33.33	3.17	5					
	Cocos nucifera		0.67	0.46	16.67	1.59	4					
	Rhynchospora corymbosa		10.50	7.28	66.67	6.35	15.75					
	Cyperus mannii		2.17	1.50	33.33	3.17	6.50					
	Pistia stratiotes		0.83	0.58	16.67	1.59	5					
	Alchornea cordifolia		2.83	1.97	33.33	3.17	8.50					

Sites	Species	% WH	Density	RD (%)	F (%)	RF (%)	A	Dmg	H'	E	D	D'
Saint Richard	*Althernanthera maritima*	85	6.17	4.28	50	4.76	12.33	3.84	2.31	0.70	0.21	0.79
	Aspilia africana		0.83	0.58	16.67	1.59	5					
	Senna alata		1.50	1.04	16.67	1.59	9					
	Ipomoea aquatica (*)		3.00	2.08	33.33	3.17	9					
TS/ TF	**27 / 20**											
Ecomite	*Cyperus mannii*	0	4.50	2.01	33.33	2.67	13.50	4.03	2.36	0.69	0.18	0.82
	Rhynchospora corymbosa		2.67	1.19	50	4	5.33					
	Lasiomorpha senegalensis (*)		51.50	22.99	100	8	51.50					
	Alchornea cordifolia		14	6.25	100	8	14					
	Nephrolepis undulata		74.83	33.41	100	8	74.83					
	Mitragyna stipulosa		2.50	1.12	33.33	2.67	7.50					
	Anthocleista djalonensis		2.33	1.04	33.33	2.67	7.00					
	Alternanthera maritima		5.50	2.46	50	4	11.00					
	Alternanthera nodiflora		1.67	0.74	33.33	2.67	5					
	Alstonia boonei		6.83	3.05	50	4	13.67					
	Elaeis guineensis (*)		4.50	2.01	33.33	2.67	13.50					
	Ficus sp.		1.33	0.60	16.67	1.33	8					
	Senna alata		0.83	0.37	33.33	2.67	2.50					
	Ipomoea pes-caprae		2.83	1.26	33.33	2.67	8.50					
	Anchomanes difformis		4.83	2.16	50	4	9.67					
	Cecropia peltata (*)		5.33	2.38	50	4	10.67					
	Dioscorea sp.		3.67	1.64	66.67	5.33	5.50					
	Mucuna sp.		3.83	1.71	66.67	5.33	5.75					
	Dalbergia sp.		12	5.36	50	4	24					
	Margaritaria discoidea		1.67	0.74	33.33	2.67	5					
	Rhynchosia mannii		7.50	3.35	50	4	15					
	Ipomoea mauritiana		2.17	0.97	16.67	1.33	13					
	Leersia hexandra		0.83	0.37	16.67	1.33	5					
	Nymphaea lotus (*)		0.83	0.37	16.67	1.33	5					
	Lemna paucicostata (*)		0.83	0.37	16.67	1.33	5					

Sites	Species	% WH	Density	RD (%)	F (%)	RF (%)	A	Dmg	H’	E	D	D’
Ecomite	*Ipomoea cairica*	0	0.50	0.22	16.67	1.33	3	4.03	2.36	0.69	0.18	0.82
	Ipomoea carnea		2.33	1.04	33.33	2.67	7					
	***Chromolaena odorata**		1.33	0.60	33.33	2.67	4					
	Ludwigia leptocarpus		0.17	0.07	16.67	1.33	1					
	Ind.1		0.33	0.15	16.67	1.33	2					
TS/ TF	**30 / 21**											

Moreover, one of the native species is now classified as an invasive species because it has become over-abundant and aggressive and has disturbed several areas: *Commelina benghalensis*. The invasive species found during the survey are also represented in Table 3.3, with GH, PB1 presenting the highest number of invasive species (9), followed by PB1, CE, FB and SR (7), EC (6), GB2 and CH (5), and finally GB1 and BV with four species each.

3.4.1.2 Family diversity

Of the 40 families identified, including the family of the unidentified species, the most representative families are Cyperaceae, Fabaceae and Rubiaceae each of which is represented by 15.38%, followed by the family of Convolvulaceae with 12.82%, and Poaceae with 10.26% (Table 3.4).

Table 3.4 Abundance and frequency of all the families found in all the sites sampled

Family	Number of species in the family	Frequency (%)
Cyperaceae	6	15.38
Fabaceae	6	15.38
Rubiaceae	6	15.38
Convolvulaceae	5	12.82
Poaceae	4	10.26
Amaranthaceae	3	7.69
Araceae	3	7.69
Arecaceae	3	7.69
Asteraceae	3	7.69
Lamiaceae	3	7.69
Caesalpiniaceae	2	5.13
Cucurbitaceae	2	5.13
Onagraceae	2	5.13
Pandanaceae	2	5.13
Sterculiaceae	2	5.13
Adiantaceae	1	2.56
Apocynaceae	1	2.56
Avicenniaceae	1	2.56
Bombacaceae	1	2.56
Cannaceae	1	2.56
Cecropiaceae	1	2.56
Commelinaceae	1	2.56
Dioscoreaceae	1	2.56
Ericaceae	1	2.56
Euphorbiaceae	1	2.56
Lemnaceae	1	2.56
Loganiaceae	1	2.56

Malpighiaceae	1	2.56
Melastomataceae	1	2.56
Moraceae	1	2.56
Nephrolepidaceae	1	2.56
Nymphaeaceae	1	2.56
Orchidaceae	1	2.56
Papilionaceae	1	2.56
Passifloraceae	1	2.56
Pontederiaceae	1	2.56
Rhizophoraceae	1	2.56
Schizaeaceae	1	2.56
Scrophulariaceae	1	2.56
Strelitziaceae	1	2.56

3.4.1.3 Percentage cover

Along the sites studied, especially those where water hyacinth was present, *E. crassipes* was the most abundant plant found, sometimes covering the whole watercourse, where percentage cover could reach 95% of the total surface of the watercourse (Table 3.5). Furthermore, the other invasive plants were also abundant in terms of surface cover and distribution along the river. These invasive plants include *Echinochloa pyramidalis* (35–60%), *Commelina benghalensis* L. (10–35%), and in some cases *Alchornea cordifolia* ((Schumach. & Thonn.) Müll.Arg.) (Euphorbiaceae) (10–30%), *Althernathera maritima* (Mart.) A. St. Hill (Amaranthaceae) (10–30%) and *Rhynchospora corymbosa* L. Britt. (Cyperaceae) (2–27%) (Table 3.5).

By contrast, at Ecomité, which was the site without water hyacinth, the main dominant plant found there was the invasive *Lasiomorpha senegalenses* which also has a high density with a percentage cover reaching 70%. This species was followed by *Nephrolepis undulata* (45%), *Alchornea cordifolia* (40%), and to a lesser extent, *Rhynchosia mannii* (27%), *Dioscorea* sp. and *Dalbergia* sp. with 26 % (Table 3.5).

Table 3.5 Macrophyte diversity in different sites expressed in ACFOR scale based on overall dominance per site according to the species recorded there.

BV: Bonassama Vallée; CE: Centre Equestre; CH: Château; FB: Forêt Bar; GB1: Grand Baobab 1; GB2: Grand Baobab 2; GH: Grand Hangar; PB1: Petit Bonanjo 1; PB2: Petit Bonanjo2; SR: Saint Richard; EC: Ecomité

R = Rare (0–5%), O = Occasional (5–25%), F = Frequent (25–50%), C = Common (50–75%), A =Abundant (75–100%)

Site / **Species**	**Family**	**BV**	**CE**	**CH**	**FB**	**GB 1**	**GB 2**	**GH**	**PB 1**	**PB 2**	**SR**	**EC**
Acrosticum aureum	Adiantaceae			R	R			R	R	R	R	
Adenia gracilis	Passifloraceae								R	R		
Aeschynomene crassicaulis	Fabaceae			R								
Agauria salicifolia	Ericaceae								O	R		
Alchornea cordifolia	Euphorbiaceae		O	O	O				F	O	O	F
Alstonia boonei	Apocynaceae								O	O		O
Alternanthera maritima	Amaranthaceae	O			O	O		O	O	O	F	O
Althernanthera nodiflora	Amaranthaceae	O			O	R			O	O		R
Althernanthera repens	Amaranthaceae				O				O	O		
Anchomanes difformis	Araceae											O
Anthocleista djalonensis	Loganiaceae			R					R	R		O
Aspilia africana	Asteraceae	O				R	R	R			R	
Avicennia germinans	Avicenniaceae			O	O						R	
Brachiaria stigmatisata	Poaceae				R		O	O	O		O	
Canna indica	Cannaceae								R			
Cayponia sp.	Cucurbitaceae									R		
Cecropia peltata	Cecropiaceae											O
Chromolaena odorata	Asteraceae		R									O
Clerodendron dusenii	Lamiaceae			F				R	O		R	
Clerodendron sp.	Lamiaceae			O								
Coccinia grandis	Cucurbitaceae								R			

Site	**Family**	**BV**	**CE**	**CH**	**FB**	**GB 1**	**GB 2**	**GH**	**PB 1**	**PB 2**	**SR**	**EC**
Species												
Cocos nucifera	Arecaceae							R			R	
Cola sp.	Sterculiaceae								R			
Commelina benghalensis	Commelinaceae	F	O	F	O	F	O	O	F	F	F	
Crudia klainei	Caesalpiniaceae								O			
Cyperus compressus	Cyperaceae								O	O	O	
Cyperus difformis	Cyperaceae				O	O					O	
Cyperus mannii	Cyperaceae				R						R	O
Dalbergia sp.	Fabaceae								O	O		F
Dioscorea sp.	Dioscoreaceae											F
Drepanocarpus lunatus	Papilionaceae										R	
Echinochloa pyramidalis	Poaceae	C	C	C	F	F	F	F	C	F	C	
Eichhornia crassipes	Pontederiaceae	C	C	A	A	A	C	A	A	A	A	
Elaeis guineensis	Arecaceae		R	R				R	R		R	O
Eleusine indica	Poaceae	R										
Eulophia alta	Orchidaceae									R		
Ficus sp.	Moraceae											O
Fuirena umbellata	Cyperaceae										O	
Heliconia latispatha	Strelitziaceae				O				O			
Heteropterys leona	Malpighiaceae			F					O	O	R	
Heterostis prostrata	Melastomataceae									O		
Ind.1	Araceae											R
Ipomoea aquatica	Convolvulaceae	O	O		O	O		O	O	O	O	
Ipomoea cairica	Convolvulaceae	R					O					R
Ipomoea carnea	Convolvulaceae	R							R	R		O
Ipomoea mauritiana	Convolvulaceae											O
Ipomoea pes-caprae	Convolvulaceae											O
Jussiaea suffruticosa	Onagraceae				O				O	O		
Lasiomorpha senegalensis	Bombicideae		R					R				C
Leersia hexandra	Poaceae							O	O		O	R

Site	Family	BV	CE	CH	FB	GB 1	GB 2	GH	PB 1	PB 2	SR	EC
Species												
Lemna paucicostata	Lemnaceae				O		O	O	O	O		R
Ludwigia leptocarpa	Onagraceae				O			O	O	O	O	O
Lygodium microphyllum	Schizaeaceae									O		
Margaritaria discoidea	Asteraceae											O
Millettia sanagana	Fabaceae			O					O	O		
Mitragyna stipulosa	Rubiaceae											O
Mucuna sp.	Fabaceae											O
Mussaenda angolensis	Rubiaceae			O					O	O		
Mussaenda arcuata	Rubiaceae			O					R	R		
Nephrolepis ondulata	Nephrolepidaceae											F
Nymphaea lotus	Nymphaeaceae				O			O	O	O		R
Oldenlandia lancifolia	Rubiaceae								O			
Ormocarpum megaphyllum	Fabaceae										R	
Pandanus baptistii	Pandanaceae				R							
Pandanus candelabrum	Pandanaceae				R				R			
Pentodon pentandrus	Rubiaceae								O			
Pistia stratiotes	Araceae						O		F		R	
Psychotria sp.	Rubiaceae									O		
Raphia sp.	Arecaceae								R			
Rhizophora harrisonii	Rhizophoraceae				O		O					
Rhynchosia mannii	Fabaceae						O		F	O		F
Rhynchospora corymbosa	Cyperaceae			R	O	R	R	O	O	O	F	O
Scleria sp.	Cyperaceae									O		
Scoparia dulcis	Scrophuraliaceae										O	
Senna alata	Caesalpiniaceae							R			R	R
Solenostemon latifolius	Lamiaceae								R			
Sterculia tragacantha	Sterculiaceae										R	

3.4.2 Cluster analysis for floristic inventory data

The cluster dendogram of similarities based on floristic inventories per site showed an overall grouping of six groups (Figure 3.3). Albeit groups 1 (EC), 2 (CH) and 5 (CE) consisted of one site, group 1, with respect to the other groups, is the only one which is not directly linked to the other groups. Indeed, the site of this group shared only 27.2% similarity with those of groups 2–6. All remaining groups, i.e. 2–6 shared 35.5% similarity. The sites constituted by group 3 (PB 1 and PB 2) were most similar to those which constituted the other groups with 71.2% similarity, although Bv and GB1 were the sites which are more similar, with 80% of similarity. Groups 2, 3 and 4 (FB, GH, and SR) were overall more similar (43.2%) than groups 5 and 6 (GB 2, BV, GB1) with 40.2% whilst groups 3 and 4 shared 46.3% similarity. Groups 4 and 6 consisted of three sites, making them the largest group with 54% and 52.4%.

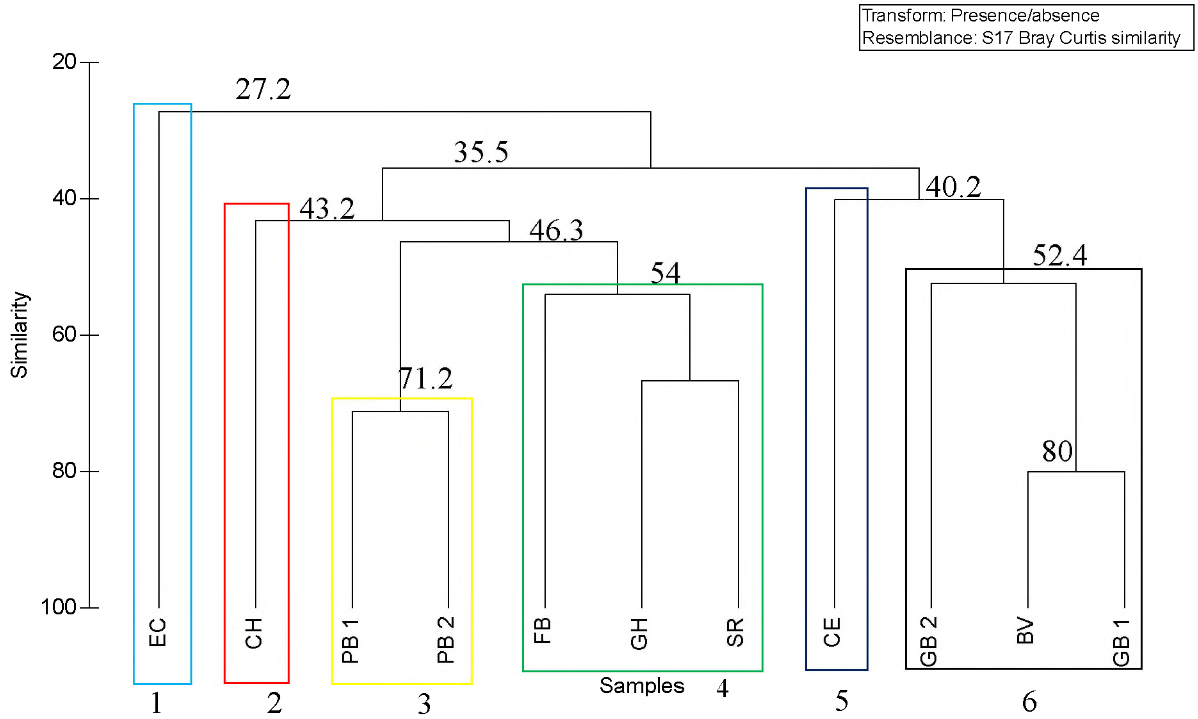


Figure 3.3 Cluster dendogram of sampling sites based on plant species presence-absence. Percent similarities are given for each junction. Full names for site abbreviation names are given in Table 3.1.

The Non-metric Multi-Dimensional Scaling (MDS) was used with water hyacinth density average per site as factor. The average density of water hyacinth was estimated using the sum of the coefficient of abundance-dominance expressed on an ACFOR scale per quadrat allocated to water hyacinth during the floristic inventory and divided by the total number of quadrats (Table 3.6). In terms of percentage, the factor attributed to each site can be translated as follows:

Table 3.6 Factor attributed to each site related to the water hyacinth cover mats for the whole site.

Abundance-Dominance	Class recovery (%)	Average recovery (%)
0 (No water hyacinth)	0	0
3	25-50	37.5
4	50-75	62.5
5	75-100	87.5

Figure 3.4 is divided in four different groups. The first group consists of EC where water hyacinth was not found. The second group consist of BV, GB 1 and 2, and CE with a water hyacinth density factor equal to 3; SR, GH, FB and CH with a water hyacinth density factor equal to 4; PB 1 and 2 with a water hyacinth density factor equal to 5 constitute the third and fourth groups.

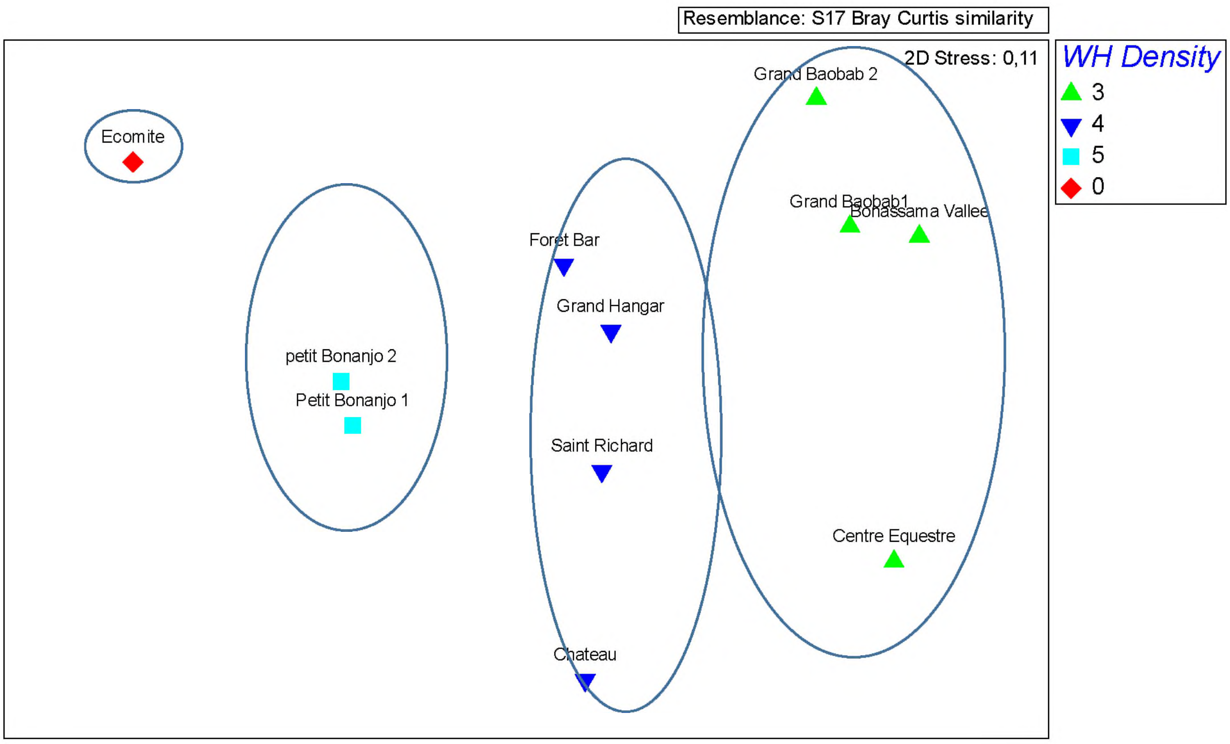


Figure 3.4 Representation of similarity between sites using water hyacinth density as a factor.

3.4.3 Comparative study of the floristic inventory

The results from the current study were compared with a study carried out between September 2002 and June 2003 by Njiokou (2003), whihad worked at 20 sites distributed in 3 of the six sub-divisions which made the Littoral Region. Among these 20 sites which were inventoried in their study, 5 sites located at Bonaberi (Douala IV) in the same area where the current study was carried, were chosen for a comparative study. Although located in the back pools (same catchment area but not in the main river), 72 species were inventoried at these sites (Table 3.7), amongst which 15 are now classified as invasive. In the current study, sites with water hyacinth share a total of 15 common species including nine invasive species, while at Ecomite, without water hyacinth, had seven common species including four invasive species in common with the previous study (Table 3.7).

The percentage cover for these different studies was expressed according to the ACFOR Scale and the results revealed that in 2003, with the exception of species like *Pistia stratiotes,* which was abundant, *Imperata cylindrica*, *Kyllinga erecta* Schumach., *Kyllinga* sp., *Cyrtosperma senegalense* = *Lasiomorpha senegalensis*, *Nephrolepis bisserata* (Sw.) Schott., *Mimosa pudica* L., *Panicum maximum* Jacq., *Setaria megaphylla* (Steud) Dur. & Schinz and *Echinochloa pyramidalis* were common, and the rest of species found were rare or frequent (Table 3.7).

By comparing the status of common species for these two studies, especially with sites with water hyacinth, the ACFOR scale for other species has changed, with the exception of *E. pyramidalis*, *Aspilia africana* and *Commelina benghalensis* which have conserved the same ACFOR scale based on overall dominance (Table 3.7).

3.4.4 Physico-chemical parameters

The water quality parameters recorded in all the eleven sites are represented in Figure 3.5. The temperature as well as the pH for all the sites were almost the same in both months of sampling and varied between 24.83–29.63 °C and 6.67–7.60 with EC presenting the highest value of temperature in September, while GH the highest value of pH. The highest value of total dissolved solids (TDS), conductivity and salinity are observed at GB2 in October and the lowest value at PB 1 in September. In contrast, GB 1 presents the highest value of nitrate and ammonium (Figure 3.5).

Table 3.7 Aquatic macrophytes species recorded in Douala IV (Bonaberi) located along the Wouri Basin in 2002 (Njiokou 2003) and in 2014 expressed in ACFOR scale based on overall dominance: R = Rare (0–5%), O = Occasional (5–25%), F = Frequent (25–50%), C = Common (50–75%), A =Abundant (75–100%); I = Invasive species; X = Presence; *** name of species** = Invasive species according to the list published by the MINEPDED (Cameroon).

Species	**Family**	**2002**		**2014 (Sites with water hyacinth)**		**2014 (Ecomite)**	
		Presence	**ACFOR scale**	**Presence**	**ACFOR scale**	**Presence**	**ACFOR scale**
Acrosticum aureum L. Walker	Adiantaceae			X	R		
Adenia gracilis (Harms)	Passifloraceae			X	R		
Aeschynomene crassicaulis (Harms)	Fabaceae			X	R		
Aframomum polyanthum K. Schum	Zingiberaceae	X	R				
Agauria salicifolia (Comm.) Hook. F. esc.	Ericaceae			X	R		
Ageratum conyzoides L.	Asteraceae	X (I)	O				
Alchornea cordifolia (Schumach. & Thonn.)	Euphorbiaceae	X	F	X	O	X	F
Alstonia boonei De Wild	Apocynaceae	X	R	X	O	X	O
Alternanthera maritime (Mart.) A. St.-Hil.	Amaranthaceae			X	O	X	O
Alternanthera nodiflora R. Br.	Amaranthaceae			X	O	X	R
Alternanthera repens (L.) Link	Amaranthaceae			X	O		
Anchomanes difformis (Blume) Engl.	Araceae					X	O
Anthocleista djalonensis (A. Chev.)	Loganiaceae			X	R	X	O
Anthocleista vogelii Planch.	Loganiaceae	X	R				
Ascolepis capensis (Kunth) Ridl.	Cyperaceae	X	O				
Aspilia Africana (Pers.) C. D. Adams	Asteraceae	X	R	X	R		
Avicennia germinans (Linn) Linn	Avicenniaceae			X	O		
Borreria monticola Mildbr. ex Hutch. & Dalziel	Rubiaceae	X	R				
Brachiaria stigmatisata (Mez.) Stapf.	Poaceae			X	F		
c.f *Canarium schweinfurthii* Engl.	Burseraceae	X	R				
Cayponia sp.	Cucurbitaceae			X	R		
Cecropia peltata (Linn)	Cecropiaceae					X (I)	O

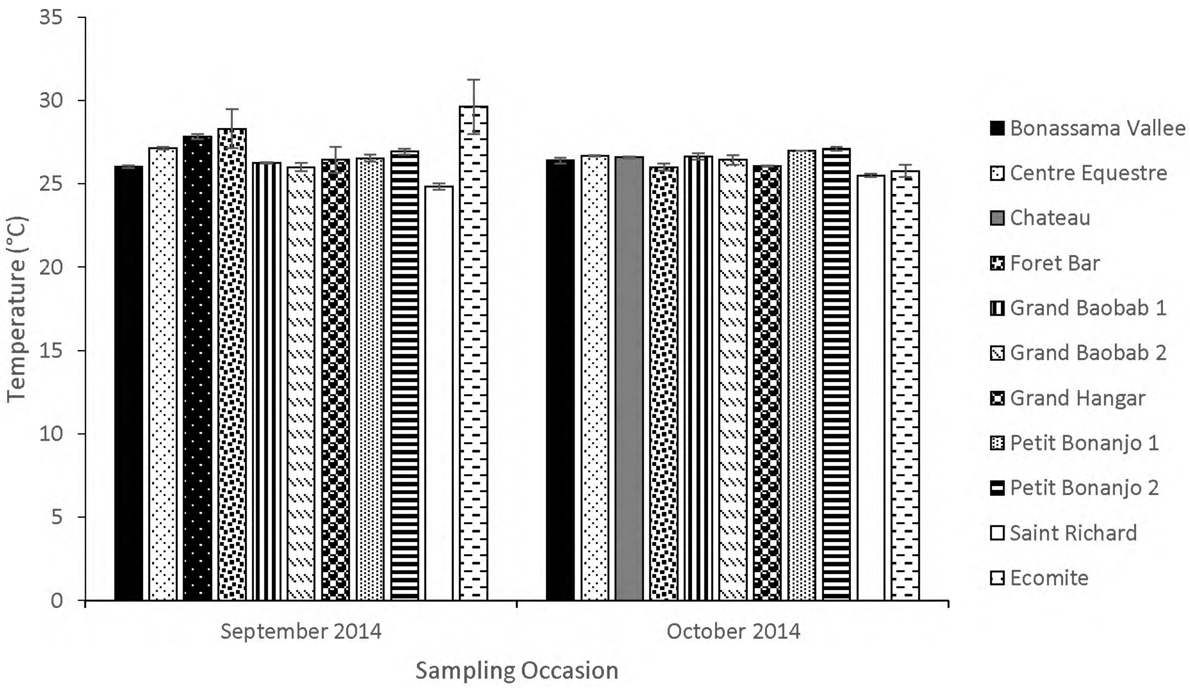
Species	Family	2002		2014 (Sites with water hyacinth)		2014 (Ecomite)	
		Presence	ACFOR scale	Presence	ACFOR scale	Presence	ACFOR scale
Centrostachys aquatica (R. Br.) Wall. ex Moq	Amaranthaceae	X	R				
Ceratophyllum demersum L.	Cerathophyllaceae	X	O				
Chromolaena odorata (L.)	Asteraceae	X (I)	O	X (I)	R	X (I)	O
Cleome ciliate Schumach. & Thonn.	Capparidaceae	X	R				
Clerodendron dusenii (Gurke)	Lamiaceae			X	O		
Clerodendron sp.	Lamiaceae			X	R		
Coccinia grandis (L.) Voogt	Cucurbitaceae			X	R		
Cocos nucifera L.	Arecaceae			X	R		
Cola sp.	Sterculiaceae	X (I)	O	X (I)	R		
Commelina benghalensis L.	Commelinaceae	X (I)	F	X (I)	F		
Costus afer Ker-Gawl	Zingiberaceae	X					
Crudia klainei (Pierre & DeWild)	Caesalpiniaceae			X	R		
Cyathea manniana Hook.	Cytheaceae	X	O				
Cyathula prostrata (Linn.) Blume	Amaranthaceae	X	O				
Cynodon dactylon (L.) Pers.	Poaceae	X	F				
Cyperus compressus L.	Cyperaceae			X	O		
Cyperus difformis L.	Cyperaceae			X	O		
Cyperus dilatatus Schumach. & Thonn.	Cyperaceae	X	O				
Cyperus distans L.f.	Cyperaceae	X	F				
Cyperus mannii (C. B. Clarke)	Cyperaceae			X	R	X	O
Cyperus sp.	Cyperaceae	X	F				
Dactyloctenium aegyptium (L.) Willd.	Poaceae	X	R				
Dalbergia sp.	Fabaceae			X	O	X	F
Desmodium adscendens (Sw.) DC.	Fabaceae	X (I)	R				
Dioscorea sp.	Dioscoreaceae					X	F
Dissotis graminicola Hutch.	Melastomataceae	X	R				
Drepanocarpus lunatus (Linn. F.) G. F. W.	Papilionaceae			X	R		
Echinochloa pyramidalis (Lam.) Hitch. & C.	Poaceae	X (I)	C	X (I)	C		
Eichhornia crassipes (Mart.) Solms Laub.	Pontederiaceae	X (I)	F	X (I)	A		

Species	Family	2002		2014 (Sites with water hyacinth)		2014 (Ecomite)	
		Presence	ACFOR scale	Presence	ACFOR scale	Presence	ACFOR scale
Elaies guineensis (Jacq.)	Arecaceae						
Elephantopus mollis Kunth	Asteraceae	X	R				
Eleusine indica (L.) Gaertn.	Poaceae	X	F	X	R		
Emilia sonchifolia (Linn.) DC.	Asteraceae	X	R				
Eragrostis ciliaris (Linn.) R.Br.	Poaceae	X	R				
Erigeron floribundus (Kunth) Sch. Bip.	Asteraceae	X	R				
Eulophia alta (L.) Faucett et Randle	Orchidaceae			X	R		
Euphorbia hirta L.	Euphorbiaceae	X	R				
Ficus sp.	Moraceae					X	O
Fimbristylis ferruginea (L.) Vahl	Poaceae	X	R				
Fuirena umbellata (Rottb.)	Cyperaceae			X	R		
Hallea stipulosa (DC.) J.-F.Leroy	Rubiaceae	X	R				
Harungana madagascariensis Lam. ex Poiret.	Hypericaceae	X	F				
Heliconia latispatha Benth.	Strelitziaceae			X	R		
Heteropterys Leona (Cav.) exell	Malpighiaceae			X	O		
Heterostis prostrata (Thorning) Benth.	Melastomataceae			X	R		
Imperata cylindrical (L.) Beauv.	Poaceae	X (I)	C				
Ind.1	Araceae					X	R
Ipomoea aquatica Forssk.	Convolvulaceae			X (I)	O		
Ipomoea cairica (Linn) Sweet	Convolvulaceae			X	R	X	R
Ipomoea carnea subsp. Fistulosa Jacq.	Convolvulaceae			X	R	X	O
Ipomoea involucrata (L.) Beauv.	Convolvulaceae	X	R				
Ipomoea mauritiana (Jacq.)	Convolvulaceae					X	O
Ipomoea pes-caprae (L.) Roth. Br.	Convolvulaceae					X	O
Jussiaea suffruticosa L.	Onagraceae			X	O		
Cyrtosperma senegalense = Lasiomorpha senegalensis Schott	Bombicidaea	X (I)	C	X (I)	R	X (I)	C
Leersia hexandra (Swartz)	Poaceae			X	O	X	R
Lemna paucicostata (Hegelm.)	Lemnaceae			X	O	X	R

Species	Family	2002		2014 (Sites with water hyacinth)		2014 (Ecomite)	
		Presence	**ACFOR scale**	**Presence**	**ACFOR scale**	**Presence**	**ACFOR scale**
Ludwigia africana (Brenan) H. Hara.	Onagraceae	X	R				
Ludwigia leptocarpa (Nutt.) Hara	Onagraceae			X	O	X	O
Lygodium microphyllum (Cavanilles) R. Br.	Schizaeaceae			X	R		
Mapania sp.	Cyperaceae	X	R				
Margaritaria discoidea (Bail.) G.L. Webster	Asteraceae					X	O
Mariscus alternifolius Vahl.	Cyperaceae	X	F				
Millettia sanagana (Harms)	Fabaceae			X	O		
Mimosa invisa Mart.	Mimosaceae	X	F				
Mimosa pudica L.	Mimosaceae	X	C				
Mitragyna stipulosa Bark	Rubiaceae					X	O
Mucuna sp.	Fabaceae					X	O
Musa sapientum L.	Musaceae	X	R				
Mussaenda angolensis (Wernham)	Rubiaceae			X	O		
Mussaenda arcuata Lam. Ex. Poir	Rubiaceae			X	R		
Nephrolepis biserrata (Sw.) Schott.	Nephrolepidaceae	X	C				
Nephrolepis undulata (Afzel.) J. Sm.	Nephrolepidaceae					X	F
Nymphaea lotus Zenkeri	Nymphaeaceae	X (I)	F	X (I)	O	X (I)	R
Oldenlandia lancifolia (Schum) D. C.	Rubiaceae			X	R		
Ormocarpum megaphyllum (Harms)	Fabaceae			X	R		
Oxalis barrelieri (L.) Kuntze	Oxalidaceae	X	R				
Oxalis corniculata (L.) Kuntze	Oxalidaceae	X	R				
Pandanus baptistii (Sanderi)	Pandanaceae			X	R		
Pandanus candelabrum (P. Beauv.)	Pandanaceae			X	R		
Panicum maximum Jacq.	Poaceae	X (I)	C				
Paspalum conjugatum P. J. Bergius	Poaceae	X	R				
Pennisetum purpureum Schumach.	Poaceae	X	R				
Pentodon pentandrus (Schum. & Thorn) Vatke	Rubiaceae			X	R		
Phyllanthus amarus Schum. & Thonn.	Euphorbiaceae	X	F				
Physalis angulate L.	Solanaceae	X	R				

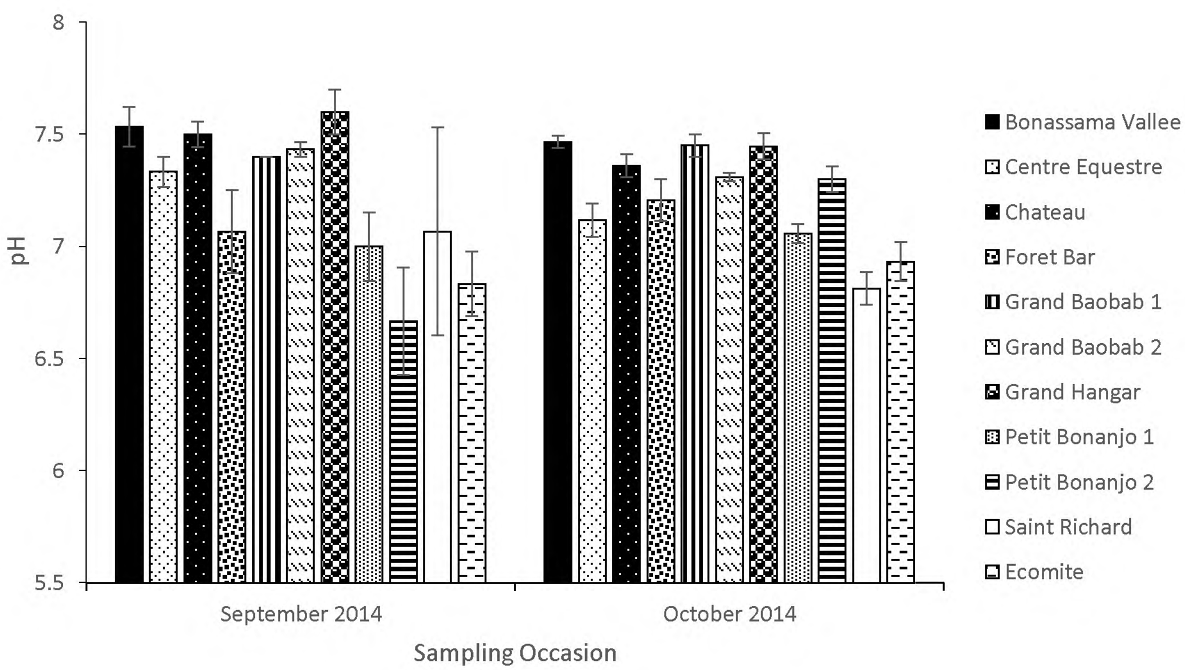
Species	Family	2002		2014 (Sites with water hyacinth)		2014 (Ecomite)	
		Presence	ACFOR scale	Presence	ACFOR scale	Presence	ACFOR scale
Piper nigrum L.	Piperaceae	X	R				
Pistia stratiotes L.	Araceae	X (I)	A	X (I)	O		
Portulaca oleracea L.	Portulacaceae	X	R				
Psidium guajava L.	Myrtaceae	X (I)	R				
Psychotria sp.	Rubiaceae			X	R		
Pueraria javanica Benth.	Fabaceae	X	F				
Pueraria phaseoloides (Roxb.) Benth	Fabaceae	X	F				
Raphia hookeri Mann and Wendl.	Arecaceae	X	R				
Raphia sp.	Arecaceae			X	R		
Rhizophora harrisonii Leechman	Rhizophoraceae			X	O		
Rhynchosia mannii (Bak.)	Fabaceae			X	O	X	F
Rhynchospora corymbosa L. Britt.	Cyperaceae	X	R	X	O	X	O
Sacciolepis africana C.E. Hubb. & Snowden	Poaceae	X	R				
Scleria sp.	Cyperaceae			X	R		
Scoparia dulcis (Linn)	Scrophuraliaceae			X	R		
Senna alata (L.) Roxb.	Caesalpiniaceae			X	R	X	R
Setaria megaphylla (Steud.) T. Durand & Schinz	Poaceae	X	C				
Solenostemon latifolius (Hochster)	Lamiaceae			X	R		
Sporobolus pyramidalis P. Beauv.	Poaceae	X	F				
Sterculia tragacantha Lindl.	Sterculiaceae			X	R		
Synedrella nodiflora (L.) Gaertn.	Asteraceae	X	R				
Urena lobata L.	Malvaceae	X	F				
Vernonia amygdalina (Del.)	Asteraceae	X	R				
Vossia cuspidate (Roxb.) Griffith.	Poaceae	X	R				

A



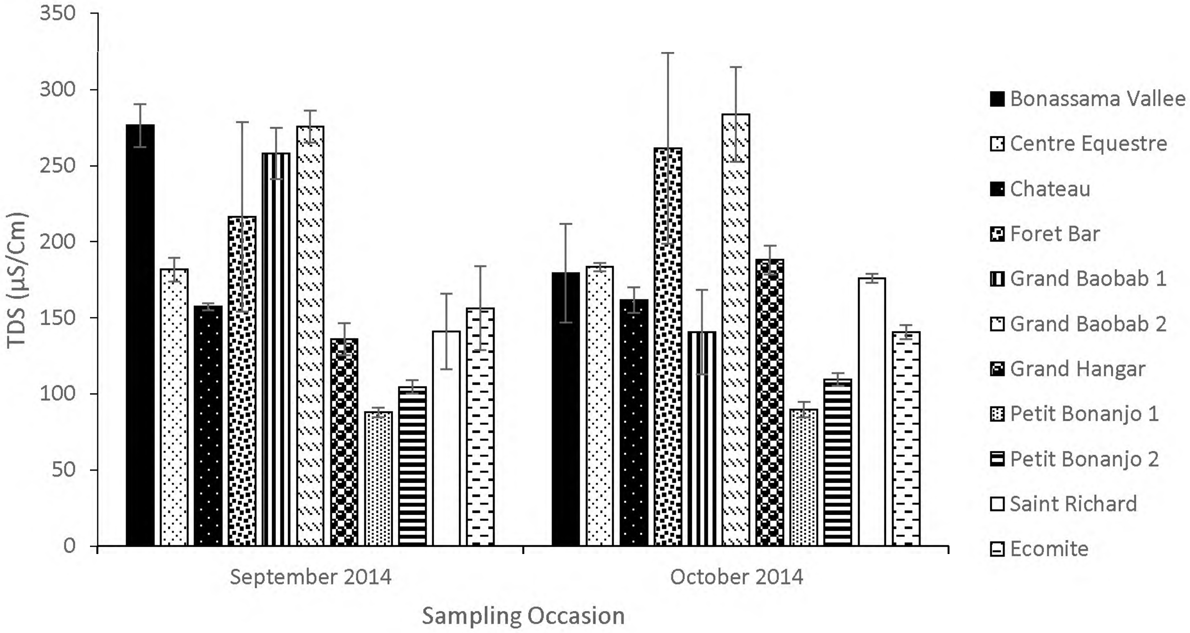
35
30
25
20
15
10
5
0
Temperature (°C)
September 2014
October 2014
Sampling Occasion
Bonassama Vallee
Centre Equestre
Chateau
Foret Bar
Grand Baobab 1
Grand Baobab 2
Grand Hangar
Petit Bonanjo 1
Petit Bonanjo 2
Saint Richard
Ecomite

B



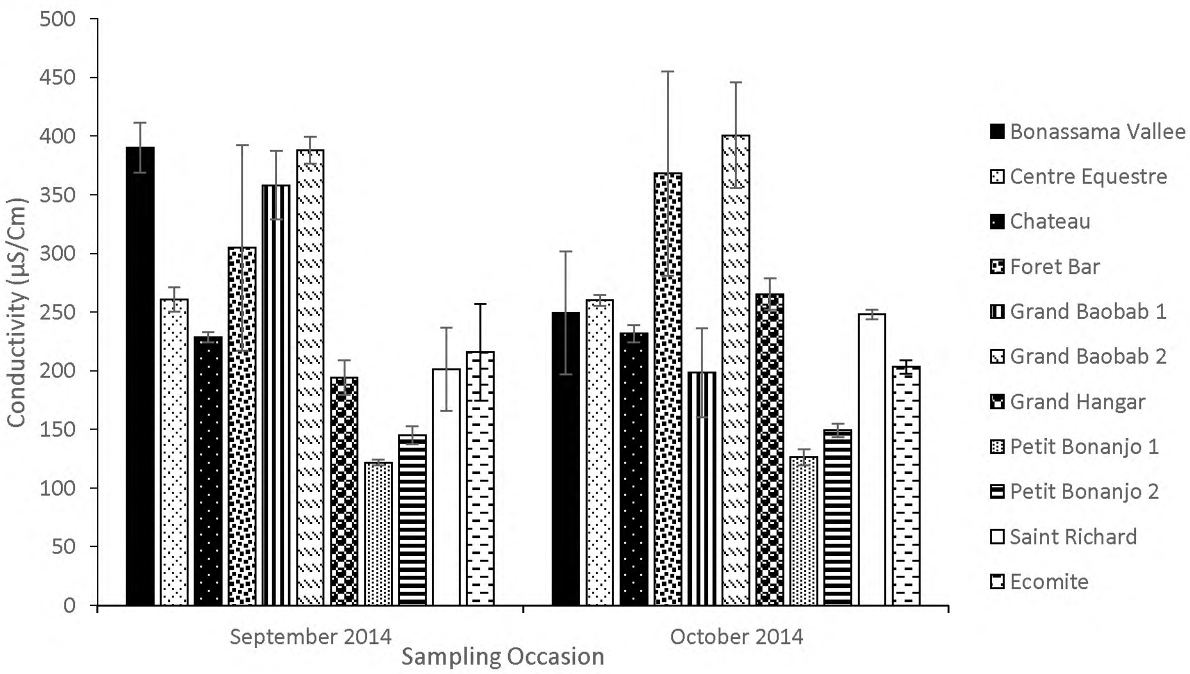
8
7.5
7
6.5
6
5.5
pH
September 2014
October 2014
Sampling Occasion
Bonassama Vallee
Centre Equestre
Chateau
Foret Bar
Grand Baobab 1
Grand Baobab 2
Grand Hangar
Petit Bonanjo 1
Petit Bonanjo 2
Saint Richard
Ecomite

C



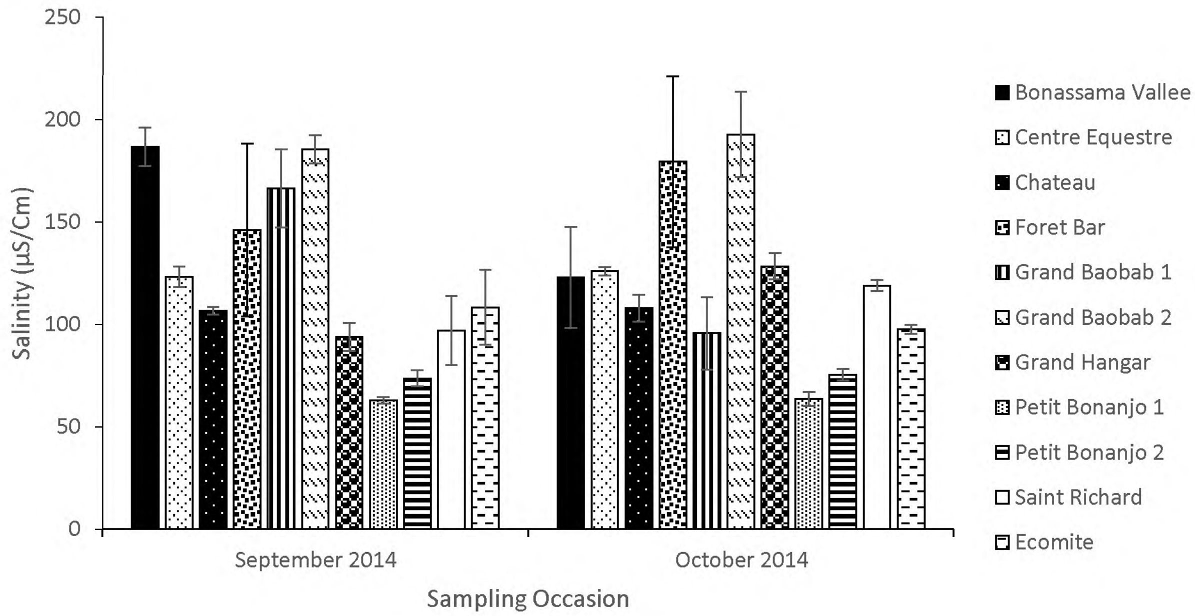
TDS (µS/Cm)
350
300
250
200
150
100
50
0
September 2014
October 2014
Sampling Occasion
Bonassama Vallee
Centre Equestre
Chateau
Foret Bar
Grand Baobab 1
Grand Baobab 2
Grand Hangar
Petit Bonanjo 1
Petit Bonanjo 2
Saint Richard
Ecomite

D



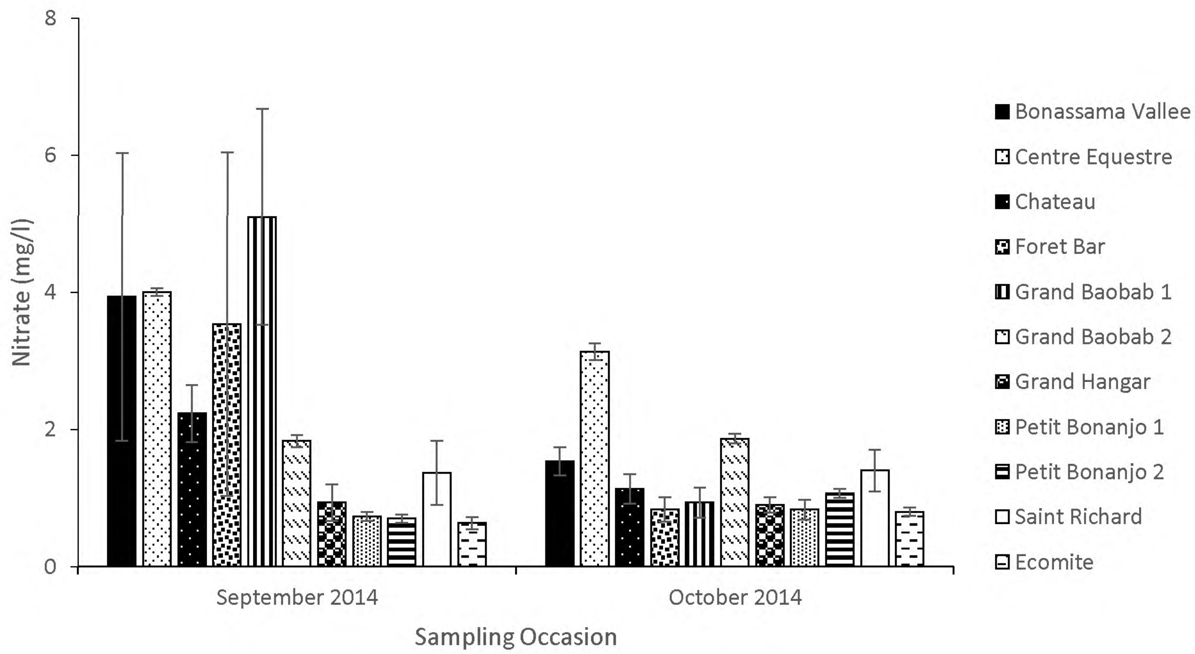
Conductivity (µS/Cm)
500
450
400
350
300
250
200
150
100
50
0
September 2014
October 2014
Sampling Occasion
Bonassama Vallee
Centre Equestre
Chateau
Foret Bar
Grand Baobab 1
Grand Baobab 2
Grand Hangar
Petit Bonanjo 1
Petit Bonanjo 2
Saint Richard
Ecomite

E



250
200
150
100
50
0
Salinity (µS/Cm)
September 2014
October 2014
Sampling Occasion
Bonassama Vallee
Centre Equestre
Chateau
Foret Bar
Grand Baobab 1
Grand Baobab 2
Grand Hangar
Petit Bonanjo 1
Petit Bonanjo 2
Saint Richard
Ecomite

F



8
6
4
2
0
Nitrate (mg/l)
September 2014
October 2014
Sampling Occasion
Bonassama Vallee
Centre Equestre
Chateau
Foret Bar
Grand Baobab 1
Grand Baobab 2
Grand Hangar
Petit Bonanjo 1
Petit Bonanjo 2
Saint Richard
Ecomite

G

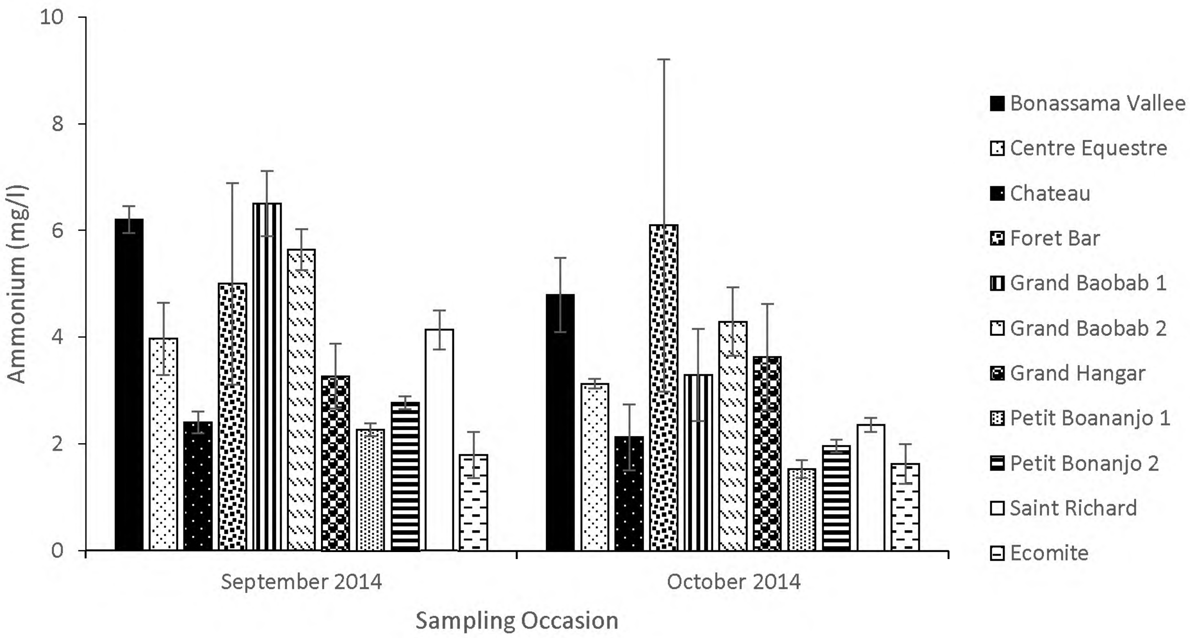


Figure 3.5 Physico-chemical characteristics of the eleventh chosen sites located along the Wouri Basin (A: Temperature; B: pH; C: TDS; D: Conductivity; E: Salinity; F: Nitrate; G: Ammonium). BV: Bonassama Vallée; CE: Centre Equestre; CH: Château; FB: Forêt Bar; GB1: Grand Baobab 1; GB2: Grand Baobab 2; GH: Grand Hangar; PB1: Petit Bonanjo 1; PB2: Petit Bonanjo2; SR: Saint Richard; EC: Ecomité.

3.4.5 Cluster Analysis for environmental variables

The cluster groups constituted by similar sites in term of physico-chemical parameters which were recorded per site and per month are shown in Figure 3.6. The cluster dendogram of the monitored sites studied was divided into seven clusters from highly polluted to less polluted. These clusters were BV and GB 1 in September, FB and GB2 in October as well as GB 2 in Septembe, SR in September, and SR and EC both in October, FB in September, while CE was in September and October. These clusters also included CH and GH in September while BV, GH, CH, GB 1 were in Octobe, EC in September and PB 1 and PB 2 both as well as in September and October.

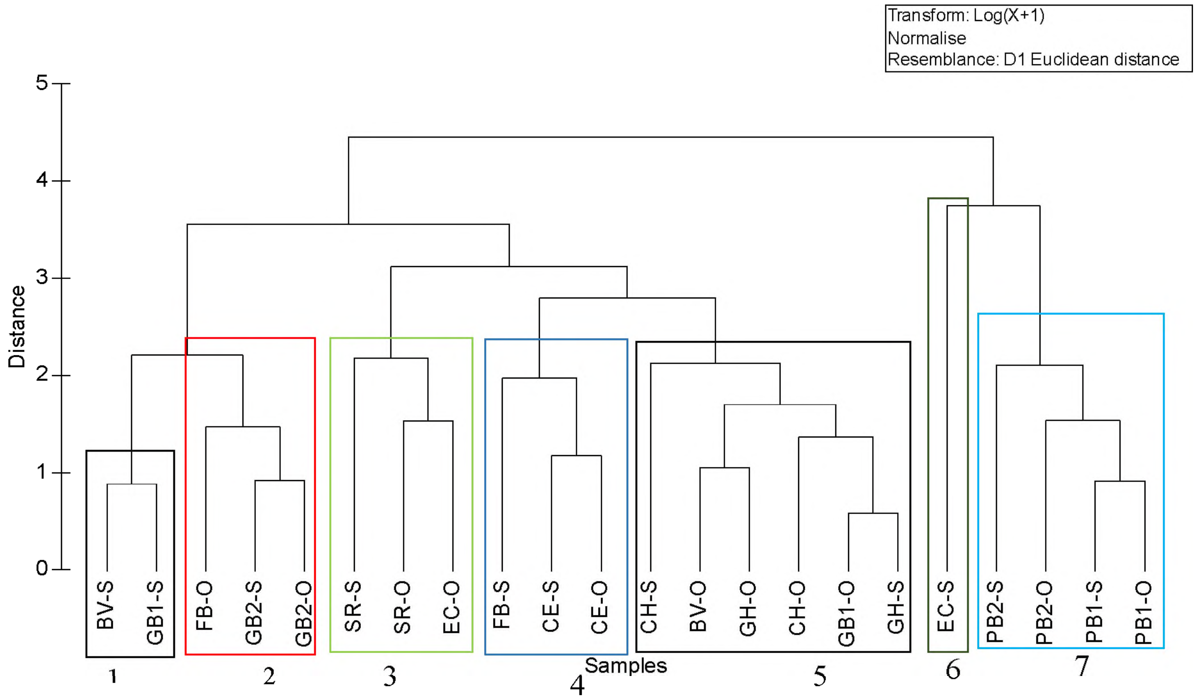


Figure 3.6 Cluster dendogram of sampling sites based on Euclidian distances, showing the distances of the sites based on environmental variables recorded each month and different groups. Full names for site abbreviation names are given in Table 3.1. **S**=September; **O**=October.

3.4.6 Principal component analysis for physico-chemical analysis for each site

Given well aware that the PCA is just a representation of the distribution of the variable according to each site per month and does not explain whether the samples are significantly different, or to what extent the variation between the samples has been explained, a Principal Coordinates Analysis (PCO) was done, as well as a Permanova test (Figure 3.7).

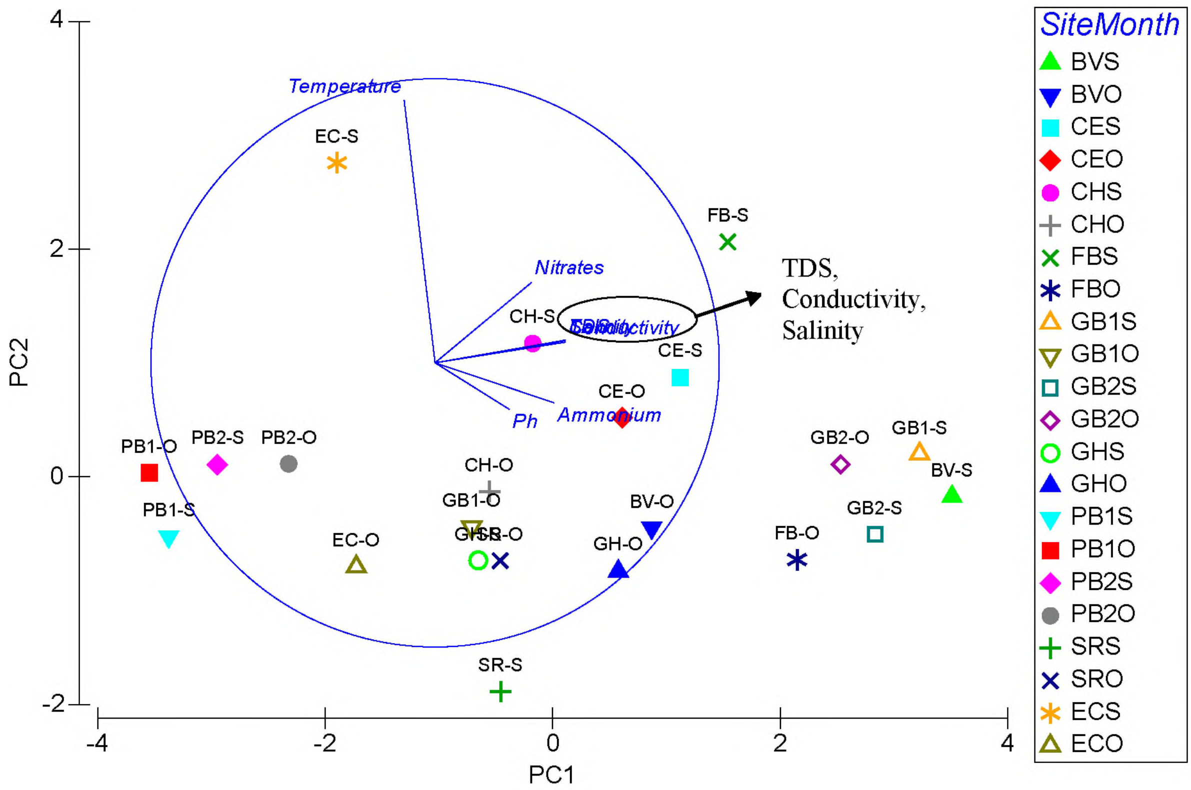


Figure 3.7 Principal Component Analysis of the environmental variables, showing the distribution pattern of these variables according to each site.

3.4.7 Principal Coordinate Analysis and Permanova test

The representation shown in Figure 3.7 is about the same as the one in Figure 3.8 with a difference of the amount of variation explained by the principal axes (PCO 1 is 63.3% and PCO 2 is 14.8%). The PCO shows that the difference between the environmental variable accounts for a total variation of 78.1% (PCO 1 + PCO 2) (Figure 3.8).

The Permanova test applied to these variables per site and per month showed that between sites there is a significant difference in composition on physico-chemical parameters (p(perm)=0.001 which is less than 0.05), while between months, there is no significant difference in terms of chemical composition (p(perm)=0.151 which is more than 0.05).

Indeed, except for a few sites like FB, CE, and CH in September, and CE in October, the other sites are grouped together, whatever the month of sampling (Figure 3.7). Apart from that, Figure 3.8 also shows the grouping amongst sites which are similar or different in terms of physico-chemical parameters.

PCO was employed to identify the difference in hydrochemistry between the two months of sampling per site. The loading of TDS, CND, salinity and nutrients (Ammonium and Nitrate were positive on PC1 (Figure 3.8) and the loading of temperature was positive on the PC 2 (Figure 3.7). PC1 (63.3 % of the variance) was called the ‘nutrients or polluted’ components and PC2 (14.8 % of the variance) was called the ‘temperature’ component.

FB had a high value of nitrate in September. The sites which had the highest value of ammonium were: GB 2 in September and October, FB in October, BV in September and GB 1 in September. The sites which are related by pH are GH (September and October), SR (September and October), CH, GB 1, EC and BV all in October. EC is the only site where the highest temperature was recorded in September. CE is the site which is correlated to the parameters such as TDS, Conductivity and Salinity for the month of September, and has a medium value of Ammonium in October. PB 1 and PB 2 are the sites where the lowest value of all these parameters were recorded.

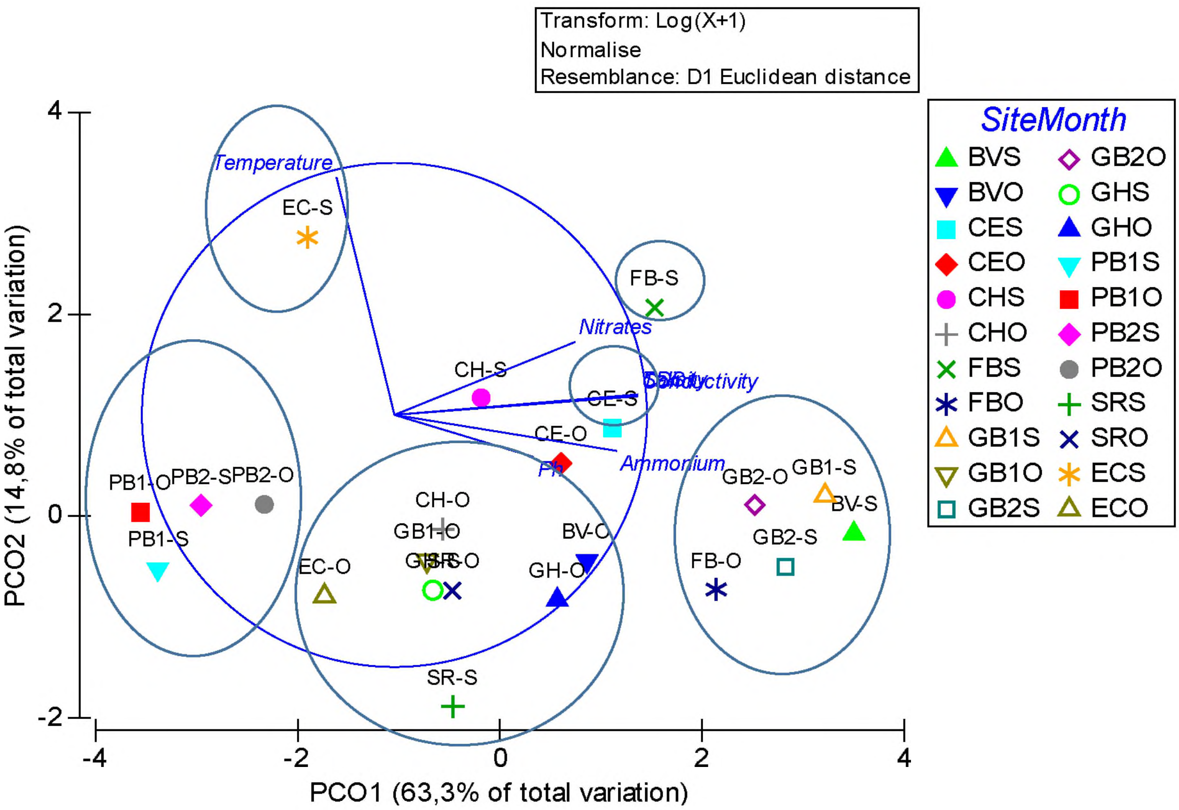


Figure 3.8 Principal Coordinates analysis based on resemblance matrix using Euclidian distance showing the amount of variation explained by each axis and the representation of different groups sites with regard to which variables are related. Permanova test showed that p(perm) between sites=0.001<0.05 and p(perm) between month=0.151>0.05.

3.4.8 Best Analysis and the Distance-Based Linear Models

To explain which environmental data are important and correlate best with the pattern in environmental data and how much the variation explains, the Best Analysis was done as well as the Distance-Based Linear Models. The results from the Best Analysis showed that pH and ammonium variables were the best parameters to explain the change in composition in each site with a coefficient of correlation between both factors of 0.578 (sample statistic ρ = 0.404; significance level of sample statistic: 0.05%) (Figure 3.9). The distance-based linear model was then applied to test this result and plot the distribution of different sites related to each of these two variables (Ammonium and pH) by excluding the other variables (Temperature, TDS, Salinity, Conductivity and Nitrate).

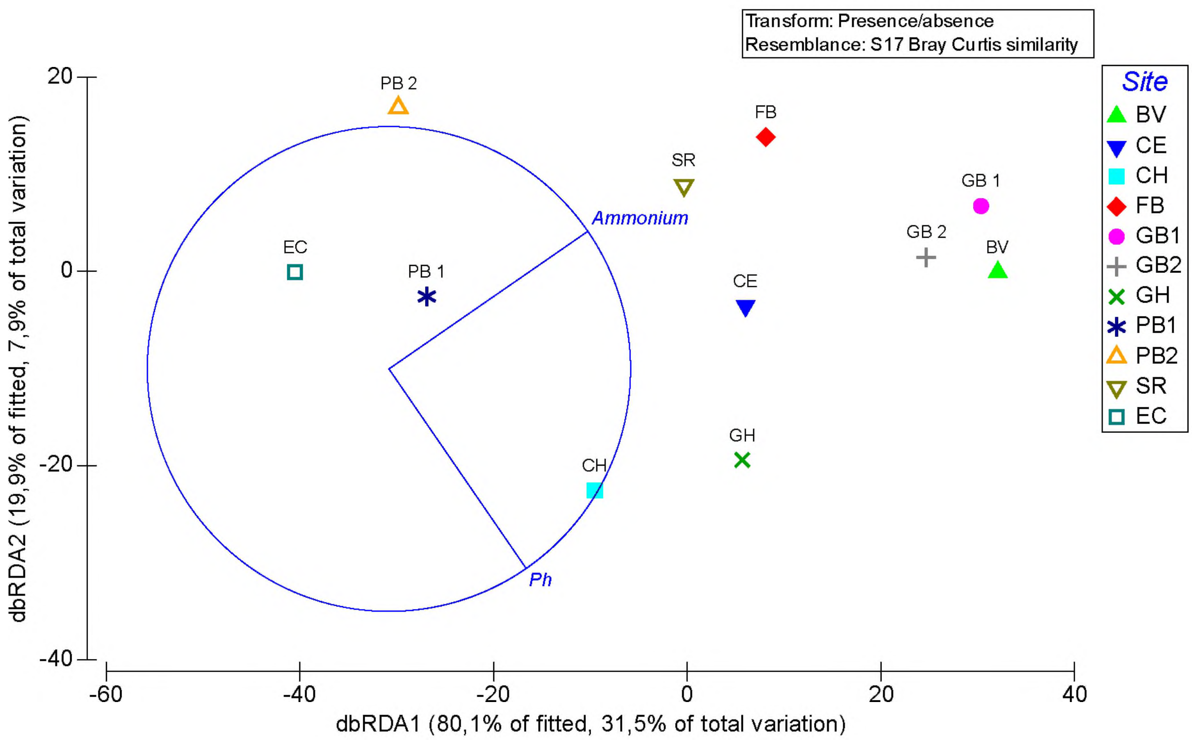


Figure 3.9 Distance-based linear models (DistLM) showing the correlation of the specific environmental variable ammonium and pH for all sites. The first axis (dbRDA 1) and second axis (dbRDA 2) explain the amount of variation for both factors, which is 31.54% and 7.9% respectively.

3.5 Discussion

This research aimed to determine the impact of water hyacinth on aquatic plant communities, make comparisons between plant diversity of sites invaded by water hyacinth and those without water hyacinth, and therefore establish a benchmark which will provide information that will assist those involved in dealing with the impact of invasive aquatic plants and exploring methods of control in future. Specifically, this chapter examined the plant communities growing with water hyacinth in general and its influence on the composition of the biodiversity of the Wouri River Basin in particular. An assessment of the floristic inventory of the selected sites during the study revealed that 76 plant species distributed in 39 families. The main families found during the study were: Cyperaceae, Fabaceae, Rubiaceae, Convolvulaceae and Poaceae. This shows an increase in diversity compared with a previous study carried out in 2003 which recorded 72 plant species distributed in 34 families, with a dominance of the families Poaceae, Cyperaceae and Asteraceae (Njiokou 2004). The increase in number of species and families can be attributed to the increase in human activities in and around the selected sites over the years 2003–2014, leading then to the decrease or local extinction of some species and the appearance of other mostly invasives.

The floristic inventory in 2002 was conducted in the back pools where the fluctuation of water is not as high as in the main river, so species can find appropriate conditions for their growth. The difference in number and abundance of species recorded during these years (2002 and 2014) could also be due to the difference in conditions prevailing in these areas. In the 2002 study, most of the species were from the families Poaceae (14), Cyperaceae (9), Asteraceae (7), while for the present study, the main families were represented by Cyperaceae (6), Fabaceae (6), Rubiaceae (6), Convolvulaceae (5) and Poaceae (4). This difference in term of species represented by family could be due to the transformation of the habitat. The demographic invasion (migration) of people from one area to another could have an impact on the stability of the diversity, leading to the destruction of ecosystems in order to build houses and shops, and the increase in human activities in the environment could have raised pollution levels (high nutrient values measured during the study), as most of waste is discharged directly into the river so the species found during this current study are adapted to and respond to this disturbance.

Another explanation for the difference in terms of species between the two studies could be the impact of tide or water fluctuation and constant floods during the rainy season, although the fluctuation of water brings freshwater especially in the Wouri Basin. Considered as a natural form of disturbance in lakes, water level fluctuation has several quantifiable components, including intensity and frequency (Keddy & Reznicek 1986). According to Bornette & Puijalon (2011), water movements, caused by waves or currents, influence macrophytes in a complex way, as they affect plants both directly and indirectly. Furthermore, exposure to currents or waves can strongly influence plant growth, development and reproduction, and clonal growth. As well as tidal movement, floods are considered as disturbances, i.e. discrete and unpredictable events that cause partial or total destruction of communities (White & Jentsch 2001; Grime 2002). Indeed, Hudon (1997) observed in Lake Saint-Pierre (Quebec-Canada) that there was a strongly negative relationship between seasonal water level and percentage of emergent plant cover. Fluctuating water levels in the Great Lakes have been reported to have impacts on the surface area (Lyon & Drobney 1984) and species composition (Quinlan & Mulamootil 1987) of wetlands. The death of existing vegetation at the upper marsh edge and availability of new space in the lower fringe could favour massive invasion by opportunistic and (or) exotic species (Koch & Beer 1996).During flooding, water current contributed to the spread of silt containing seeds of water hyacinth and water lettuce, as well as offsets and ramets of water hyacinth, and animal also participate to the spread of vegetative propagule of these plants within and between water bodies (Howard & Harley 1998). As stated by Howard and Harley (1998), best conditions for growth of floating aquatic weeds result from the modification of hydrological regimes through construction of impoundments, locks and weirs, and construction of supply channels

Petit Bonanjo 1 and 2, Saint Richard, Forêt Bar (with water hyacinth), and Ecomité (site without water hyacinth) were the sites where the highest number of species were recorded. While Bonassama Vallée, Grand Baobab 1 and 2 were the sites with the lowest number of species. The variation in the number of species per sites could be explained, by the size of the different sites, but also by the similarities or differences in prevailing conditions in each of these habitats which could favour one species over another. These values suggest that these different sites are poor in species diversity. A river or site can be regarded as poor species-rich or high species-rich when the values range from 1.5 (for low species richness) to 3.5 (high species richness), although in occasional cases, these values could exceed 4.5 (Kent & Cooker 1994). The value of Simpson's index of diversity showed that Ecomite was more diverse than the other sites with water hyacinth, which means that the individuals in the community are distributed more equitably among these species (Magurran 1988); indeed, the greater the value, the greater the sample diversity as the Simpson's diversity index is a measure of diversity which takes into account both richness and evenness.

At the sites where water hyacinth was present, amongst the species which were found with a high level of abundance-dominance, three were common to those found by Priso *et al.* (2009) in their study (Douala-Cameroun) *Pistia stratiotes*, *Commelina benghalensis*, *Echinochloa pyramidalis,* whilst *Lasiomorpha senegelensis* which had as well a high level of abundance-dominance was the only common species found by Priso *et al.* (2009) and at Ecomité. At Ecomité, the main species with a high level of abundance-dominance are *Cyrtosperma senegalense* (*Lasiomorpha senegelensis*), *Nephrolepis undulata* (Afzel.) J. Sm. (Nephrolepidaceae), *Alchornea cordifolia, Rhynchosia mannii* (Bak) (Fabaceae), *Dalbergia* sp. (Fabaceae) and *Dioscorea* sp. (Dioscoreaceae).

The main difference between the two types of habitats (with and without water hyacinth) is the presence of invasive plants other than water hyacinth which are not floating but rooted, and therefore water hyacinth cannot compete with them. This difference can also be translated through the floristic composition of the different sites, and through the abundance (ACFOR scale) of the species found in each of these sites. Moreover, compared to sites invaded by water hyacinth, the vegetation at Ecomite is more diverse, with a high abundance of each species.

All the sites with water hyacinth, with few exceptions, had the same composition in term of species. Furthermore, at these sites, other free-floating plants were not found, with the exception of water lettuce and *Lemna paucicostata* which are floating, while *Ipomoea aquatica*, and *Nymphea lotus* are not truly floating, but attached and were found only sparsely. And yet, where these species were found, the invasion of water hyacinth in this area might prevent them to establish, especially because of the growth system of water hyacinth which covers the surface of water depriving the watercourse of oxygen and light. Although all these species are floating or attached, in terms of biological form, water hyacinth is more competitive than the above-mentioned species and the way it invades a habitat is more aggressive, finally out-competing other free-floating species. A study carried out by Coetzee *et al.* 2005 on the impact of the biocontrol agent *Eccritotarsus catarinensis* (Carvalho) (Heteroptera: Miridae), a sap-feeding mirid, on the competitive performance of water hyacinth, *Eichhornia crassipes* showed that in the absence of herbivory, water hyacinth was 23 times more competitive than water lettuce, but only 10 times more competitive when exposed to mirid feeding. A possible explanation is that the leaves of water hyacinth form a canopy that out-shades other species as Howard and Harley (1998) observed in the Democratic Republic of Congo and southern Sudan in the case of the grass *Vossia* sp. which was expelled from its preferred habitat by water hyacinth mats. Indeed, various studies in other countries showed that water hyacinth at the beginning of its invasion co-existed with other aquatic species, but as it expanded, it completely eliminated these other species from the habitat, especially species of the genera *Pistacia* and *Sesbania* (Little 1975).

At all the sites with water hyacinth, the percentage cover of the watercourse was high (up to 95%) with healthy and luxuriant mats, especially at sites such as Petit Bonanjo 1 and 2, Foret Bar, Saint Richard and Grand Hangar. In these areas, the mats formed a monospecific population which was sometimes interrupted by the presence of the other species like *Commelina benghalensis, Adenia gracilis, Scleria sp.* and *Ipomoea aquatica*. Yang & Nakagoshi (2004) noticed that, in Shanghai, wherever water hyacinth was found, it formed a monospecific population, preventing the establishment of other plants. Indeed, apart from water hyacinth, three 'categories of formation' were observed along the Wouri estuary: the first formation was composed of trees which either were present in the river before the invasion by water hyacinth, or had grown since water hyacinth had already become established; the next formation was composed of plants growing or completing their life cycle on top of water hyacinth mat, and the third formation was of plants found along the edge of the river. Almost similar to this study, sixty-three species were found growing on mats of water hyacinth in Louisiana (southern of USA) among which 33 were aquatic, 21 wetland, and nine terrestrial (Penfound & Earle 1948). Herbaceous plants and shrubs are usually found in the littoral zone of lakes because of the opportunity offered by the floating mat, depending on its size and integrity (Adams *et al.* 2002). If these plants reproduce by seed, they germinate and may complete their life cycle on floating mats (Adams *et al.* 2002).

Additionally, water hyacinth mats block the sunlight and oxygen exchange and hence prevent the growth of immersed and submerged plants (Brendock *et al.* 2003). A study carried out on the impact of water hyacinth in the Guadiana River Basin (Spain) (Tellez *et al.* 2008) showed that, except for a few species such as *Phragmites communis* Trin. (Poaceae), *Typha latifolia* L. (Typhaceae), *T. angustifolia* L. (Typhaceae), *T. domingensis* Pers. (Typhaceae), *Echinochloa crus-galli* L. (Beauv.) (Poaceae) which were abundant, the free floating species as *Lemna minor* L. (Araceae), *Azolla filiculoides* Lam. (Azollaceae), macrophytes as *Cerathophyllum demersum* L. (Ceratophyllaceae), *Potamogeton crispus* L.

(Potamogetonaceae) and *P. natans* L. (Potamogetonaceae) were less abundant, although under the conditions which prevails in the Wouri Basin, these submersed plants do not grow. Water hyacinth grows so quickly that it completely eliminated these associated aquatic species from the habitat. Except for the species such as *Alchornea cordifolia, Alternanthera maritima, Echinochloa pyramidalis* and *Rhynchospora corymbosa* L. Britt. (Cyperaceae) which were present in both the habitats, the habitats rich in water hyacinth are poor in diversity, while the habitat without water hyacinth is rich in diversity, completely different from sites with water hyacinth. In Yunnan (China), regional authorities have noticed a decrease of more than 60% of aquatic plant diversity in the Lake Dianchi since the introduction of water hyacinth; that is, the species diversity decreased from sixteen macrophytes species in 1960 to three in 1990 (Jianqing *et al*. 2000; Chu *et al.* 2006).

Water hyacinth cannot compete with other invasive rooted species like *L. senegalensis, N. undulata* and *Cyperus* sp. because the primary factor that promotes the development and proliferation of water hyacinth is the availability of open water. The more free and open a river is, the more it offers favourable conditions for the establishment of water hyacinth, especially when there are no other floating species. Although *E. pyramidalis* was found in almost all the sites, especially at Forêt Bar, it was noted that the progress of water hyacinth forced *E. pyramidalis* out which suggests the domination of *E. crassipes* over *E. pyramidalis.* Unfortunately, despite some studies which were done in the Wouri-Basin in respect to the impact of water hyacinth on the composition of water and to spatial distribution of *P. stratiotes* in some aquatic ecosystems of the city of Douala, no study has been carried out on the floristic composition before the appearance of water hyacinth, especially for the sites infested by water hyacinth today, so a comparison in terms of biodiversity is impossible. Even if the abundance of aquatic macrophytes is fundamentally influenced by turbulence (wind and wave action) (Sculthorpe 1967), it is also dependent upon the lake's chemical and physical properties, including the amount of light available, water levels, temperatures, types of lake bottom sediments, current or wave action, and the concentration of dissolved gases and nutrients (Smith 1982). As shown in Figure 3.5, the group formed by different sites could be explained by their affinity to each environmental variable recorded during the sampling. So, temperature alone impacts Petit Bonanjo 1, Petit Bonanjo 2 and Ecomité, Grand Hangar and Forêt Bar; at the other extreme, Centre Equestre correlated mainly with nitrate and pH. Bonassama Vallée, Grand Baobab 1 and 2 correlate with ammonium, salinity, conductivity and TDS. The high level of the variables do not really influence the presence of species at Saint Richard and

Château. Ecomite is an outlier because there is no water hyacinth there. So, the health of water hyacinth mats and their proliferation in these different areas, as well the establishment of other invasive species at Ecomite, could be explained by the constant availability of nutrients which come from the waste of houses, the slaughterhouse, and from societies located around the sample sites, all of which drain their waste in the river.

The different physico-chemical parameters recorded in each of these sites are favorable for water hyacinth growth. For the sites with water hyacinth, the physico-chemical parameters correlate with the optimal parameters for water hyacinth growth found by François (1970), and Berg (1961), whilst at Ecomité, the average of temperature was 27.7 °C, pH 6.83, TDS 148.5 µS/cm, CND 209.42 µS/cm, salinity 102.98 µS/cm, nitrates 0.72 mg/l and ammonium 1.72 mg/l. Almost the same values of CND were recorded by (Bini *et al.* 1999) who found that conductivity between 36 and 260 µS/cm supports massive growth of macrophytes.

Similar studies carried out by by Nguelo (2007) found that, under the Wouri Bridge, at Bonendale and Bekoko located in Douala IV, CND was between 40 and 498 µS/cm, pH between 5.17 and 6.70 and finally NO_3^- between 6.4 and 38.4 mg/l. Later, the Watershed Task Group (WTG 2012) found that the value of pH recorded in the different estuaries of the Wouri Basin varied between 6.33 and 6.65, with a conductivity between 60.70 and 958 µS/cm, Ammonium between 0.02 and 1.2 mg/l (Petit Bonanjo, Crique Lobe, Crique Bipele, Bona Eloka and fishing Port). Another study carried out by Priso *et al.* (2009) in Bonendale and around Bonaberi showed that the pH value was between 6.3 and 6.6, CND between 226 and 309 µS/cm, and Ammonium between 0.6 and 15.6 mg/l and nitrate between 9 and 25.1 mg/l. These high values of nutrients enlightened the fact that nothing has changed over the time, but that the level of pollution increases continuously.

As stated by Terry (1991), where these elements (nitrogen, phosphorus and potassium which are mostly important for the growth of water hyacinth, and secondly calcium, magnesium, sulfur, iron, manganese, aluminum, boron, copper, molybdenum and zinc) occur at excessive levels (especially in eutrophic water) uptake by weeds can be beneficial; but under normal conditions their removal may limit growth of other species.

This variation in values according to each site could be explained by the fact that the major sources of pollution of the Wouri Basin are located downstream of the industrial zone, and the dynamics of the watercourse which bring freshwater (movement of tides, current, waves), together with the anthropogenic activities of human beings downstream, distribute organic pollution through the sites located upstream of the Wouri Basin where the condition of the habitat is more favourable for the proliferation of aquatic species such as water hyacinth and *L. senegalensis.*

The different analyses to correlate the environmental variables and the biological data, showed that pH and ammonium were strongly correlated with the species found in different sites. This could be explained by the fact that, although the oxidised form of nitrogen in the river is nitrate (Cronck & Fennessy 2001), aquatic plants show a preference for nitrogen in the form of ammonium rather than nitrate (Nelson *et al.* 1980).

3.6 Conclusion

As this study is the first one, there was no clear support for a considerable difference in overall species diversity at sampling sites covered by the plant when compared to non-covered sites. Although we cannot present clear proof for this, these differences could, to some extent, be caused by the significant difference in physical and chemical variables of sites. The physical presence of water hyacinth blocks sunlight and oxygen exchange and hence prevents growth of immersed and submerged plants (Brendock *et al.* 2003); as a result, submerged macrophytes are scarce or absent in the lake, while floating species dominate the macrophytes community in the littoral zone of the lake (Brendock *et al.* 2003). Although water hyacinth remains a problematic plant with huge impact on the biodiversity, other invasive plants were found at Ecomité might have had an equal impact on native biodiversity.

Therefore, although it is evident from this study and others that water hyacinth negatively impacts aquatic biodiversity where systems are disturbed in terms of water quality and hydrology, removal of water hyacinth is unlikely to result in a restoration of indigenous biodiversity, but rather create an opportunity for invasion by another species. So, as an attempt of restoration of these ecsystems, an integrated management plan that involves all the actors located along the tributaries is important. This will consist to sort out the pollution coming into these different tributaries, and to a certain extent their monitoring.

Moreover, as this study was the first one to take in account the diversity associate with water hyacinth, further studies involving more sites without water hyacinth should be carried out in order to follow up any changes in biodiversity in these ecosystem.

4 Chapter 4. Socio-economic and health impacts of water hyacinth on riparian communities in the Wouri-Basin (Douala, Cameroon)

4.1 Introduction

Infestation of the watercourses by invasive alien species (IAS) has drastically caused ecological and economic loss and harmed society (Sala *et al.* 2000). Water hyacinth mats have caused huge financial losses directly (navigation, fisheries, etc), and have severe environmental impacts affecting ecosystem structure and functioning which, in turn has led to the loss of biodiversity or unique habitat (Chapter 3) (Da Fatima 2013). Estimating the economic cost of controlling water hyacinth infestation depends on the cost of control. The success of different methods varies according to of the cover of infestation and accessibility of the area and estimates must include the cost of equipment and frequency of treatment (Villamagna *et al.* 2010).

Although it is recognized that invasive species have increased impacts on economies and people's livelihoods, there is relatively little further assessments of these impacts. The most published figures are certainly the work by Pimentel *et al.* (2001) who estimated the most directs costs caused by pest and invasive pathogens. In their study on "The Socio-economic Links between Invasive Alien Species and Poverty" Perrings *et al.* (2005) took into account these costs in relation to agricultural GDP (Gross Domestic Products) of these countries in 1999, and demonstrated that the impact of invasive species is considerably more severe in developing countries than in developed countries. This study has estimated that damages caused by IAS can represent up to 50 % of the Gross Domestic Product (GDP) in developing countries (31 % in UK, 48 % in Australia, 53 % in USA) and exceed 100 % of PIB in some emergent countries like India (78 %), South Africa (96 %), and up to 112 % in Brazil (Anonymous 2007; Hytec & Mary 2007).

The main impacts of water hyacinth can be classified as economic, social and environmental. The dichotomy of socio-economic impacts which are associated with invasive species were reported by Villamagna *et al.* (2010) who stated that as much as there are benefits and costs that result from the presence of water hyacinth, there are also benefits and costs in preventing, managing or eradicating the species, including the ecological impacts of all these actions. The invasion of water hyacinth into freshwater systems presents a problem for many human uses, especially for developing countries that do not have the resources to control the invasion, further, the estimation of human distress to these communities in monetary terms is often not available (Charudattan 2001).

According to Binimelis *et al.* (2007) and Zavaleta *et al.* (2001), two types of impacts can be identified according to the livelihoods of riparian populations along infested water bodies. The ecological impact includes the direct impact of invasion on ecosystem functions and on human wellbeing, and the social impact that refers to indirect impacts which stem from the implementation of response actions such as control costs or the side effects of the introduction of biological control agents. Both types of impacts are important for a good decision-making process, although the distinction between them is not always easy (Binimelis *et al.* 2007).

The socio-economic impact of water hyacinth also depends on the different uses of the water-course; the more the water body supports human use, the greater the socio-economic impact will be (Villamagna *et al.* 2010). Thus, the impacts will be noticed in terms of the changes of prices in the market, or in the change in ecosystem services such as access to water and fishing (Akpabey 2012). The change in the market price will be driven by the decrease of wildlife, especially in fisheries and aquaculture products, so the scarcity or disappearance of certain kinds of fishes leads to an increase in the price of available fish in the market; the decrease or unavailability of water for industrial purposes, and the clogging of navigation in the local rivers or lakes leads to a rise of price in transportation; the loss of water quality leads to the increase of costs for water treatment. Finally, the reduction of the aesthetic value of the river leads to the decrease of tourism and recreational activities for people (Ciruna *et al.* 2004). These environmental consequences can also be translated into socio-economic impacts when they influence the ability of the ecosystem to provide goods and services for people (Reaser *et al.* 2007). According to De Groote *et al.* (2003), the utilitarian value of the ecosystem to its inhabitants can be assumed to be much larger than other values, and therefore, can be ignored without much of loss of precision because their impacts are not noticed directly or take a long time to be noticed. However, in some cases, the mats of water hyacinth can lead to the death of riparian communities through starvation because they are prevented from reaching food sources and protein because there are no longer any fish (Navarro & Phiri 2000) and even to the abandonment of entire villages (Mbati & Neunschwander 2005). There is a danger that the if socio-economic impact in certain areas goes unnoticed for a long time, and no action is taken, the damage may increase over time, as a result of synergistic biological or economic interaction (Parker *et al.* 1999; Villamagna *et al.* 2010), and any management action must take into account the stage at which the biological invader was introduced (Holmes *et al.* 2009) (Figure 4.1).

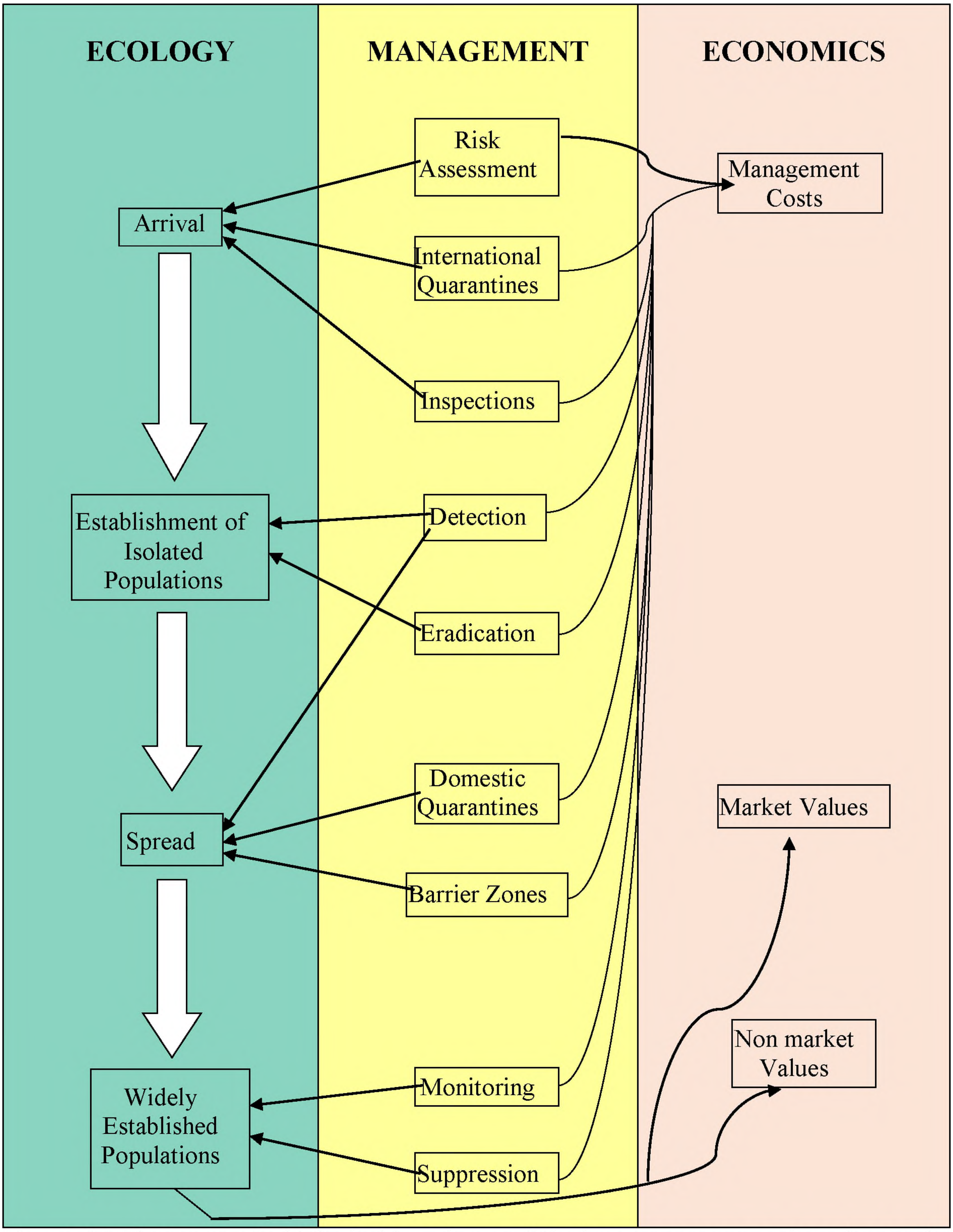


Figure 4.1 The stages of a biological invasion are linked to management actions that can be applied at each stage; each of these management actions has economic implications (Source: Holmes *et al.* 2009).

Even though it remains difficult to estimate them, the potential impacts of the introduced weed should be quantified (Ciruna *et al.* 2004), in view of the loss these impacts cause to different activities and in different countries, but also to determine what the benefits of control was. Several studies (Table 4.1) have attempted to do this.

Table 4.1 Evidence of economic impacts of water hyacinth (modified after Wise *et al.* 2007).

Study	Economic impact	Estimated degree and cost of negative impact	Country
Agriculture and environnent			
Massifwa *et al.* (2001)	Marked reduction in the abundance and diversity of micro-invertebrate	Negative impact	Northern Lake Victoria, Uganda
Mailu (2001)	Loss of water supply for domestic, stock and agricultural purposes	US$0.35million per annum	Uganda
Wise *et al.* (2007)	Loss of species richness, diversity and abundance	Significantly negatively impacted	South Africa
Chikwenhere *et al.* (Undated A)	Impact on the amount of agricultural products sold	50%	Zimbabwe
Transport			
Chikwenhere *et al.* (undated A)	Impact on transport time	50% (increase)	Zimbabwe
De Groote *et al.* (2003)	Impact on household income from trading food crops	17 %	Benin
Wise *et al.* (2007)	Palm wine collectors using river for transport	Decreased productivity by 14%	Central African Republic
Mailu 2001	Maintaining clear passage for ships to dock	US$3–5 million per year	Uganda
Fishing			
Joffe & Cooke (1997)	Impact on fishing yields	40–50%	Nigeria and Malawi
Mailu (2001)	Loss of local fisheries	US$0.2 million per year	Uganda
Mailu (2001)	Decrease of three types of fish especially *Oreochromis*, *Clarias* and *Mormyrus*	14%, 37 % and 59 % respectively	Kenya

De Groote *et al.* (2003)	Total economic loss from fishing per year	64.1 %	Benin
De Groote *et al.* (2003)	Total economic loss from fish trade	24 %	Benin
Chikwenhere *et al.* (Undated B)	Impact on fishing yields	30 %	Zimbabwe
Wise *et al.*(2007)	Gill net fishing	Decreased catch by 26 %	Central African Republic
Wise *et al.*(2007)	Fish and Wildlife losses	Decreased productivity of fisheries	6 S.E. States of USA and Uganda
Infrastructure			
Mailu (2001)	Clogging of the hydroelectric power at Jinja	Cleansing (US$1 million per annum)	Uganda
Mailu (2001)	Loss of water supply	Increase of the price of m^3 (from $0.02 to $1.6)	Uganda
Opande (2002)	Blocking of the Dunga water intake point	Reduction of 25% to the Kisumu Municipal Council water supply	Lake Victoria
Wise *et al.* (2007)	River weir	Washed away due to pressure from water hyacinth	Nseleni River, South Africa
Wise *et al.* (2007)	1 to 5 turbines of hydropower generation dam closed	Metal surfaces corroded due to build-up of sulphur dioxide under a water hyacinth mat	Kafue River, Zambia
Human health			
Mailu (2001)	Malaria	Decrease in incidence of 35%	Uganda and Kenya
	Typhoid	Decrease in incidence of 64%	
Wise *et al.* (2007)	Malaria	Increase in vector borne disease	Uganda
Masifwa *et al.* (2001)	Bilharzia	Increase of the two gastropod vectors *Bulinus* and *Biomphalaria*	Uganda

One of the often under-evaluated impacts of aquatic weeds is human health. Studies conducted by Masifwa *et al.* (2001) in the northern part of Lake Victoria, Uganda showed an increase in the incidence of bilharzia patients, according to the reports provide by the medical centre around the lakeshore. They also noticed the abundance of two gastropod vectors in the water hyacinth root mats, *Bulinus* and *Biomphalaria*, which were a serious health hazards to the lakeside communities, particularly to the fisher folk and those who have regular contact with the water-body. A report from World Health Organization (WHO) (1985) and a study carried out by Ntiba *et al.* (2001) showed that in the tropical countries, water hyacinth contributes to the increase schistosomiasis/bilharzia in the population, a disease which afflicts 83 million people globally.

4.2 Objectives

4.2.1 General aim

The aim of this study was to evaluate the socio-economic and health impacts of water hyacinth in the life of riparian communities in the Wouri-Basin (Douala-Cameroon) and the methods they use to control it.

4.2.2 Specific objectives

The specific objectives were to estimate the impact of this weed on the income and health of the riparian populations and also the costs and benefits of management actions.

4.3 Materials and methods

4.3.1 Study site

The Wouri River Basin was described in detail in Chapter 2. The population living along the Wouri River Basin thrive on the natural resources supplied by the basin and derive many benefits from this area where fisheries, sand extraction, tourism, aquaculture, logging of mangroves are the main activities.

Since its identification in this basin in the late of 1990s, water hyacinth has grown rapidly and has already covered more than 14 000 ha (WTG 2011). The areas most affected by water hyacinth are the districts of Dibombari, Fiko, Douala I, Douala IV, Douala V and Yabassi (WTG 2011; Cho Mujingni 2012). Along the Wouri Estuary, the sub-divisions chosen for this survey as mainly impacted by water hyacinth were Douala I where most people are involved in sand extraction and transport; Douala IV because of people living along the areas infested by water hyacinth and where all the study sites for this work were located. Most of the healthcare personnel interviewed were also from in this area. Douala V as the main activities were fishing and sand extraction, and Dibombari where the main activity is fishing.

4.3.2 Questionnaire design and data collection

Using the method of simple random sampling, 100 survey questionnaires were administered to different people living around the selected areas. Selection of the respondents was based on stratified random sampling, the towns are the strata and in each stratum (town) simple random sampling was employed to select 100 respondents based on the type of house (from well built to shacks) in order to get the different categories representing the society. Stratified sampling ensures that an adequate number of respondents are gained for each subgroup of interest. This also helps to ensure that a representative sample is achieved. The size of a sample is an important element in determining the statistical precision with which population values can be estimated. In general, increased sample size is associated with decreased sampling error. The larger the sample, the more likely the results are to represent the population (Dattalo 2008).

Each respondent was chosen randomly and entirely by chance, such that each respondent had the same probability of being chosen at any stage during the sampling process. The main study expanded the scope to cover in four of the five sub-divisions of the Wouri division and 25 sampling points representing these respective villages and quarters were chosen to conduct the face to face questionnaires; indeed, the way in which questionnaires were administered either by self-completion, or interview can influence the responses as indicated by several studies (Lyons *et al.* 1999). So four questionnaires were administrated per sampling pont with Douala IV which has 13 sites (Centre Equestre, Grand Hangar, Bonassama Vallee, St Richard, Bonendale, Petit Bonanjo, Grand Baobab, Sodiko, Ngwelle, JPS, Foret Bar, Bonamatoumbe), Douala V with eight sites (Bonamoussadi, Terminus Bonamoussadi, Mbangue, Mbanguecarriere, Bonangang, Denver, Ancien Auberge, Bonangando), Douala I three sites (Akwa Nord, Deido beach, Bonamouang) and Dibombari with one site (Bonaloka).

The questionnaire administered for the research focused especially on the areas or sub-division which were infested by water hyacinth, and it consisted of the three following sections, with the third part divided in 7 sub-parts (see Appendix A1). The first part consisted of six questions about individual characteristics: respondent's gender, age, occupation, status and for how long they had been living in the infested area. The second part focussed on information concerning the plant for example: did they know the plant, could they describe it, what the origin of the plant was, and what were the different activities which were carried out in the area before the invasion by water hyacinth. The third part was about how the plant affects their life, their activities; it questioned the nature of impacts (financial, social and/or health problems), the different uses of the plant, the impact of the weed on other plants which were in the river, the solutions adopted by the population to manage the plant and the estimated costs of doing this; the monthly average income from the different activities during the period with and without infestation by water hyacinth, in order to estimate the impact of the weed on these different activities.

Beacsuse the study carried out by Masifwa *et al.* (2001) on the impact of water hyacinth on the abundance of macroinvertebrates showed that the floating root mat of water hyacinth increased the incidence of the two vectors *Bulinus* and *Biomphalaria* of Bilharzia, we assumed that an investigation of small healthcares centre located in areas where water hyacinth proliferates should also helps to understand the impact that water hyacinth might have on the health of riparian communities, but also to add more weight to the responses which were given by the respondents during individual interviews. All the responses or data (record per disease) given were analysed anonymously. Beside, healthcare staffs were also interviewed to gather their opinions about the connection between water hyacinth and disease if there was any. The questions asked were related to the main diseases recorded in the clinic, the number of patients registered per disease and the age group most affected. In case the healthcare was present in the area before the appearance of water hyacinth, question was asked on whether there had been any change from before, to after water hyacinth infestation, whether in their opinion the fluctuation of these diseases could be related to the presence of water hyacinth in the area. They were also asked to give their own perception of the impact of water hyacinth on their lifestyle and to what extent, if any, water hyacinth had been responsible for increase of diseases.

To reach the objectives, individual interview and focus groups discussions were also conducted. Questions used in the both questionnaires were collected from different literature sources and were adjusted to conform to the study objectives.

4.4 Data analysis

The data collected during the survey were recorded using the CSPro4.1 software and were then imported and analysed using the SPSS software (Statistical Package for Social Sciences) version 20. Two sets of data analysis were carried out: a descriptive and statistical analysis. The descriptive part was based on information from the qualitative survey (gender, age, status) and was used to analyse the characteristics of the respondents and their perception of the weed. The descriptive statistics include:

4.4.1 Frequency

Frequency was used to illustrate the demographic characteristics of the sample population, It was also used to look if the characteristics of the sample population were similar or not.

4.4.2 Cross-tabulation

A cross-tabulation analysis was used to identify a relationship between the demographic characteristic of the sample population and their answer about the first notification of the presence of water hyacinth in the area and therefore find if there was any correlation between the answer.

4.4.3 Multiple response tests

Multiple response tests were used to analyse all the data which were given by the respondents together and therefore help to provide frequencies and percentage of each response option by the total number of response and by cases. The statistical analysis was used from the quantitative survey data. To state if there was a significant difference between the periods where water hyacinth was not yet present in the area and now that it is present, some statistical analyses were done. All the data were tested at the significant level of p=0.05 (5%).

4.4.4 t-Test

The independent t-test was used for testing the differences between the means of two independent groups.

4.4.5 Analysis of variance

The difference among subdivision regarding their activity and number of riparian community involved in these activities, as well as the impact on their income toward the introduction of water hyacinth were analysed using an analysis of variance (ANOVA).

4.4.6 Chi-square test

The single-variable chi-square test compares the observed frequencies of categories to frequencies that would be expected if the null hypothesis were true. The chi-square statistic was calculated to compare the observed values (with water hyacinth invasion) against the expected values (before water hyacinth) for each of the data and examining the differences between them and therefore to determine whether there is a significant difference between the two variables.

4.4.7 Levene's test

The Levene's test was used to test if whether the invasion of the watercourse by water hyacinth has an impact on the sand extraction activity and therefore confirm if the data had equal variances or not.

4.5 Results

4.5.1 Characteristics of the respondents

Of the 100 people interviewed in the four water hyacinth-infested sub-divisions which make up the Wouri-Basin (Douala I, Douala IV, Douala V, Dibombari), 68.3% (68) of the respondents were men, and 31.7% (32) were women. Of the respondents, 93.1% (94) were older than 25 years, and 6.9% (7) were under 25 years old. Of the male respondents, 71.01% (49) were married, while 28.99% (20) were not. Among married men, 75.51% (37) of them had one wife, while 24.49% (12) had two wives. Of the 32 women interviewed, 75% (24) were married, while 25% (8) were not married. The number of children per family varied from one to twelve with the highest number of respondents having between two to four children (78.57 %). The high number of male respondents could be explained by the fact that activities like fishing, sand extraction, and transport along the Wouri-Basin are carried by men. Twenty-four respondents were fishermen, nine respondents were involved in sand extraction and three were involved in the transport (Table 4.2).

Table 4.2 Biogeographical characteristic of the population living in the Wouri-Basin per sub-division

Gender		**Male**				**Female**			
Sub-division		**Douala I**	**Douala IV**	**Douala V**	**Dibombari**	**Douala I**	**Douala IV**	**Douala V**	**Dibombari**
Age of the respondents	<25	2	2	1	0	0	0	1	0
	>25	7	31	23	3	3	20	7	1
Marital status		6	25	16	2	3	14	6	1
Fishermen		6	8	5	3	/	/	2	/
Sand Extractor		/	2	7	/	/	/	/	/
Transportation		1	/	2	/	/	/	/	/
Total number of respondents (N)		9	33	24	3	3	20	8	1

64 respondents were house owners (63.4%) i.e. had their own house in the area, while 30 (29.7%) were leaseholder, and seven (6.9%) lived with a parent (Figure 4.2). With reference to the number of years spent by the respondent in the area, 25.7% (26) of the respondents were present in the area for less than five years, 25.7% (26) between 5-10 years, while 28.7% (29) were present in the area there between 10-15 years and 19.8% had lived there for more than 15 years ago (Figure 4.2).

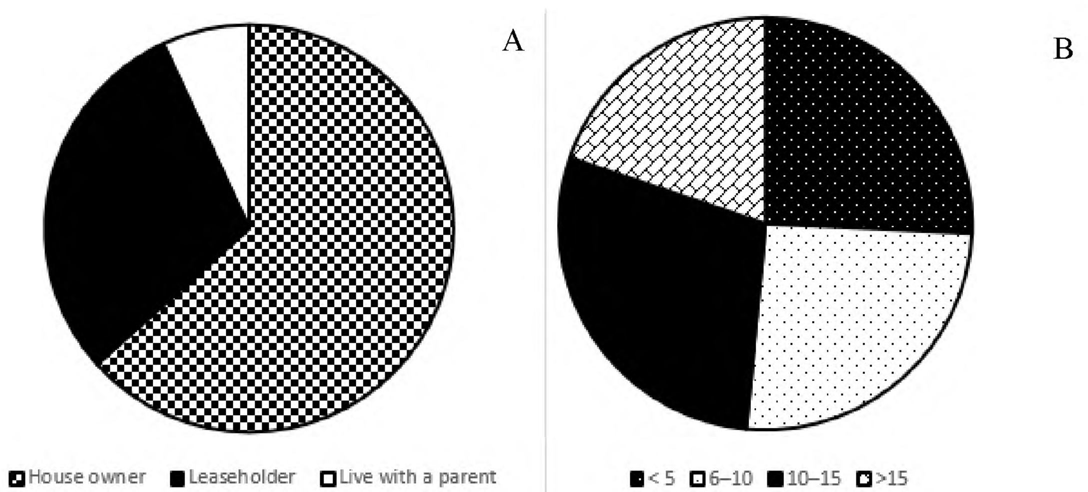


Figure 4.2 The accommodation status of the respondents (A) and the number of year spent in the area investigated (B).

4.5.2 Knowledge of water hyacinth invasion by riparian communities living along the Wouri-Basin

93 (92.1%) of the respondents were aware of the existence of the invasive alien species and especially water hyacinth, and described the plant as a floating aquatic plant (22.8%), with beautiful flowers (41.6%), large green leaves (18.8%) with a long petiole (6%), which when it grows, forms a dense mat (11%). Among these respondents, 55.4% did not know where the plant originated, while of those who knew where it came from, 15.8% stated that the weed came from neighbouring countries and continents (Nigeria, USA, and Europe). Of those asked about the introduction of the weed, 48.5% believed that the weed was introduced by men and 26.7% stated that the weed was brought by the boats which regularly land in the Douala Port. Only few of them, 8.9% said that the weed was washed down the river.

A cross-tabulation between the number of years the respondent spent in the area and the first notification of water hyacinth in the area showed that the answers were connected. The first notification of the plant in the area by the respondents depended on the number of years they had spent there. So, respondents that had lived in the area for only a short time could only respond that the weed had been there as long as they had noted it; so a better indication was those who had been there longer than 10 years who had noted an increase in infestation over that time (Table 4.3). indeed, a significant relationship between the number of years spent in the area by the respondent and how long water hyacinth had been present was found ($\chi^2 = 9.557$; $p = 0.02$).

A multiple response test on the distribution and spread of water hyacinth in the areas surveyed showed that, according to the answers given by the respondents, water hyacinth is mainly found along the Wouri-Basin in the river/streams (91%), followed by the ponds (67 %), the wetlands (30%) and finally the lagoons (7%). Further, when the weed invades an area, its method of spreading is to invade the whole water course (80%), while it can also spread at the edge of the river/lake (58.4%) or as a heap/tuft (42.4%) (Figure 4.3).

Table 4.3 Cross-tabulation of the number of years spent by the respondents in the area and the first notification of water hyacinth.

			When was water hyacinth first noticed in the area		Total
	Years		**Less than 10 years ago**	**More than 10 years ago**	
Number of years spent in the district	**< 5**	Count	21	5	26
		% within year	80.8%	19.2%	100%
	6-10	Count	18	8	26
		% within year	69.2%	30.8%	100%
	10 – 15	Count	16	13	29
		% within year	55.2%	44.8%	100%
	>15	Count	0	20	20
		% within year	0%	100%	100%
Total		Count	55	46	101
		% within year	54.5%	45.5%	100%

Chi-square: $\chi^2 = 9.557$; $p = 0.02$

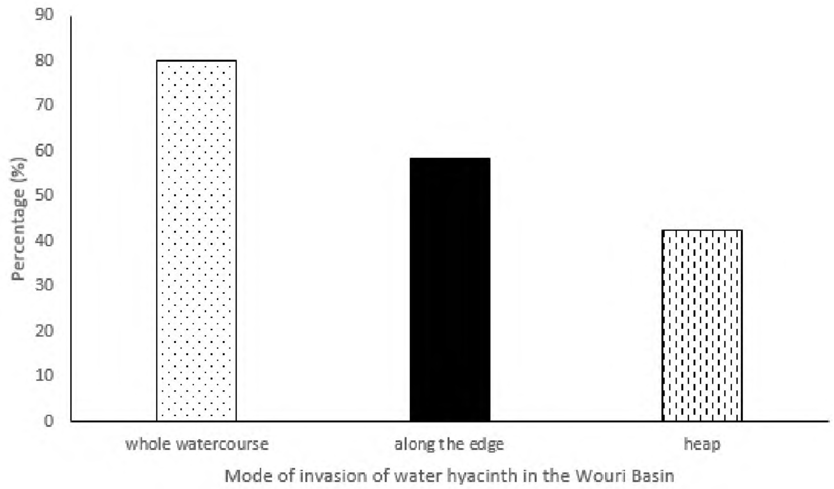


Figure 4.3 Respondent's view on the mode of invasion or dispersion of water hyacinth along the Wouri-Basin.

According to the respondents, activities which were regularly performed along the Wouri Basin before the appearance of water hyacinth were: fishing (83.2%), transport (46.5%), sand extraction (39.1%), mangrove exploitation (9.6%), looking for shells (8.4%) and agriculture (6%). However, the invasion of the waterways by this plant has interfered in their activities, especially fishing which decreased to 76.2%, transportation (35%) and sand extraction (35.6%), while activities like looking for shells, mangrove exploitation and agriculture were not as severely impacted by water hyacinth invasion (Figure 4.4). Furthermore, the weed mats made these activities very difficult to be executed and affected the quality of water for domestic use by changing the odour, taste and colour. The presence of water hyacinth blocked the watercourse, and, at the same time navigation, reduced fish species, clogged fishing gears, had an impact on the quality and quantity of sand, and finally caused siltation and water loss.

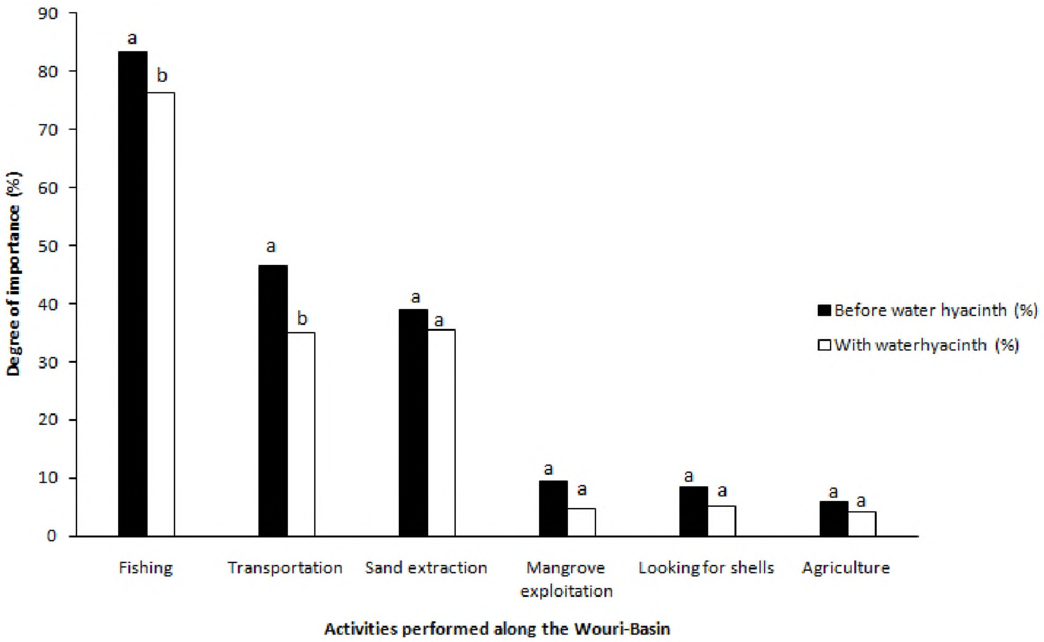


Figure 4.4 Impact of water hyacinth in the different activities performed along the Wouri-Basin before and with the appearance of water hyacinth. (For each activity, when the letter is different, it means that there is a significant difference, $p<0.05$).

4.5.3 Impacts of water hyacinth on the economic activities related to the riparian communities living along the Wouri-Basin

As noted earlier, the main activities carried out in the Wouri-Basin are fishing, sand-extraction and transportation from one area to another. The impact of water hyacinth on these different activities before and after the appearance of water hyacinth was quantified at different levels (social, environmental, economic) in order to understand how much of a problem the weed is or not. Specifically it was to determine what has changed in their life and communities since the appearence of water hyacinth, or what where the activities that they used to do before and that they could no longer do with the presence of water hyacinth.

4.5.3.1 Impact of water hyacinth on fishing activity

The results recorded from the 24 fishermen interviewed showed that the age group mostly involved in the fishing activity was between 25 – 35 years, excepted at Bonassama and Centre Equestre where the age group involved in fishing was between 15 – 25 years old as they were fishing for home consumption, while in the others areas they were fishing for commercial purposes. Women were also involved in this activity especially in Bonangang (Douala V) (Figure 4.5).

Figure 4.5 Pictures of fishermen involved in their activity.

According to the answers given by the respondents, the main district where fishing was carried out before the appearance of water hyacinth was Douala V with a total of 234 fishermen, Douala IV with 186 fishermen, Douala I (42) and finally Dibombari with 27 fishermen (Table 4.4). However, since the invasion of the water course by the weed, results show a decrease of at least 67.8% of the number of fishermen in the area surveyed, with respectively 103 for Douala V, Douala IV (54), Douala I (12) and Dibombari (7) fishermen.

As for the number of fishermen, Douala V was the first district where the highest quantity of fish were caught weekly before the appearance of water hyacinth, followed by Douala IV, Douala I and Dibombari, although a decrease of 66.7% was noticed in a quantity of fish caught after the appearance of water hyacinth (Table 4.5). There was a significant difference between the number of fishermen involved in fishing activity before and after the appearance of water hyacinth (Table 4.4).

Table 4.4 Number of fishermen involved in fishing activity before and with the appearance of water hyacinth in the different sub-division. (Standard deviation)

Sub-division	Age group most involved	Number of fishermen			
		Before water hyacinth		During the peak of water hyacinth	
		Total	Mean±(SD)	Total	Mean±(SD)
Douala I	25-35	42	7±0.68	24	4±0.45
Douala IV		186	31±3.50	54	9±3.67
Douala V		234	39±4.16	102	17±1.71
Dibombari		27	4.5±0.34	12	2±0.45

(F_{Before} (3, 20) = 39.43, p= 0.00000138; p< 0.5) ($F_{With\ water\ hyacinth}$ (3, 20) = 10.63, p<0.000215; p<0.5)

There was a significant difference between the quantity of fish caught by riparian communities involved in fishing activity before and after the appearance of water hyacinth (Table 4.5).

Table 4.5 Mean weekly fish caught per fisherman involved in fishing activity before and with the appearance of water hyacinth in the different sub-division.

Sub-division	Age group most involved	Mean of fish caught (Kg)			
		Before water hyacinth		During the peak of water hyacinth	
		Total	Mean±(SD)	Total	Mean±(SD)
Douala I	25-35	54	9±0.63	18	3±0.37
Douala IV		150	25±6.51	54	9±2.48
Douala V		450	75±9.92	150	25±1.83
Dibombari		48	8±2.5	12	2±0.26

(F_{Before} (3, 20) = 27.89, p= 0.00000027; p< 0.5) ($F_{With\ water\ hyacinth}$ (3, 20) = 46.72, p=0.0000000321; p<0.5)

Before water hyacinth invaded the area surveyed, 50% of fishermen used to go fishing four times a week, 30% going every day, while 20% used to go there three times a week. Now, with the presence of water hyacinth, 42% went fishing three times a week, while 29% went fishing four times a week and the same percentage every day. The number of day they go fishing has decreased because they cast their net and come back days later to check because the fish are so rare.

In addition to the decreased number of fishermen in the sampled areas, the appearance of water hyacinth in the sampled areas has also caused the decrease in the average income from the fishing activity. This decrease in the income is noticeable in some areas located at Douala IV especially at Bonassama, Centre Equestre, where people no longer fish, or if they do, just occasionally (Table 4.4 and Table 4.5). The income that the fishermen make depends of the type, size and quality of fish that they catch. Unlike the retailers who sell fish by weight, fishermen usually sell their product by the basket. So, before the invasion of water hyacinth, the price for a 5 Kg basket of fishes like catfish (*Clarias* sp.), Mallay (*Trichochus senegalensis*),Yenda (*Chrysichthys nigro-digitatus*) and Nile perch (*Lates niloticus*), was 8000 Fcfa (US$16), 7500 Fcfa (US$15), 8500 Fcfa (US$17) and 10 000 Fcfa (US$20) respectively; but since the invasion of water hyacinth the increase in demand which is related to the exponential growth of the population, coupled with inflation (due to the international market price) and the general increase in price of everything, the price for the same basket of fish has increased and is now 15 000 Fcfa (US$30) for catfish, 13 000 Fcfa (US$26) for Mallay, 18 000 Fcfa (US$36) for Yenda and 20 000 Fcfa (US$40) for Nile perch. When the fish is smoked, five small fish cost 1000 Fcfa (US$2), while 5 big fish cost 3000 Fcfa (US$6). Although, the fish that are caught are usually sold on the same day, with the decrease in biomass of fish caught, people can retain a certain quantity of fish which can be taken to the market later and can therefore give them more income. The fish are kept in the fridge, in a basket near the shores in the water, or just smoked. The steep drop in the quantity of fish caught is also due to the fact that the fishing methods used are still traditional: nets, traps, fishing rods, arrows. Fishermen have never used chemicals. Therefore, for those who are still involved in fishing, the techniques that they have developed to increase their catch consist of buying more nets (5 to 15 per years), and increase the number of traps which leads to longer than usual stays in the river. Among problems that fishermen have is the rainy season when heavy rain makes it difficult to fish, and sometimes prevent them going out altogether.

Table 4.6 Mean weekly income per fisherman before and with the appearance of water hyacinth per sub-division.

Sub-division	Mean weekly income (Fcfa)			
	Before water hyacinth		During the peak of water hyacinth	
	Total	Mean	Total	Mean
Douala I	180 000	30 000±2886.75	30 000	5000±288.67
Douala IV	174 000	29 000±4932.89	36 000	6000±516.40
Douala V	255000	42 500±9287.08	54 000	9000±1949.36
Dibombari	195 000	32 500±2813.65	3000	5000±1095.44

(F_{Before} (3, 20) = 1.204, p= 0.334; p> 0.5) ($F_{With\ water\ hyacinth}$ (3, 20) = 2.679, p = 0.0746; p<0.5)

Whether before or during the invasion of watercourses by water hyacinth, there is not a significant difference in the income by fishermen in each of the districts, while comparing the period before the appearance of water hyacinth and after the invasion by water hyacinth, a significant difference was recorded in the weekly income of population involved in this activity ($F_{(3, 20)}$ = 89.883, $p<0.05$). This difference in the income could be explained by the fact that the amount of fishes that they used to catch has decreased, and sometimes after they have casted their nets, they will wait for days before having fish for the lucky fishermen or will not catch what they can sell on their market.

Nevertheless, fish can be sold by weight, and according to the quantity and quality of fish, the price varied between 1000 – 2000 Fcfa (US$ 2-4) before the appearance of water hyacinth; now, water hyacinth, and the difficulties that the fishermen faced during their activity, the price of fish per kg has increased from 1500 to 3500 Fcfa (US$3 to US$8). In fact, since the invasion of the watercourse by water hyacinth, the size of fish has been reduced. Furthermore, the species of fish caught has also changed. Before the appearance of water hyacinth, Carp (*Cyprinus carpio*), Yenda (*Chrysichthys nigro-digitatus*), Tilapia (*Oreochromis niloticus*), Mallay (*Trichochus senegalensis*), Catfish (*Clarias* sp.), Mud fish (*Parachanna obscura*), Capitaine / Nile perch *(Lates niloticus*), and to a lesser extent barels / Moudjamoto (*Barbus* sp.), crabs and prawns were readily caught. However, even if some of these fish are still present in the area, their numbers have decreased, while in others areas, prawns and crabs have disappeared. As a positive impact of the presence of water hyacinth, 29.2% of the fishermen mentioned the presence of a fish called Cameroon or Kanga (*Heterotis niloticus*) which appeared with the water hyacinth mats and which, according to the fishermen, feed on water hyacinth.

Among the 24 fishermen interviewed, six are no longer fishing as their main activity, because it is no longer profitable, and have found work as technicians in some dockyard, or are traders or drivers.

4.5.3.2 Impact of water hyacinth on sand extraction

Sand extraction is an old activity which has taken place along the Wouri-Basin for many decades. Two types of sand extraction can be distinguished: the first kind is the most common and the more dangerous method for the sand extractor. It involves the immersion of the sand extractor deep into the river to get the sand; and the second method is carried out along the edge of the river, or after a heavy rain. In some quarters, extraction involves between three and seven people, with several boats. In contrast to fishing which is carried out by women in some areas, sand extraction is strictly reserved for men. Compared with fishing, most people involved in sand extraction are between 25 and 35 years old (average 27). Nevertheless, young men under the age of 24 years can be found doing this activity (Figure 4.6).

According to this study, the areas where the highest number of sand extractors were found were Bonamouang, Mbangue Carriere, Bonangang in Douala V which harboured the biggest sand depot in the city of Douala (Table 4.7 and Figure 4.7). The number of sand extractors, remained highest in Douala V, but has dropped overall since the appearance of water hyacinth in the region. The area most affected by the appearance of water hyacinth was JPS in Douala IV where they no longer practised sand extraction because of the invasion of the whole river by water hyacinth (Table 4.7 and Figure 4.7).

Figure 4.6 (A)Picture of youths involved in the sand extraction and (B) sand depot in Douala V.

Table 4.7 Mean number of sand extractors for the areas before and after the appearance of water hyacinth.

Sub-division	Area	Age group	Mean number of sand extractor	
			Before	**After**
Douala IV	JPS	15-25	20±2.04	2±0.41
	Bonendale	15-25	20±4.56	2±0.71
Douala V	Bonangang	25-35	110±4.56	90±4.56
	Bonamouang	25-35	120±2.04	100±2.85
	MbangueCarriere	25-35	100±3.53	80±7.35
	Terminus Bonamoussadi	25-35	90±3.53	60±4.56
Total			**460**	**334**

Levene's test: $F_{(1,10)} = 0.53$, $p = 0.823$

The number of sand extractors has also decreased as old people have departed and were replaced by fewer new sand extractors or because members of the group have deserted. Moreover, the decrease in the number of sand extractors can also be explained by the various problems that they encounter during their activity such as snake attacks, fouling and blockage of the boat motor by water hyacinth which is time-consuming and therefore costly; skin and others kinds of diseases, and drowning.

Before the invasion of the watercourse by water hyacinth, up to 15 sand boats (1 sand boat = 6 m^3, up to 90 m^3), were extracting sand each week from the river at Mbangue Carriere (Douala V) while today, after the invasion, this number has decreased to the point of abandonment in some areas investigated, namely JPS in Douala IV (Table 4.8).

The decrease in the quantity of sand extracted and the number of sand extractors in Douala V can be explained by the fact that, because of water hyacinth mats, sand extractors need to go further (main channel of the Wouri River) to carry out their activity, or sometimes they go to other areas to look for new sand extraction jobs which are more lucrative. This is the case for the Mungo Division which has a very big depot as a result of the increasing demand due to the demographic explosion and development of various construction projects in and around the Littoral Region (Table 4.8).

Table 4.8 Areas investigated for sand extraction before and after the appearance of water hyacinth.

Sub-division	Area	Mean quantity of sand (number of boats) extracting per week			
		Before		After	
		Boat	m^3	Boat	m^3
Douala IV	JPS	2±0.58	12	0±0	0
	Bonendale	7±1.08	42	4±0.71	24
Douala V	Bonangang	12±2.86	72	11±1.29	66
	Bonamouang	14±2.45	84	12±1.22	72
	MbangueCarriere	15±2.04	90	12±1.41	72
	Terminus Bonamoussadi	10±2.04	60	8±1.08	48
Total		**60**	**360**	**47**	**282**
Note: 1 boat = 6 m^3					

Levene's test: $F_{(1, 10)} = 0.022$, p= 0.885

Levene's test for equality of variances was found to be violated for the number of sand extractors, $F_{(1, 10)} = 0.53$, p = 0.823, as well as for the quantity of sand extracted before and during water hyacinth invasion (Levene's test: $F_{(1, 10)} = 0.022$, p= 0.885). Owing to this violated assumption, a t-statistic test not assuming homogeneity of variance was computed, so no significant variation was found in the number of sand extraction and the quantity of sand extracted either before or during the invasion of the watercourse by water hyacinth.

When conditions are good and especially during the dry season, the activity can be carried out every day, up to three times a day without problems, but this is not the case during the rainy season (end of June until September) where the activity can be done up to four times a week and twice a day as a maximum. During the rainy season, the tides are too high and the fluctuation of water brings mats of water hyacinth down the river, decreasing the amount of sand that can be extracted during this period of the year. The decrease in supply, together with the risks and difficulties of working conditions, increases the price of sand.

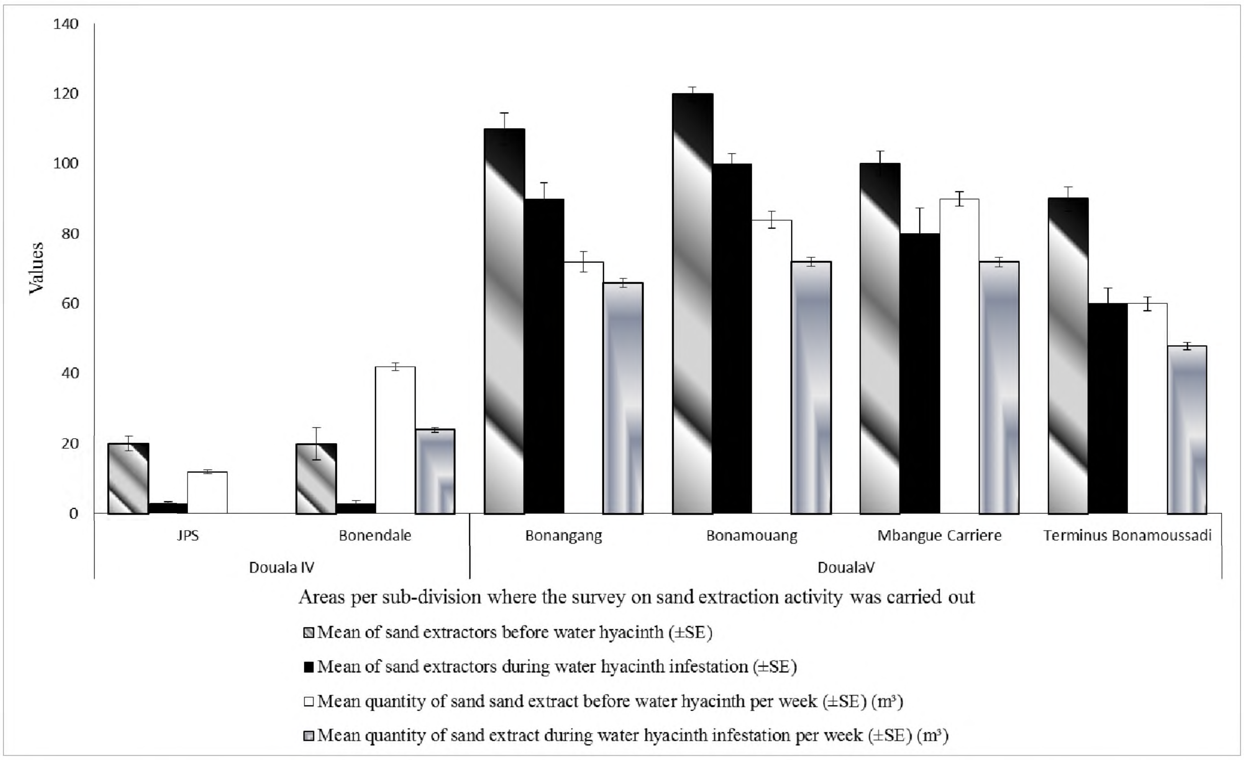


Figure 4.7 Sand extraction activity including the number of sand extractors and quantity of sand extracts in the sampled districts per areas before and after the invasion by water hyacinth.

Classified in three categories which are soft, soft-sharp and sharp sand, sand is sold directly from the collecting point to the buyers who come with trucks to collect it, and its price depends on the quality or type of sand, and the quantity (wheelbarrow or truckload). Trucks may carry loads of 20 T or 25 T (Table 4.9). Although the number of sand extractors and the quantity of sand extract has decreased, the price of sand has increased several times with the invasion of water hyacinth. As the respondents stated, the increased price of sand on the market is due, first of all, to the increase in the price of fuel on the national market; secondly to the difficulties of sand extraction activities.

Table 4.9 Average price of sand (Fcfa) and US$ before and after the appearance of water hyacinth

Quality of sand	Prices (Fcfa) before the appearance of water hyacinth			Prices (Fcfa) after the appearance of water hyacinth		
	Wheelbarrow	Truck 20 T	Truck 25 T	Wheelbarrow	Truck 20 T	Truck 25 T
Soft	500 (US$1)	15000 (US$30)	20000 (US$40)	800 (US$1.6)	25000 (US$50)	30000 (US$60)
Soft-sharp	600 (US$1.2)	18000 (US$36)	25000 (US$50)	1000 (US$2)	28000 (US$56)	35000 (US$70)
Sharp	700 (US$1.4)	22000 (US$44)	28000 (US$56)	1200 (US$2.4)	30000 (US$60)	40000 (US$80)

4.5.3.3 Transportation

Riparian communities are called "people of the water" because their lives are so closely bound up with the river and their lifestyle and livelihoods depend upon it. Transportation using river was for a long time the only way for the riparian communities living along the Wouri-Basin to reach the town (Douala) or others villages. Roads were poor and not tarred, and sometimes non-existent especially during the rainy season, so most families living in these areas owned at least one row boat that they could use to move from one area to another, and rarely paid for transportation across the river. However, when they had to go to town to sell their goods in the market, they paid for a motor boat which, before the invasion of water hyacinth, was cheaper and very fast. But since the invasion of water hyacinth, the cost of motorboat transport has increased, not only because of the presence of water hyacinth, but also because of the increase in the price of fuel on the market and the cost of living as well. Thus, water hyacinth has had an impact on the activity of transportation as the number of motorboat owners has decreased, followed by the number of clients.

Of the three people interviewed who were still involved in water transportation, two of them work at Bonamouang (Douala V) and have carried out this activity for more than 10 years; while the person interviewed at Mbangue (Douala V) started transportation five years ago. Whether before or after the invasion of the watercourse by water hyacinth, the destination where they usually went to remained the same: Akwa-Nord, Bodiman, Bonangang, Yassem, Djebale, and Bonaloka, Lendi and Tonde. However, Lendi and Tonde are no longer destinations: at Lendi, water hyacinth has invaded the whole watercourse forcing the riparian community to use land transportation, while at Tonde, people now prefer to travel by road as it is tarred and shorter. Transportation was efficient and well-organized, before the spread of water hyacinth. Before the spread of water hyacinth, the transportation was provided four times a week and now just twice a week and sometimes less, as a result of both water hyacinth invasion and the lack of clients. Nevertheless, the boat can still be hired for some activities or occasions like funerals, races, traditional events in a particular area. People, goods and occasionally sand is transported across the river from one area to another, and during funerals, the coffin is also transported. The amount of fuel used is the same with an average of 60 litres and the price of transportation is given according to the destination of the clients, so the further destination, the higher the price. Thus, according to these estimates, riparian transportation operators lost income even though they increased the price of transportation. Cost of transportation according to the distance where the client was going to, was comprised between 1500-2500 Fcfa (US$3-5) per person, while now with water hyacinth, the cost varied between 2500-4000 Fcfa (US$5-8).Concerning the cost for the transport of goods, a price was given to the client according to the quantity of luggage that he had; so for this, the price varied between 500-2500Fcfa (US$1-5), which is almost the same actually with the presence of water hyacinth, the price varying between 500-3000 Fcfa (US$1-6). In fact, along with the problems they face with water hyacinth, boat owners sometimes have to change their route to reach the village. So when they manage to overcome all these situations, the drivers noticed a loss of income of around 100 000 Fcfa (US$2000) for some months especially during the rainy season.

Albeit, fishing, sand extraction and transportation were the main activities impacted by water hyacinth, other (supplementary) activities carried out by riparian communities were found to be also impacted by the presence of water hyacinth. These activities included: trade, mangrove exploitation, agriculture, wood exploitation and sale of land (Table 4.10). A significant difference was noticed in term of populations involved in these activities before and after the invasion of water bodies by water hyacinth.

Table 4.10 Others economic activities performed by the riparian communities and percentage of population involved in these activities before and after water hyacinth invasion.

Sub-division	Area	Number of respondents	Other economic activities	% of population involved	
				Before	After
Douala I	Deido beach	2	Mangrove exploitation	30	10
Douala IV	Bonamatoumbe	1	Mangrove exploitation	35	10
	Bonendale	4	Trade / agriculture	40	25
	Bonassama	2	Mangrove exploitation / trade	45	15
	Centre Equestre	2	Agriculture	25	10
	Ngwelle	1	Trade	20	10
	Sodiko	3	Mangrove exploitation	35	15
	Bonangando	2	Sale of land	25	10
Douala V	Denver	2	wood exploitation	20	5
	Mbangue Carriere	1	Sale of land	40	15
Dibombari	Bonaloka	1	Mangrove exploitation	50	30

$F_{before\ (3,\ 10)} = 2.368$, $p = 0.139$; $F_{with\ water\ hyacinth\ (3,\ 10)} = 5.769$, $p = 0.018$

4.6 Environmental impacts

Among different environmental impacts caused by water hyacinth, are loss in term of biodiversity, degraded water supply, siltation, regular flooding and indirectly health problems.

4.6.1 Biodiversity

Water hyacinth's rapid growth has led to the extinction some plant and animal species (Chapter 3). Infestations reduce the light in the river and therefore reduce the oxygen. During the survey, the riparian communities stated that before the appearance of the water hyacinth, there were many fish and plants present in the river in good quantities, but with the presence of water hyacinth, some plants have disappeared, while both the size and the quantity of fish have decreased, and, in some areas, crustaceans have also disappeared (Table 4.11).

Table 4.11 Situation of some fishes, crustaceans and plants before and after water hyacinth infestation in areas surveyed according to responses given by respondents interviewed (=↘ Decreased).

Biodiversity		Situation before and after		Place where it has disappeared
		Before	After	
Fish	Catfish (*Claria* sp.)	Very Good quantity	↘	Bonassama, Centre Equestre, Ngwelle
	Tilapia (*Oreochromis niloticus*)		↘	
	Mud fish (*Parachana obscura*)		↘	Bonassama, Centre Equestre, Ngwelle
	Carps (*Cyprinus carpio*)		↘	
	Yenda (C*hrysichthysnigro digitatus*)		↘	Bonassama, Centre Equestre, Ngwelle
	Nile perch (*Lates niloticus*)		↘	
	Moudjamoto (*Barbus* sp.)		↘	Bonassama, Centre Equestre, Ngwelle
Crustaceans	Prawns	Good quantity, especially during dry season	↘	
	Crabs		↘	
	Gambas		↘	
	Crayfish		↘	
Plants	*Ageratum conyzoides*	Present	Endangered	
	Sissongho (*Pennisetum purpureum*)	Present	Disappeared	All the areas surveyed
	Nympheae lotus	Present	↘	
	water lettuce (*Pistia stratiotes*)	Present	↘	Bonangang, Bonaloka

Some of plants which have disappeared and are no longer present in water hyacinth-infested areas had medicinal value (Table 4.12)

As water hyacinth out competes some plants, there are others which appear or grow easily with it, such as *Echinochloa pyramidalis* and *Commelina benghalensis*, making the mat tighter and providing a good shelter for snakes, crocodiles, mice, mosquitoes and some species of crabs which live under the mat and which are not suitable for consumption. To some extent, water hyacinth has some positive impacts even if they cannot be quantified. Its positive impacts include the fact that it can be used as a fodder crop for pigs and chickens as raw materials for crafts such as making chairs and hand bags; as a fertilizer (compost) for agriculture, and occasionally as medicine plant to threat fever and typhoid.

Table 4.12 Name of plants which disappeared with water hyacinth infestationin specific areas and their medicinal value according to the respondents and correlated with publication from (Jiofack *et al.* 2010). Species in bold are those which were classified as invasive in Cameroon in the last report from the MINEPDED (*).

Name of plants	Use in traditional medicine
***Ageratum conyzoides** (King of herbs)	Fever, painful kidneys, antibiotic, stomach ache, headache, poisoning, quick delivery, gastritis, haemorrhoids
Eremomastax speciosa	Generalised pains, dermatitis, tiredness
Solenostemon monostachus	Blood, fever, ease child birth, frontal headache
Ocimum gratissimum (Massepu)	Gastritis, fever, frontal headache, constipation, conjunctivitis, gum disease
Cassia alata	Expels worms, worm diseases, eyes, fever, quick delivery, yellow fever, haemorrhoids, ringworm, mycosis, typhoid
Chromolaena odorata	Fresh wounds, diarrhoea, malaria
Nymphaea lotus (white lotus)	Depressant, treatment of male sexual disorders
Pistia stratiotes	Cough

4.6.2 Water quality and quantity

Water quality, like biodiversity is impacted by water hyacinth proliferation, and in the Wouri Estuary, its impact on water is more profound as some villages still rely on water from the river for laundry, bathing, and cooking especially at Bonangang, Bonaloka, Bonendale, Bonamtoumbe and Sodiko. Before using water for cooking and drinking, villagers first boil it or expose it to the sun for some hours on top of the roof. When they want to bathe, they remove or push away the plant if it has invaded where they usually bathe; otherwise they look for a new place. In other areas, water from the river can no longer be used as it is totally covered by water hyacinth, leading to change in the colour and taste of water which becomes dark, highly polluted, and skin irritation. With the proliferation of water hyacinth, water in these areas can no longer be used; the river has become a dustbin for every kind of waste. In addition, most of the toilets are on stilts and the waste falls directly into the river. In the case of modern houses, the drainage systems flow directly in the river making water unusable (Figure 4.8). Inhabitants, who live close to the town, rely on water from wells or use water from the national drinking water dispenser (Camerounaise des Eaux (CDE)).

Figure 4.8 (A) Drainage systems of the house falling into the river and (B) toilet builds in water hyacinth mat.

As most of the areas investigated are located close to the sea, or in the swampy area, flooding is part of the inhabitants' life, especially during the rainy season and during high tide. On average, floods occur around 35 times per year. The study was carried out during the rainy season (July—September), and the floods were regular. The riparian communities also say that the floods are caused by the waste and water hyacinth which have blocked the normal flow of water. During the floods, and especially those associated with rain, almost all the households are affected with an average of 40 houses per areas, and the lost encountered are estimated between 20 000 Fcfa to 40 000 Fcfa (US$40—US$80). These lost can be in term of electronic devices, and others equipment in the house.

Agriculture is not the main activity for the riparian communities living along the Wouri Basin, and for those involved in farming, they have their farms either behind the house or close to the riverside. Farming pollutants are organic (such as chicken dung and compost) rather than industrial, chemical fertilizers.

4.6.3 Health

The impact of water hyacinth on health was also investigated. As mentioned earlier, water hyacinth mats provide a breeding-grounds for vectors of diseases like mosquitoes which cause malaria and lymphatic filariosis, and snails which cause bilharzia (schistosomiasis)

(Buzzle 2011, Calvert 2002). A multiple-response analysis of the diseases which are regularly encountered in the areas investigated revealed that malaria (98%) and typhoid (65%) are the main diseases that affect people, followed by filariasis (27%), cholera (6%) and in very rare cases schistosomiasis (bilharzia) (2%). Others diseases that were also listed, were diarrhoea, yellow fever, scabies and coughs due to the humidity.

As in every tropical country, mosquitoes are present in these areas, and since the appearance of water hyacinth, 79% of respondents stated that the number of mosquitoes had increased. The majority (64%) of respondents maintain that the water hyacinth mats have increased the prevalence of diseases especially malaria, while for 34% the presence of water hyacinth had not changed. The remaining 2% did not know. In areas with vegetation, snakes and crocodiles have become common (51%) since appearance of water hyacinth, which was not the case before. As snakes have become more common, they are killed on sight and so snakes-bites have become less frequent.

Self-medication using drugs bought from informal traders is the common means of treatment for the riparian communities. The treatment of cholera can cost an average of 10 000 Fcfa (US$20), typhoid 15 000 Fcfa (US$30), malaria 7000 Fcfa (US$14), filariasis and schistosomiasis 5000 Fcfa (US$10) each. But when referning to a doctor in a hospital for treatment the cost increases; thus the cholera is around 50 000 Fcfa (US$100), including fees for hospitalization. For typhoid, the average cost is around 35 000 Fcfa (US$70), while for malaria is around 30 000 Fcfa (US$60) and for filariasis 20 000 Fcfa (US$40).

Malaria is the most common disease affecting riparian communities, with an average frequency per member of a family or household being between twice and six times per year. On average, a family member can suffer from typhoid twice a year, a frequency that may be under-reported because these cases are diagnosed after medical examination; many patients may have the diseases without knowing. Cholera is rare, certainly not as common as malaria, and there are families which have never had a case of cholera. However, during an epidemic, the disease spreads quickly from one area to another one, and especially when rules of hygiene and recommendations are disregarded, and can kill within just two days. According to the riparian communities, case of schistosomiasis specially was rare and sometimes they don't know what it is. Of others diseases recorded, diarrhoea was the most problematic with an average of five times a year.

To compare or to add more value to the responses given by the riparian communities, epidemiological data relevant to incidence of human diseases were obtained from some of the health care centres located in the area investigated, especially in Douala IV where six care centres were surveyed and four in Douala V. Of the ten centres surveyed, two respondents (20%) did not know water hyacinth, while 80% confirmed that they knew water hyacinth. According to the diseases recorded, all the health care centres reported to have received patients suffering from malaria (10), eight health care centres had treated typhoid and diarrhoea, cholera (3), filariasis (3), schistosomiasis (2), scabies (7), stomach pain (5), cough (6) and amoebic dysentery (8) (Figure 4.9).

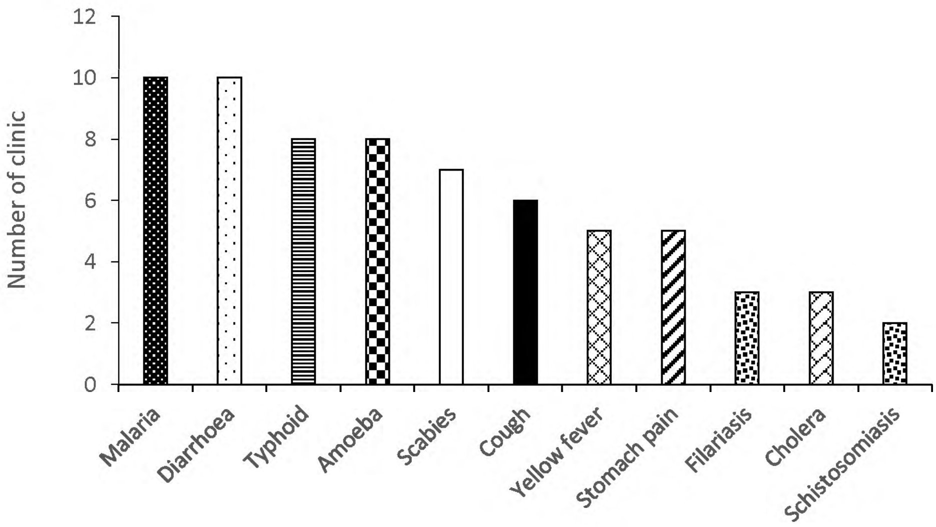


Figure 4.9 Main diseases recorded according to each health care centres.

Of patients who came to the health care centres, the highest number is represented by women with an average of 30%, followed by children 28%, teenagers (22%) and men (20%) (Figure 4.10). Most of these patients suffer from malaria (56%), 32% from typhoid, 8% from filariasis. For diseases related to water quality like diarrhoea or gastro-intestinal disorders, an average of 26% patients are recorded per year in these health care centres. The age group most affected by various diseases differs: for malaria, the people most affected are between five to 24 years old with most of the cases recorded being children from five to ten years old.

The age group most affected by typhoid varies between 10 years to more than 25 years, with a majority of patients being older than 25 years (60%), while in the case of cholera; the age group most affected are adolescents between 10-24 years old. Most schistosomiasis cases are recorded in patients older than 25 years, while the group most affected by filariasis is between 10-24 years. Diarrhoea appeared to be the disease must affecting children between 1-5 years the most.

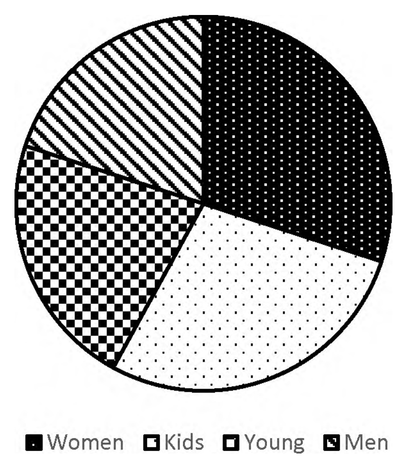


Figure 4.10 Average frequency of patients visiting the health care surveyed.

Most of the health care centres investigated were not present in the area before the invasion of water hyacinth, and therefore found the plant already well established. They believe that the increase in the number of patients during these years can be explained by the increase of the number of residents in the areas (rural exodus, the poor condition in which people live which is sometimes very bad, as most of the time they ignore rules of hygie and the drinking water from wells which is not of good quality because the distance between the toilet and the well is too close and sewage contaminates the groundwater and finally;

Health care workers, stated that, according to the data they have, the rate of patients who come in the clinic varies over the years and they cannot affirm if it is because of the presence of water hyacinth or no, however the number of paitients these last years has been constant.

4.7 Community-based control options for water hyacinth in the Wouri Basin

Amongst various methods of control employed to manage water hyacinth, manual removal remains the only way riparian communities manage the weed. The manual removal consists of 1) cutting the plant and leaving it for the water current to carry away, 2) cutting and putting it along the edge of the river or 3) cutting and burning it. Of the people interviewed, 85.40% have already attempted to manage the plant, while 14.60% have never done anything.

In some areas, populations make a plan to manage the weed once a month, or when the weed has totally covered the water surface. During this day of cleaning of the watercourse, men go into water with machetes to cut back the weed. The use of herbicides to control the plant was not mentioned during the survey, nevertheless, however sometimes (especially women), pour hot water on water hyacinth mats, or for women who cook with firewood, they toss hot ashes onto the mats.

The techniques adopted by populations (manual removal), considered in the long-term are not successful because within two weeks, the plant has started to grow again and invade the water way nullifying the effort made to clean the watercourse and so discouraging the inhabitants. According to their response's after a multiple response test, the plant rejuvenate too quickly (99%), the seeds germinate and grow very fast (13%) and finally the plant sprouts from cuttings of all its parts (24%). As they have never tried herbicides they don't know how they could work. Faced with this problem, the population really needs help to deal with the plant. Seeking advice and assistance from NGOs is one solution, but they would also like to see a commitment from the government and especially from the Ministry of Environment to solve or control this situation. 97% of the respondents would like to see the plant totally controlled and have their watercourse free from water hyacinth, as in the past, while 3% don't have a problem with the plant around them. Given that, biological control has never been applied in Cameroon, respondents wanted more information about this method of control to be sure that the introduced enemies of the water hyacinth would not bring new problems and attack their agriculture as well. So, for good management of the plant, 42% of the respondents proposed continuing with regular manual removal of the plant to solve the problem; 41% stated that if the introduction of new species to really controlled the plant without damaging anything else, that would be the best solution for controlling the plant as physical effort would not be necessary as it is with manual removal; 18% stated that chemical products should be applied.

Of the respondents, 87% did like to be involved in the process of managing the weed, whereas 13% did not see themselves involved in the process. From those who did like to be involved, the way that they contribute is to: 1) to report the occurrence of the weed (20%), 2) to cooperate with and support researchers and extension staff (31%), and 3) to help in the propagation of the method of control (35%). With the exception of, 4% who preferred to provide financial assistance if needed, the rest of the respondents were not willing to pay for IAS management. Referring to the threats posed by water hyacinth, 84% of respondents did not agree with the introduction of any new plants in the area, because in their view, those plants might take over the environment and damage the biodiversity (89%), they might bring several health problems (63%), introduce pest and diseases (58%), reduce water quality (31%), and therefore increase the cost of water treatment (8%) (Table 4.10). A small percentage of respondents (16%) were willing to support the introduction of new plants if they have medicinal value if it resulted in economic and recreational benefits; indeed, they stated that new plants might prove to be good as medicinal plant (43%) and possess aesthetic value (43%); they could be used as food for domestic animal and wild life (36%), as botanical pesticide (29%), and finally could enhance fishing (8%). Therefore, to prevent the recurrence of water hyacinth in the community, 69% of the respondents planned first of all to remove and destroy it before it spread, while 32% would prefer to report strange plants to external officers, NGOs, and district assemblies.

In the process of controlling water hyacinth, it is also important to note the efforts made by the Ministry of Environment (MINEPDED) through an NGO, WTG (Watershed Task Group) to reduce the impact of the weed on riparian communities and therefore on the water course. In 2010, MINEPDED implemented the project N°00103/M/MINEPDED/SG/DAG/SDBMM/SM/2010 based on collection, valorisation and management of waste from water hyacinth in order to control the invasion by this plant effectively. A budget of 200 000 000 Fcfa (US$400000) has been allocated to manage the plant throughout the country, in all the regions infested by the plant and others invasive aquatic species, and especially in the Littoral Region (Wouri River). The program established in the Wouri Basin, even if it is still manual, consists of a specific method called removal using the "Claw of Goliath". The NGO consists of by different teams, among which a team of 30 people (especially riparian population) working in a project, collect and valorise water hyacinth. These peoples work two weeks per month, and yet when the money is available. The budget per day of work is outlined in the Table 4.13 below.

Table 4.13 Estimated cost of manual control of water hyacinth in the Wouri Basin by WTG.

Average cost spent per working day	Budget Fcfa ($)
Salary per day of work / 30 peoples	150000 ($300)
Cost for fuel for boat and truck	25000 ($50)
Cost for fuel for truck	25000 ($50)
Cost for material	20000 ($40)
unforeseen	30000 ($60)
Total	**250000 ($500)**

Between the project launch in 2010 and December 2015, a budget of 600 000 000 Fcfa (US$1200000) was allocated to manage this scourge in three of the regions invaded (North Region, Littoral Region and Centre Region). Among these regions, the Departments involved were the Department of Wouri with the municipality of Douala IV and Douala V, the department of Moungo with the municipality of Bonalea (Fiko) in the Littoral Region, the department of Nyong et So'o with the municipality of Mbalmayo in the Centre Region, the Department of Benoue with the municipality of Lagdo in the North Region. The budget was divided as followed:

- 75 000 000 Fcfa (US$150000) for the monitoring and evaluation study;
- 140 000 000 Fcfa (US$280000) for pilot sites construction in each of these Regions, and also for the purchase of material and finally
- 385 000 000 Fcfa (US$770000) used in the collect and valorisation (bags, chairs, compost, etc) of water hyacinth and other invasive aquatic species as in the case of the North Region with Brachiara aquatica.

In 2016, 80 000 000 Fcfa (US$160000) was transferred to each of these municipalities for the management of water hyacinth in Mbalmayo, Douala IV and Douala, and the management of *Bracharia aquatica* in Lagdo.

4.8 Discussion

Various issues associated with water hyacinth impacts on the lives of riparian communities in the Wouri Basin have been highlighted and need to be addressed to solve the problem of water hyacinth infestation. Water hyacinth was reported in Cameroon and especially in the Wouri Basin in 1997 (Forpah 2009), but it could have occurred in the system at an earlier date. Indeed, the first specimen of water hyacinth found in the National Herbarium (Yaoundé-Cameroon) showed that it has been collected for the first time in the Sangha River, on 12 April 1971. Moreover, during the survey, it became clear that the plant had been present for more than 30 years in some of the areas investigated. The port of entry of this aquatic weed in the Wouri Basin is still unknown (Anonymous 2008), but it occurred there in the form of stationary thick mats covering more than two-third of the infested water courses, and along the shore of the estuary, in addition to mobile mats that are propelled around the estuary by the water current.

4.8.1 Negative impact of water hyacinth in the Wouri-Basin

The nature and extent of invasive alien species, their effects on available water resource, the threats they pose to ecological environment and the impact they have on society need to be understood to ensure the success of an integrated approach to control the spread of IAS elsewhere and especially in Cameroon. The lifestyle of human riverine and wetland communities in several countries is directed by the characteristic of water body. Research carried out around the world on the effect of water hyacinth invasion shows that these plants transform ecosystems in different ways by using excessive amounts of resource (especially nitrogen, light, oxygen and water) (Richardson & van Wilgen 2004).

It was estimated that an average of US$500 per working day was spent by the MINEPDED through WTG in the Wouri Basin using manual control. During the peak growing season of water hyacinth, riverine population and especially fishermen, sand extractors and people involved in transportation encountered a number of problems among which was an increase in the number of hours spent to carry out their activity. This estimated time was spent either cutting the weed which blocked the way, or removing shoots fouling the nets of fishermen, or simply finding an appropriate place to carry out their activities. This is because, for the riparian communities living in/around the Wouri-Basin, their main activities are related to water, like fishing, sand extraction, transportation and mangrove exploitation. They also faced the hazards of snakes, crocodiles, and hippos, which, according to reports by the riverine population, have increased as a result of water hyacinth proliferation. A finding that concurs with studies by Navarro & Phiri (2000) and Da Fatima (2013) in Mozambique in water hyacinth mat. Similar blockages and/or massive interference in irrigation and water treatment were reported in Kenya by Opande *et al.* (2004), Mailu (2001). In Lake Chivero, due to the decline of water quality, the cost of water treatment increased from 40 mg.l in 1982 of dosage of alum to 100 mg.l in 1995 (Jarawaza 1997).

As the economic capital of Cameroon, the Littoral Region is the centre of industrialization with several industries established around the Region and especially in Bonaberi (Douala IV) which is considered to be the industrial zone of Douala. Several of those industries ignore the environmental standards; and uncontrolled discharges of pollutants into the environment have been reported. These factors have opened a way to the proliferation of IAS, especially water hyacinth leading to the loss or decrease of fish diversity and quantity, to the loss of plant diversity, which were important in traditional medicine for some of the population, and other aquatic biota which were not quantified in this study. Moreover, the basin is covered by mangrove forests which are under high pressure from humans due to intensive logging. Besides, the Wouri River is also a touristic and recreational area for the riparian communities. Every year, foreigners and the population of the Littoral Region and Wouri Division especially are invited to celebrate the most important cultural ceremony organized in the Wouri River with the five tribes constituting the Sawa clan of Douala. The ceremony named "Myengu" the god of waters is held in the first week of December and which time the people thank thegods for their protection during the year. During this cultural activity, a festival named "Ngondo" is held on Saturday and Sunday; on the Sunday, spiritualist carrying a sacred pot with the gifts for "Myengu" is immersed in the river. After 10 minutes under the water, he is expected to return with a message from Myengu for Sawa people for the next year. When the pot is brought back to the surface, it is not wet and contains the message from the ancestors, which the spiritualist decodes before announcing it to the waiting crowd. In addition, a canoe race featuring the best rowers from each Sawa tribe is also organized. Over the years, the Ngondo festival has proven to be the most popular display of culture in the River Wouri in Cameroon (Fri 2010), and the presence of water hyacinth might be a threat to this cultural event given that patches of water hyacinth are regularly present in this area and need to be removed before the beginning of the ceremony.

Studies carried out by Focardi *et al.* (2006) and Luilo (2008) in Uganda reported that aquatic biodiversity had been greatly affected by some problems like sedimentation, increased turbidity, eutrophication, algal blooms, deoxygenation, reduced density and spread of submerged macrophytes, reduction in lake—shore wetland vegetation cover, increased atmospheric deposition, aquatic weed proliferation and water level changes. Barliwa (2009) reported further that urban and industrial expansion along the lakeshore has increased sewage and other effluents discharges to the lake, thus increasing nutrient loading and water pollution which doubled the biological productivity of Lake Victoria during the last three decades.

The impact of water hyacinth on plant diversity and fish plant definitely has an impact on health as it is estimated that 80% of rural population in Cameroon depend on traditional medicine and products from the sea (Anonymous 2008). In 2008, the national production of fish was estimated at 180 000 tons/year with 38 species which have been identified in

Cameroon's continental waters (Anonymous 2008). Loss of aquatic biodiversity has been attributed to: various forms of pollution, over-exploitation, habitats degradation, poor capacity building, and non-optimization of use of traditional knowledge (Anonymous 2008). In Papua New Guinea, people along the Sepik River relied entirely on water transport, and when the lakes and oxbow lagoons beside villages became chocked with *Salvinia* and later water hyacinth, villagers could no longer travel, trade, fish or harvest other staple foods. All this leading to the evacuation of people living in these villages as they started to starve (Howard & Harley 1998). The same effects were observed in the Congo, where entire villages were abandoned (Mbati & Neuenschwander 2005).

Moreover, even if officially, chemical control has never been applied in Cameroon to control water hyacinth mats, some respondents mentioned that in the 1990s, some industries in association at Bonaberi applied chemicals to control the spread of water hyacinth which was blocking their drainage canals, but unfortunately, because of deaths in some of riparian communities downstream, they stopped and nothing has ever been reported. Wherever this study was done, a decrease in quantity of fishes caught was noted and at some places, their total disappearance especially for fish like catfish, Moudjamoto and crustaceans was reported. All fish were threatened due to over fishing, use of improper fishing techniques, industrial pollution and loss of habitat (Anonymous 2008). In addition, it was also reported that siltation has had an effect on breeding, nesting and nursery grounds for inshore fish like the Nile Tilapia *Oreochromis niloticus* (Barliwa 2009). The study carried out by Chikwenhere & Phiri (2001) reported a drastic drop in fish catches from a co-operative which contemplated closure in Lake Chivero. Before the invasion of water hyacinth, the average fish catch by this co-operative was between 50—60 kg per day and today varies between 2.5—3 kg. At the same time, the presence of the weed led to a drop in revenue from ticket sale for approximately 45%. An experiment carried out it USA showed that, population of *Tilapia aurea* was found to be reduce by 50 % by a cover mat of 10-25 % of water hyacinth (McVea & Boyd 1975 in Terry 1991). In Nigeria, 24000 fishermen were affected when 500 km^2 of the coastal lagoons was invaded by water hyacinth, number which may increase to 2million if nothing is done. Similarly, fish population densities were reduced by changes in the food web resulting from shading by floating aquatic weed and by changes in water chemistry, especially availability of oxygen (Howard & Harley 1998).

Of the respondents' surveyed during the current study, 78% reported that, the main diseases recorded were: malaria, diarrhoea, typhoid, filariasis, cholera, schistosomiasis, scabies, and yellow fever. A socio-economic assessment of impacts of the sunken water hyacinth in Uganda showed that 95% of respondents reported that the weed was affecting water quality by making it muddy, contaminating it with debris, creating an unpleasant odor and changing color (Barliwa *et al.* 2009; Jarawaza 1997). In addition, the debris of water hyacinth was associated with vectors and diseases specially snails, worms, mosquitoes larvae; the most prevalent diseases being bilharzia, diarrhea, skin rash, malaria and abdominal pain (Barliwa *et al.* 2009).

Indeed Opande (2002), Mailu (2001), and Opande *et al.*(2004) reported that transmission of encephalitis, coughs and schistosomiasis were enhanced by the weed, while Masifwa *et al.* (2004), Navarro & Phiri (2000), Mehra *et al.* (1999) found that the spread of diseases such schistosomiasis and malaria, in addition to cholera and typhoid were facilitated with the presence of water hyacinth. In a similar way, on the Kenyan side of the Lake Victoria, the number of cholera cases recorded in Nyanza Province was closely associated with the annual presence of water hyacinth coverage (Feikin *et al.* 2010). These data were also confirmed by the data collected in the health care centres present in the infested areas investigated, showing the rise of these diseases especially malaria. This could be explained by the fact, since 2009, the Ministry of Public Health launched a programme to curb this disease throughout the national territory, first by distributing impregnated mosquito nets to every household in each region, according to the size of the family and the number of bedrooms in each household and secondly, distributing free "Mectizan" to every citizen to cure filarial disease.

4.8.2 Positive impacts of water hyacinth in the Wouri Basin

In addition to negative impacts on the environment and riverine communities, there are some positive impacts of water hyacinth in the Wouri-Basin with the contribution of WTG which employs local population in a small industry using water hyacinth to manufacture paper, hand bag, chair and shoes (Figure 4.11). For instance, water hyacinth despite its negative impacts is viewed as a source of income to communities and organization who get paid to control it. In the same way, the whole plant of water hyacinth is used together with cow dung to make compost or fertilizer. Water hyacinth is also used by the riparian population as animal fodder for their pigs, chickens and ducks. Similar products, and baskets are made in India for the tourists industry (Calvert 2002), and in the Philippines, Indonesia and India for the production of paper (Ndimele 2008, Ndimele *et al.* 2011).

Figure 4.11 Bag, fertilizer, paper, and chair made by the local industry at WTG.

4.9 Conclusion

The socio-economic and health impacts of water hyacinth infested sites on the life of riparian communities in the Douala, Cameroon revealed that most of the problems facing the Wouri Basin can be viewed as a result of a weak enforcement of governmental mechanisms. So appropriate measures to reduce the spread of water hyacinth and other IAS need to be introduced and implemented to ensure the stability and health of the environment. As suggested Reaser *et al.* (2007) and Binimelis *et al.* (2006) any plan to eradicate or control IAS needs to consider the potential impacts of the proposed actions and the people that depend upon them in the way that study or control will not just be a scientist's duty, but everyone's concern; so every person has the responsibility to avoid introducing or diffusing invasive species (Yang & Nakagoshi 2004).

5 Chapter 5. Fungi associated with water hyacinth in the Wouri Basin (Douala Cameroon), and their contribution to the control of water hyacinth mats.

5.1 Introduction

Biological control of water hyacinth by means of plant pathogens has gained attention because it is logical, safe, and provides favourable results in terms of environmental sustainability for a long-term solution to water hyacinth infestation and a method of managing agro-ecosystems (Howard & Harley 1998; El-Morsy 2004; Charudattan 2005; Ray & Hill 2012). The variation in the level of importance of enemies depends on two factors or scales: temporal and spatial (Center *et al.* 1999a, b). The spatial scale considers the impact of plant enemies at the level of an individual plant, a single population, or an entire community, while the temporal scale examines the short-term ecological dynamics, or the long-term evolutionary dynamics. Although enemies can have an important impact at the scale of plant populations, they might impact individuals with little resultant effect on the population. The capacity for invertebrate herbivores and pathogens to affect or suppress the fitness of the plant, leading to its decrease/death can be considered as the success of the biological control (McFayden 1998, Morin *et al.* 2006b).

Of the various pathogens that occur on water hyacinth, several phytopathogenic fungi have been successful in controlling the weed (Charudattan 1996a, b; 2001c,d), and several studies have been carried out to isolate, identify, and measure the pathogenicity of the fungi associated with water hyacinth in its native range as well as in several water hyacinth-infested areas of the world (Freeman *et al.* 1981; Evans & Reeder 2001) (Table 5.1), but not in Cameroon.

Table 5.1 Mycobiota recorded on *Eichhornia crassipes* worldwide (from Barreto & Evans 1996 in Evans & Reeder 2001).

Fungi	Distribution
Ascomycotina and Deuteromycotina	
Acremonium crotocigenum (Schol-Schwarz) W. Gams	Australia (IMI 288070[a])
Acremonium implicatum (Gilnam & Abbott) W. Gams	Australia (IMI 271067)
Acremonium sclerotigenum (F. & R. Moreau ex Valenta) W. Gams	Sudan (IMI 284343)
Acremonium strictum W. Gams	Australia (IMI 288318, 288319)
Acremonium zonatum (Sawada) W. Gams	Australia, India, Pakistan, Panama, USA, Sudan
Alternaria alternata (Fr.) Keissler	Egypt
Alternaria eichhorniae Nag Raj & Ponnappa	Egypt, India, Thailand, USA, Kenya, Ghana, South Africa, Zimbabwe
Alternaria tenuissima (Ness ex Fr.) Wiltshire	Hong Kong
Bipolaris urochloae (Putterill) Shoemaker	Egypt (IMI 324728)
Bipolaris sp.	USA, Brazil
Blakeslea trispora Thaxter	Thailand
Cephalotrichum sp.	USA
Cercospora piaropi Tharp	India, Sri Lanka, USA
Cercospora rodmanii Conway	USA, India (IMI 329783), Nigeria (IMI 329211)
Chaetomella sp.	Malaysia
Cladosporium oxysporum Berk. & Curt.	Hong Kong, Nigeria (IMI 333543)
Cochliobolus bicolor Paul & Parbery	India (IMI 138935)
Cochliobolus lunatus (=*Curvularia lunata*) Nelson & Haasis	Egypt (IMI 318639), India (IMI 162522, 242961), Sri Lanka (IMI 264391), Sudan (IMI 263783)
Coleophoma sp.	Sudan (IMI 284336)
Curvularia affinis Boedijn	USA
Curvularia clavata B. L. Jain	India (IMI 148984)
Curvularia penniseti (M. Mitra) Boedijn	USA
Cylindrocladium scoparium var. brasiliense Batista	India
Didymella exigua (Niessl) Saccardo	Trinidad, USA
Drechslera spicifera (Bainier)V. Arx	Sudan
Exserohilum prolatum K.J. Leonard & E. G. Suggs	USA
Fusarium acuminatus Ellis & Everhart	Australia (IMI 266133)
Fusarium equiseti (Corda)Saccardo	India, Sudan (IMI 284344)
Fusarium graminearum Schwabe	Australia (IMI 266133)
Fusarium moniliforme Sheldon	Sudan (IMI 284342)
Fusarium oxysporum Schlechtendal	Australia (IMI 288317)
Fusarium solani (Martin) Saccardo	Australia (IMI 270062)
Fusarium sulphureum Schlechtendal	India (IMI 297053)
Fusidium sp.	South Africa (IMI 318345)
Gliocladium roseum Bainier	Australia (IMI 278745)
Glomeralla cingulate (Stonem) Spauld & Schrenk	Sri Lanka (IMI 264392)
Helminthosporium sp.	Malaysia
Leptosphaeria eichhornia Gonzales Fragoso & Ciferi	Dominican Republic, Panama
Leptosphaerulina sp.	USA

Memnoniella subsimplex (Cooke) Deighton	USA
Monosporium eichhorniae Sawada	Taiwan
Mycosphaerella tassiana (De Notaris) Johanson	USA
Myrothecium roridum Tode ex Fr.	India, Philippines, Thailand, Burma (IMI 79771), Malaysia (IMI 277583)
Pestalotiopsis adusta (Ellis & Everhard) Steyaert	Taiwan, Hong Kong (IMI 119544)
Pestalotiopsis palmarum (Cooke) Steyaert	India (IMI 148983)
Phoma sorghina (Saccardo) Boerema *et al.*	Sudan, Australia (IMI 288313, 288311, 288312, 288315, 333325)
Phoma sp.	USA
Phyllosticta sp.	Nigeria (IMI 327627, 327628)
Spegazzinia tessarthra (Berk. & Curt.) Saccardo	Sudan 284335
Stemphylium vesicarium (Wallroth) E. Simmons	USA
Basidiomycotina	
Doassansia eichhorniae Ciferri	Dominican Republic
Maramiellus inoderma (Berk.) Singer	India
Mycoleptodiscus terrestris (J. W. Gerdermann) Ostazeki	USA
Rhizoctonia oryzae-sativae (Sawada) Mordue	Australia (IMI 289087)
Rhizoctonia solani Kuhn	India, Panama, Thailand, USA
Rhizoctonia sp.	India, USA
Thanatephorus cucumeris (Frank) Donk	China, Taiwan, India (IMI 3075)
Tulasnella grisea (Raciborski) Saccardo & Sydow	Indonesia (Java)
Uredo eichhorniae Gonzales Fragoso & Ciferri	Argentina, Brazil, Dominican Republic
Chromista	
Pythium sp.	USA

[a]International Mycological Institute isolate reference number

However, few fungi were reported on water hyacinth in its native range; so of the sixty potential pathogens cited in this list (Table 5.1), 54 are from countries where water hyacinth was introduced and considered as an invasive alien species, of which 36 are exclusively Old World such as Australia and Papua New Guinea (Evans & Reeder 2001). The remaining are from the New World, of which 18 originated from the USA, three from the Caribbean or Central America, and two from Brazil (South America) (Evans & Reeder 2001).

Of the sixty fungi reported, several have been found to be highly virulent and known to cause diseases on water hyacinth in different parts of the world (Aneja *et al.* 1993; Charudattan 1996; Charudattan 2001) (Figure 5.1). These fungi are: *Acremonium zonatum* (Sawada) W. Gams, *Alternaria alternate* (Fr.) Keissler, *Alternaria eichhorniae* Nag Raj & Ponnappa, *Bipolaris* spp., *Cercospora piaropi* Tharp. (= *Cercospora rodmanii* Conway), *Fusarium* *chlamydosporum* Wollenw & Reinking, *Helminthosporium* spp., *Myrothecium roridum* Tode ex Fr., *Rhizoctonia solani* Kühn and *Uredo eichhorniae* Gonz.-Frag. & Cif. (Charudattan 1996, Babu *et al.* 2003, Shabanna 2005).

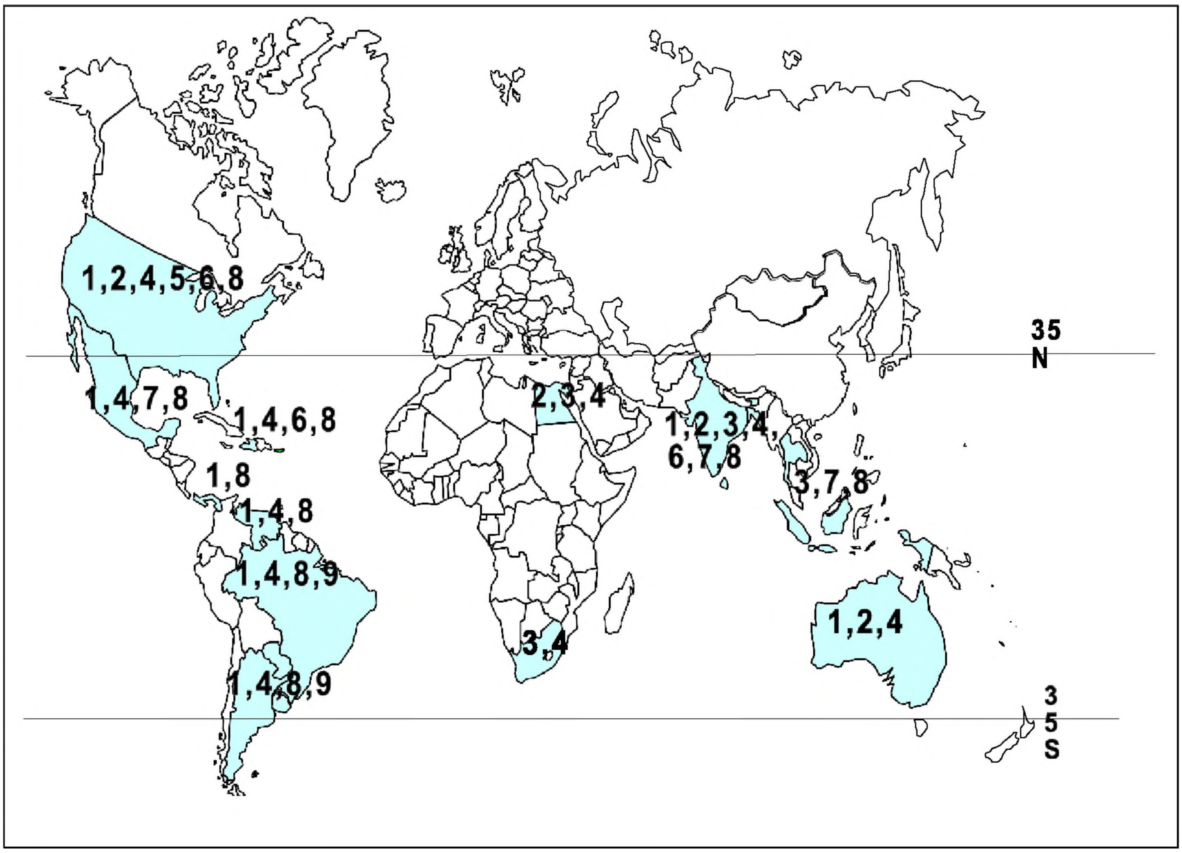


Figure 5.1 A provisional distribution map of major fungal pathogens of water hyacinth (*Eichhornia crassipes)* (from Charudattan 1996).

Numbers in the map refer to the occurrence of the following pathogens in the respective regions:

1: *Acremonium zonatum*	2: *Alternaria alternata*	3: *Alternaria eichhorniae*
4: *Cercospora piaropi*	5: *Cercospora rodmanii*	6: *Helminthosporium/Bipolaris* spp.
7: *Myrothecium roridum*	8: *Rhizoctonia solani*	9: *Uredo eichhorniae*

On the African continent, the most promising pathogens, in order of preference, for development as mycoherbicides were *A. eichhorniae, A. zonatum, C. piaropi, R. solani, A. alternate* and *M. roridum* (Bateman 2001).

Although these pathogens appear to be safely used as a mycoherbicides, some limitations were noticed by several authors (Table 5.2).

Table 5.2 A list of fungal pathogens of water hyacinth and their value for biocontrol. Adapted and modified from Gopal 1987, Dagno, 2006).

Name	Type of damage	Test of efficacy		Limitation(s) as a bio-control agent	Specificity test and degree of satisfaction	Practical use	Important references
		Green house	Field				
Acremonium zonatum (=*Cephalosporium zonatum*) = C. eichhorniae	Zonate leaf spot, often damaging to the entire lamina	Yes	No	Slow rate of disease progress; secondary spread is limited ,	Yes	Yes	Rintz 1973, Martyn and Freeman 1978, Charudattan 1984, Dagno 2006, 2011
Alternaria eichhorniae	Leaf spot and severe leaf blight	Yes	No	Requires at least 10 hours of dew to allow the applied inoculum to germinate and infect, and to colonize the weed to some extent	Yes	Yes	Shabana *et al.* 1995a,b,c, Dagno 2006, 2011
Bipolaris oryzae	Severe foliar blight	Yes	No	Pathogen lacks host specificity	Not tested	Doubt on the efficacy	Charudattan *et al.*1978, Charudattan 1984, Dagno 2006, 2011
Cercospora piaropi	Leaf spot, leaf necrosis, and general debilitation	No	No	None apparent, rate of disease progress may be too slow to afford sufficient pressure on the host	Not Tested	Yes	Tharp 1917, Freeman and Charudattan 1974, Dagno 2006, 2011

Name	Type of damage	Test of efficacy		Limitation(s) as a bio-control agent	Specificity test and degree of satisfaction	Practical use	Important references
		Green house	**Field**				
Cercospora rodmanii	Leaf spot, leaf necrosis, and general debilitation	Yes	Yes	None, rate of disease progress can be too slow in relation to the rate of host growth, resulting in lack of control	Yes	Yes	Conway 1976a,b, Conway and Freeman 1977, Conway *et al.* 1978, Freeman and Charudattan 1984, Dagno 2006, 2011
Helminthosporium bicolor	Leaf spot surrounded by yellow halo	Yes	No	Information lacking, may have potential in biological control	Not tested	Doubt on the efficacy	Charudattan 1984, Dagno 2006,2011
Myrothecium roridum	Necrotic leaf spot	No	No	Lacks host specificity	Not tested	Doubt on the efficacy	NagRaj and Ponnappa 1967, Ponnappa 1970, 1971, Dagno 2006, 2011
Rhizoctonia solani Incl. Rhizoctonia state of Corticum solani,	Foliar blight	Yes	No	Lacks host specificity	Not tested	Yes	NagRaj and Ponnappa 1967, Joyner and Freeman 1973, Dagno 2006, 2011
Uredo eichhorniae	Chlorotic and necrotic spot and pustule	Yes	Yes	Information on host specificity and efficacy are lacking	Yes	Yes	Charudattan and Conway 1975, Charudattan *et al.* 1976, 1981, Dagno 2006, 2011

The movement of an infected host is viewed as one of the principal ways in which transmission and dispersion of a pathogen occurs in a new habitat (Fuxa & Tanada 1987). Similarly, invertebrate natural enemies of the host can also disperse pathogens that it has been contaminated by during foraging (Roy & Pell 2000). On this basis, a pathogen indigenous to an area could be an ideal candidate for development as a non-classical (augmentative or inundative) biological control agent (Cuda *et al.* 2008).

Research has been carried out around the world and in some countries of West and Central Africa (Benin, Mali) (Dagno 2011) to identify promising microbial agents that might be used as bio-herbicides or combined into an integrated method of control to manage the invasion of waterways by water hyacinth. However, even if adequate research concerning the list of invasive crops and diseases was done by the MINEPDED in 2014 in Cameroon, the fungi associated with water hyacinth, as well as the role that these potential pathogens of water hyacinth might play in controlling the mat of this weed in Cameroon, has not yet been carried out.

5.2 Aims and objectives

The aims of this study were to survey, collect, identify and evaluate potential pathogens associated with water hyacinth in the Wouri Basin and, if found, determine any relationship between these pathogens and arthropods on the plants.

5.3 Material and Methods

5.3.1 Survey of habitat and sites infested by water hyacinth in the city of Douala and environs

Surveys were conducted in the city of Douala (Wouri Basin) and specifically in the ten selected sites (see Chapter 2) to gather information on the occurrence and distribution of any diseases attacking water hyacinth, during both the rainy (June–October 2014) and the dry seasons (November 2015–April 2016).

5.3.2 Assessment of the disease severity caused by the pathogens in the field

The estimate of the severity of the plant disease was made visually both for the field as a whole and for individual plants. The disease severity is the area (relative or absolute) of the sampling unit in this case the leaf showing symptoms of disease, and expressed as a percentage or proportion (Bock *et al.* 2010; Nutter *et al.* 1991).

In each of the ten sites surveyed, disease severity was measured following an interval scale which is the field key (Table 5.3) described by Anon (1947), and reported by Bock *et al.* (2010) in their paper on "Plant Disease Severity Estimated Visually, by Digital Photography and Image Analysis, and by Hyperspectral Imaging". According to Anon (1947), in Bock *et al.* (2010), field keys are a scale based on percent severity (for example, 0.1, 1.0 2.0, 5.0 %. . . 100%) and used in conjunction with a descriptive or diagrammatic portion of the scale that offers an explanation as to the likely distribution/frequency of the symptom in the field or on plants, and which field keys contain quantitative information.

The degree of the disease-damage induced by the pathogen to the plant was estimated on 10 plants per site. On each chosen plant, the total number of leaves was counted, as well as the number of daughter plants, and the number of damaged leaves per plant. The degree of damage by pathogens on each leaf was also estimated, using a 0 to 5 scale rating system: 0 = no symptoms or healthy; 1 = light; 2 = moderate; 3 = heavy, 4 = severe and 5 = highly severe (Table 5.4 and 5.5) (Ray & Hill 2012, Xu *et al.* 2004).

Table 5.3 A qualitative disease key used to estimate disease-damage by fungi on water hyacinth in the field (after Anon (1947) modified).

Rating (%)	Severity characteristics
0.0	Not seen in the field
0.1	Only few plants affected here and there
1.0	General light damage
5.0	Light damage with about 10% of leaves damaged per plant
25.0	Nearly all leaves affected, plants still in normal form and field looks green
50.0	Every plant affected and about one-half of leaf area destroyed. Field looks green flecked with brown
75.0	About three quarters of the leaf area destroyed, field looks neither green nor brown, green color coming from new and youngest leaves which escaped infection
95.0	Only a few green leaves remaining
100.0	All leaves dead, petiole dead or dying

Table 5.4 Data sheet used for the **e**stimation of the degree of damage on each plant recorded

	FUNGI DAMAGE:								
Plant	**Total number of leaves main plant**	**Number of pathogen-damaged leaf, main plant**	**Scale rating for each pathogen-damaged leaf, main plant**	**Number of daughter plants**	**Total number of leaves daughter plant**	**Number of pathogen-damaged leaf, daughter plant**	**Scale rating for each pathogen-damaged leaf, daughter plant**	**Quantification of damage on whole plant**	**Presence of feeding scars?**
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

Table 5.5 Estimation of the degree of damage per plant according to the infestation on the leaf, based on the scale rating.

Fungi damage quantification:	
0 (Healthy)	No damage
1 (Light)	1–10% of leaf area infected
2 (Moderate)	11–25% of leaf area infected
3 (Heavy)	26–50% of leaf area infected
4 (Severe)	51–75 % of leaf area infected
5 (Highly severe)	≥ 75% of leaf area infected or leaf almost dead

Using this rating system, a disease index (DI) was calculated (Bruton *et al.,* 2000; Chaube & Singh 1991) on each of the 10 plants sampled per site, per month as per observations, using the following formula:

$$\textit{Disease Index}(DI) = \frac{\textbf{Sum of all numerical ratings x 100}}{\textit{Total number of leaves measured x } 5}$$

Where the sum of all numerical ratings = (0 x N_0) + (1 x N_1) + (2 x N_2) + (3 x N_3) + (4 x N_4) + (5 x N_5); N_o = number of leaves with score 0; N_1 = number of leaves with score 1; and … N_5= number of leaves with score 5.

After the DI of each plant was calculated, a mean DI per month was calculated to have an estimate of the DI per site per month.

5.3.3 Collection of fungi associated with water hyacinth in the chosen sites

Water hyacinth leaves with disease symptoms, especially on laminae and petioles, suspected of being damaged by potential fungal pathogens, were collected from each of the sites surveyed. Samples were wrapped in layers of dry paper towelling to absorb moisture and prevent secondary microbial growth, and kept in plastic bags previously tagged with Silica gel. The bags were clearly labelled with date, collection site and sample number. All disease symptoms exhibited at the sampling site were noted. A good quantity of plant parts exhibiting each of the different symptoms was collected per sampling site and randomly. Where plants with a particular symptom were few, the maximum number available were collected. The samples were then taken to the laboratory in South Africa for isolation. The different methods used for the purpose of this work were identified as part of the methodology for isolation and pathogenicity testing used by Elwakil *et al.* (1989), El-Morsy (2004), Mohan Babu *et al.* (2002), Dagno *et al.* 2011, and Ray and Hill (2012).

5.3.4 Isolation of pathogens

Stored diseased leaves of water hyacinth were washed thoroughly in running tap water to remove unwanted soil particles or surface debris.

The isolation of the potential fungal agents was performed by transferring disease marks on the leaves to the media plates. About 2 mm^2 cross-sectional segments of the leaves and petiole were cut from the margins of necrotic or chlorotic lesions. These segments were sterilized three times, the first and second time by sequential immersion in 70% ethyl alcohol for 30 seconds to improve sodium hyperchlorite penetration, the third time in 10% sodium hypochlorite (v/v) for 30 seconds to eliminate contaminating superficial propagules. Finally, they were immersed three times in sterile distilled water to eliminate traces of disinfectants used. The medium for the isolations was rose bengal chloramphenicol agar, Sabouraud Dectrose 4% Agar and potato dextrose agar (PDA), supplemented with antibiotic chloramphenicol (10%w/v) in petri dishes. Surface-sterilized segments (4 per plate) were plated on the different mediums. The plates were used for leaves of each of the sites and were then incubated under sterile conditions at 27 °C, with the return air humidity at 60.2% in the CE room for few days until sporulation.

5.3.5 Culturing and sub-culturing

The fungi that developed from pieces of water hyacinth leaves were purified and isolated by sub-culturing techniques (Agarwal & Hasija 1986). The growing edges of fungal colonies isolated were transferred to 0.5% malt yeast extract agar (MEA) plates. Fungi were transferred serially until pure cultures were obtained. Cultures that appeared to be contaminated with other fungus were sub-cultured and purified.

5.3.6 Identification and maintenance of isolates

The purified cultures of all the isolates were numbered and multiplied on PDA plates. The stock cultures of the micro-organisms were maintained on PDA slants and stored at 4–7°C in a refrigerator. Using various literatures sources, the researcher identified the fungi on the basis of their morphological growth characteristics, sporulation, conidial measurement and ability to produce pigmentation on the growth media (Ellis 1971, 1976; Ainsworth *et al.* 1973; Holliday 1993; Lacap *et al.* 2003; Domsch *et al.* 2007). All the pictures (micrographs) used for the identification were taken in the Electron Microscopy Unit (Rhodes University, South Africa) using a microscope (Olympus) connected to a desktop (Figure 5.2).

Figure 5.2 Equipment used during the morphological identification of the pure culture obtained after culture and sub-culture (Electron microscope (Olympus SC30) connected to a Desktop).

5.3.7 Frequency of occurrence of fungal isolates

Compared to other genera, the frequency of occurrence of each genera was counted from the fungal genera isolated from various water hyacinth-infested sites where the leaves were collected. The isolation frequency for each genus was expressed as the percentage of the total number of fungal isolates per season representing a given genus through the formula:

$$\boldsymbol{Frequency}\ (\%) = \frac{\boldsymbol{Number\ of\ isolates\ in\ a\ genus\ for\ each\ season\ x100}}{\boldsymbol{Total\ number\ of\ isolates\ found\ in\ the\ season}}$$

5.3.8 Interaction between insects and pathogens

In each of the selected sites, a survey was carried out to identify any feeding scar damage on leaves caused by the *Neochetina* weevils, and leaves that also presented signs of disease by pathogens. In sites where these feeding scars were found, weevils were collected from the plant by hand in order to identify the weevil's species. Plants showing feeding scars were removed from the water, and weevils were collected. Leaves damaged by weevils and pathogen were then collected. These data were used to estimate the biological control agents' population density per area or per site.

5.4 Data analysis

After that the normality test was run, the percentage data recorded for evaluating DI per plant and per site, per month and season were subjected to arcsine transformation prior to being compared using one-way analysis of variance (ANOVA), followed by the Tukey HSD to determine the significant differences using the software STATISTICA version 12.

5.5 Results

5.5.1 Disease status and rating disease damage per site

Since the discovery of water hyacinth in Cameroon, and despite all the studies which have already been carried out on water hyacinth, to our knowledge, this is the first extensive survey of pathogens infecting water hyacinth in this country. This survey included all the sites selected at the beginning of this study for a long-term study of the Wouri Basin and its tributaries where water hyacinth is reported as a serious problem.

Of the ten sites selected after the initial survey of the Wouri Basin, the presence of potential pathogens damaging water hyacinth were recorded at in seven sites during the wet season (June 2014–October 2014) and eight sites during the dry season (November 2015–April 2016) (Table 5.7). Two sites, Bonassama Vallée and Grand Baobab 1 showed no damage by pathogens in either the rainy season, or the dry season. By contrast, at Centre Equestre, leaves damaged by pathogens could not be collected during the rainy season, and were collected only during the dry season. Water hyacinth plants in these sites were found to be infected by various fungi and displayed a wide variety of symptoms of pathogenic infection: leaf necrosis, zonate ring spots, blight chlorosis, lesions, browning, blight chlorosis, root rot and water-soaking (Figure 5.3).

During the rainy season, biological control agents were not found at any of the sites monitored, but they were found at Château and Petit Bonanjo 1 and 2 during the dry season. However, the presence on weevils, established through the feeding scars left on the leaf on the plant, was not related with the presence of pathogens, given that damage by pathogens was not found on the plants damaged by weevils. The weevils which were found in these sites during the dry season were *Neochetina eichhorniae* and *N. bruchi*.

The disease damage caused by fungi on water hyacinth in each of the sites investigated increased from 5.0 during the rainy season, to 25.0 during the dry season at Château, Forêt Bar, Grand Hangar, Petit Bonanjo 1 and 2, while at Saint Richard it changed from 50.0 during the rainy season to 75.0 during the dry season. However, at Grand Baobab 2, the change was the reverse of what occurred in other sites, and decreased from 50.0 during the rainy season, to 25.0 during the dry season (Table 5.6).

Figure 5.3 Diseased *Eichhornia crassipes* leaves affected by various fungal species showing different spots collected in different sites of infestation.

Table 5.6 Description of disease status, symptoms and the presence of weevils per sites and per season. (x = absent, √ = present).

Sites name	Diseases status		Rating disease damage per site		Weevils		Symptoms	
	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
Bonassama Vallée	x	x	0	0	x	x	None	None
Centre Equestre	x	✓	0.1	5	x	x	None	Zonate leaf spot, leaf necrosis
Château	✓	✓	5.0	25.0	x	✓	Leaf necrosis, leaf spot	Leaf necrosis, leaf spot, necrotic spot
Forêt Bar	✓	✓	5.0	25.0	x	x	Leaf necrosis, leaf spot, foliar blight	Leaf necrosis, leaf spot, blight necrosis
Grand Baobab 1	x	x	0	0	x	x	None	None
Grand Baobab 2	✓	✓	50.0	25.0	x	x	Leaf necrosis, leaf spot, foliar blight	Leaf necrosis, leaf spot, foliar blight
Grand Hangar	✓	✓	5.0	25.0	x	x	Leaf necrosis, zonate leaf spot	Leaf necrosis, zonate leaf spot
Petit Bonanjo 1	✓	✓	5.0	25.0	✓	✓	Leaf necrosis, zonate leaf blight, foliar blight	Leaf necrosis, zonate leaf blight, foliar blight, leaf spot
Petit Bonanjo 2	✓	✓	5.0	25.0	✓	✓	Leaf necrosis, zonate leaf blight, foliar blight	Leaf necrosis, zonate leaf blight, foliar blight
SR	✓	✓	50.0	75.0	x	x	Leaf necrosis, zonate leaf blight, foliar blight, leaf blight, leaf spot	Leaf necrosis, zonate leaf blight, foliar blight, leaf blight, leaf spot

5.5.2 Disease index

At the end of both the rainy and dry season surveys, the mean disease index per month was calculated per season (Figure 5.4) and per site (Figure 5.5). The DI determined per season indicated a significant difference in term of damage by pathogens on the whole plant between the two seasons ($F_{(1,72)}$=5.38, p=0.23), as well as a significant difference per site per month ($F_{(7,792)}$=49.28, p<0.05).

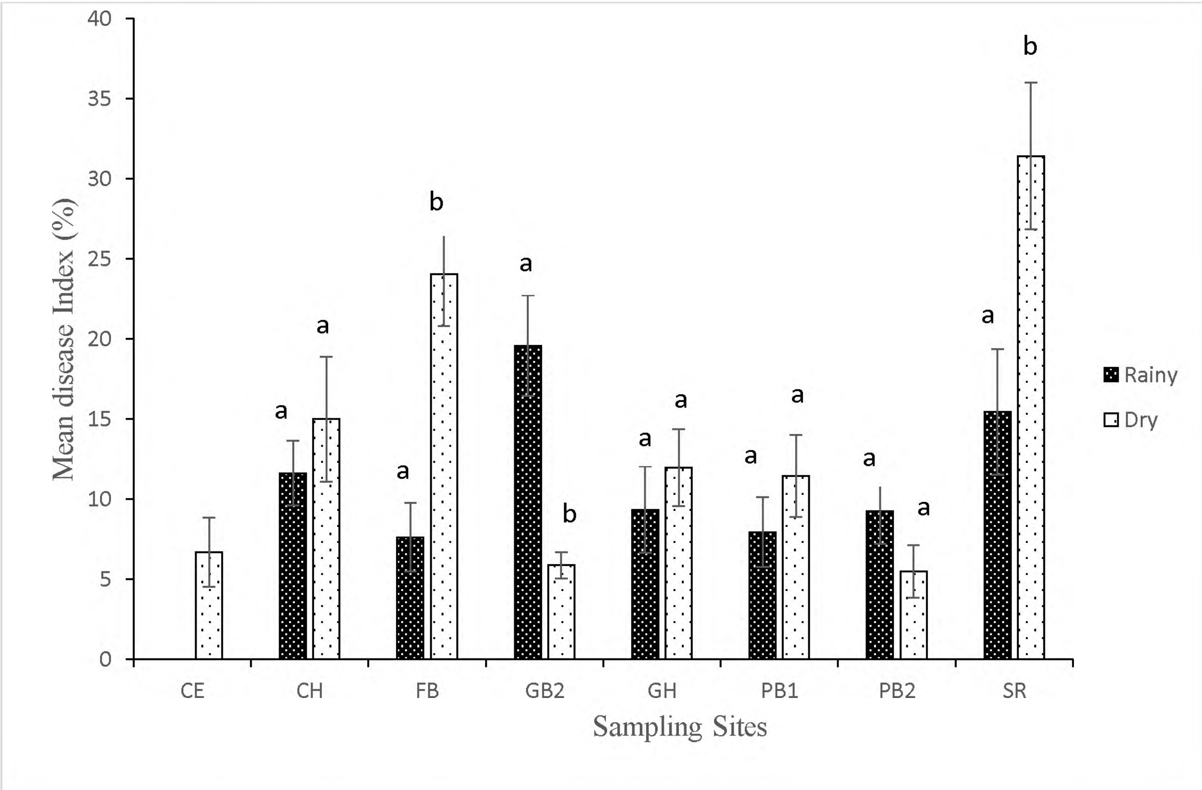


Figure 5.4 Mean Disease index (%) of damage to leaves by pathogens on the whole plant per season (rainy and dry).

5.5.3 Occurrence and distribution of pathogenic fungi in the Wouri Basin

5.5.3.1 Incidence of fungal pathogens on water hyacinth in the Wouri Basin during the rainy season (June–October 2014)

During the rainy season, 130 fungal isolates (pure cultures) belonging to twelve genera of the phylum Ascomycetes were purified from the diseased plant parts on the basis of their morphological characteristics and the arrangement and structure of their conidia.

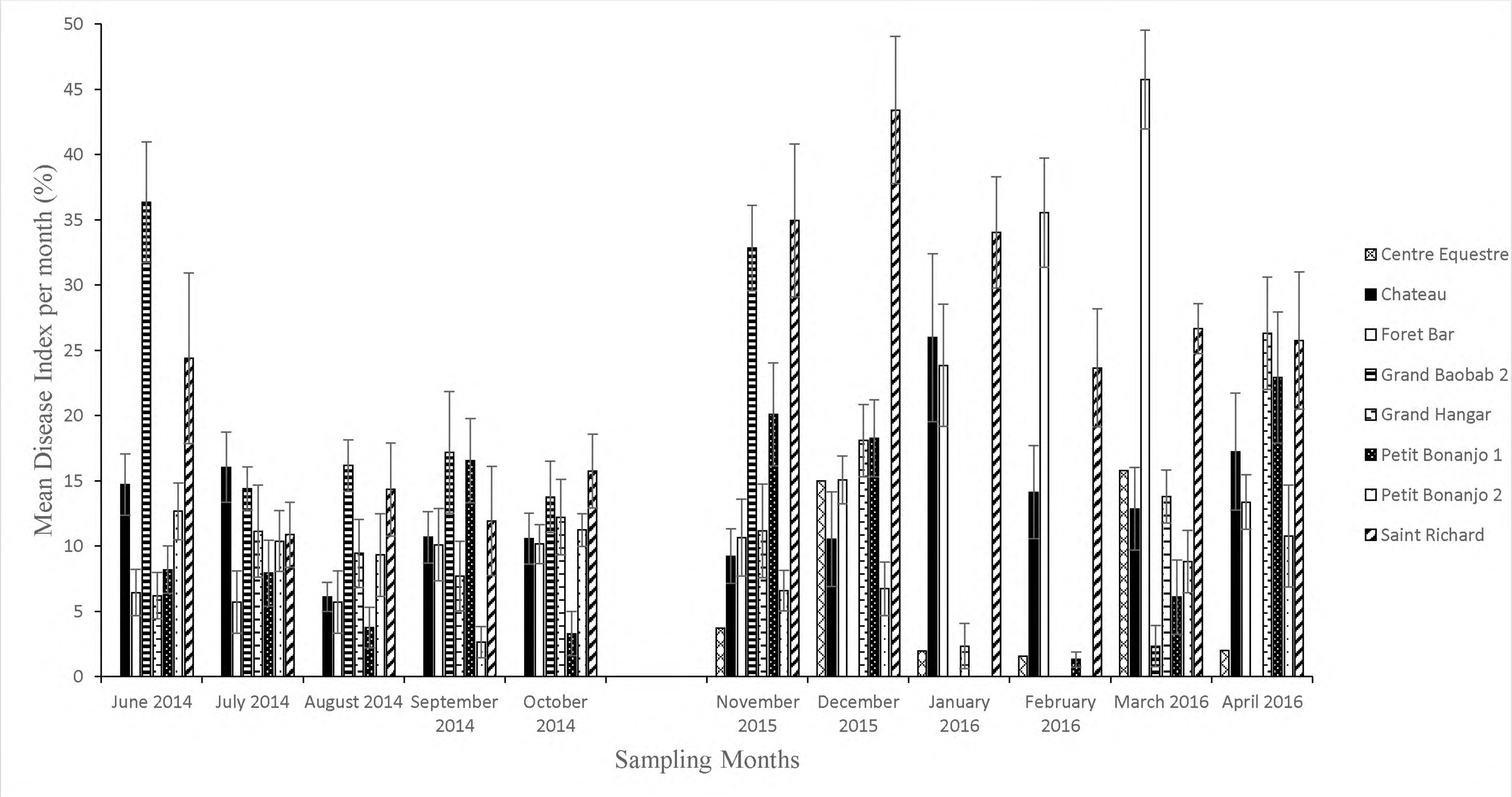


Figure 5.5 Mean Disease Index (%) of damage to leaves by pathogens on the whole plant per site and per month.

However, ten isolates were eliminated from further consideration because they either failed to grow, or belonged to the non-pathogenic and non-sporulating mycelia sterile group. The number of isolates were almost the same in all the sites surveyed, with 20 isolates recorded at Grand Hangar, Château and Saint Richard; 18 isolates at Forêt Bar, Petit Bonanjo 1 and 2, while 16 isolates were found at Grand Baobab 2.

From the 130 pure fungal isolates obtained at the end of the purification process, 64 fungal isolates were not identified although pure cultures were obtained, of which 16 belonged to Forêt Bar, 11 to Château, eight to Grand Baobab 2, 10 to Grand Hangar, three to Petit Bonanjo 1, seven to Petit Bonanjo 2, and nine to Saint Richard (Table 5.7). Saint Richard showed the highest number of species (seven) followed by Petit Bonanjo 1 and Grand Baobab 2 which presented six species; Petit Bonanjo 2 showed five, while Château, Forêt Bar and Grand Hangar showed three species each (Table 5.7).

Table 5.7 Fungi isolated from water hyacinth leaf in the Wouri Basin during the rainy season (2: Château, 3: Forêt Bar, 4: Grand Baobab 2, 5: Grans Hangar, 6: Petit Bonanjo 1, 7: Petit Bonanjo 2, 8: Saint Richard).

Fungal isolates	Location of isolation	Countries from which the isolates have previously been reported
Chaetomium strumarium J.N. Rai, J.P. Tewari & Mukerji	7, 8, 2, 3	
Aspergillus niger Tiegh.	2, 4, 5, 6, 7, 8	Kenya, Nigeria
Cladosporium sp.	4, 6	India, USA, South Africa
Colletotrichum gloeosporioides (Penz.) Penz. & Sacc.	6	
Colletotrichum sp.	6,8	South Africa
Chaetomium sp.	4, 5, 7, 8	Egypt, South Africa
Curvalaria pallescens Boedjin	7	Kenya
Periconia sp.	8, 3	Mexico, USA, South Africa
Acremonium zonatum (Sawada) W.Gams	3, 4, 5, 6, 7, 8	South Africa, Kenya,
Lasiodiplodia theobromae (Patouillard) Griffon & Maublanc	4	
Phoma sp.	4	Brazil, India, Peru, USA, Uganda, South Africa, Mali
Bipolaris sp.	8	South Africa
Rhizoctonia sp.	6	
Macrophomina sp.	2	

During the rainy season, the most represented genus with the highest frequency of occurrence was *Chaetomium strumarium* with 11.54%, followed by *Aspergillus niger* with a frequency of occurrence of 10.76%. *Acremonium zonatum* had a frequency of 9.24%, while *Cladosporium* sp., *Colletotrichum* sp. and Periconia sp., had respectively 3.08% and 2.31%. *Chaetomium* sp. and *Rhizoctonia* sp. had the same frequency of 1.54 %. *Lasiodiploidia theobromae*, *Curvalaria pallescens*, *Phoma* sp., *Bipolaris* sp. and *Macrophomina* sp., each has a frequency of 0.77 % (Figure 5.6). Although pure cultures were obtained, their morphology was not determined, or when determined, it was not as good to be identified; these species were classified as unidentified.

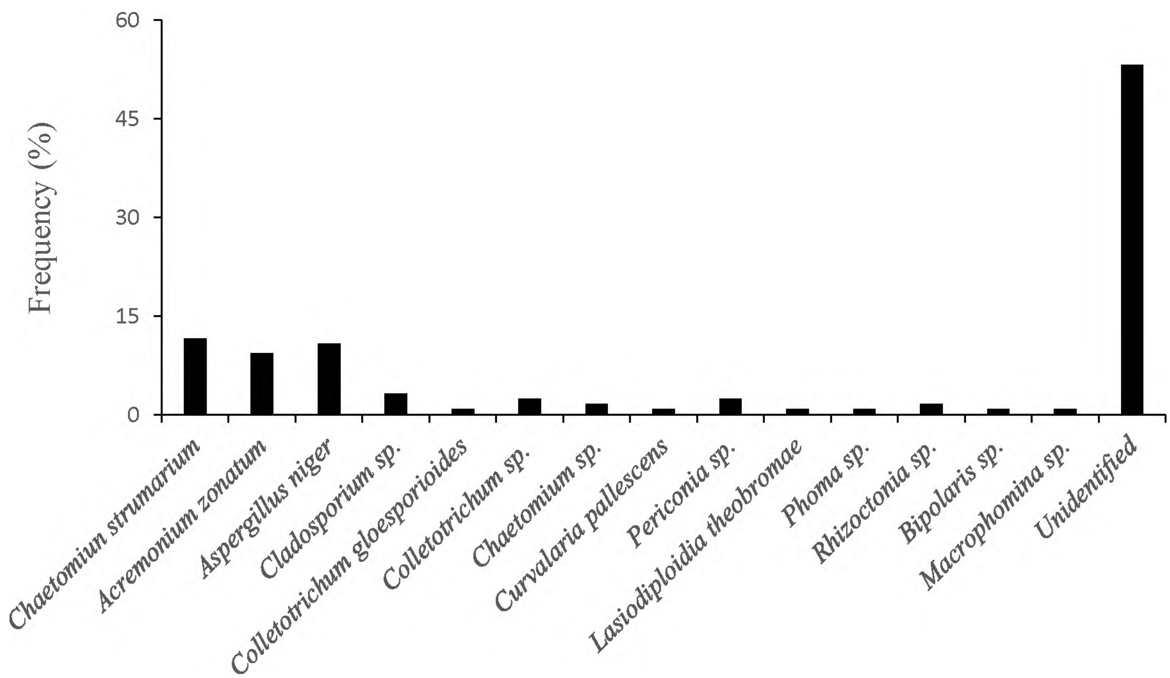


Figure 5.6 Percentage frequency of occurrence of different fungal genera found on water hyacinth during the rainy season.

5.5.3.2 Incidence of fungal pathogens on water hyacinth in the Wouri Basin during the dry season (November 2015–April 2016)

During the dry season, a total of 299 fungal isolates (pure cultures) belonging to 23 genera were purified from the diseased plant parts on the basis of their morphological characteristics and the arrangement and structure of their conidia. However, 627 isolates were eliminated from further consideration because they either failed to grow, or belonged to the non-pathogenic and non-sporulating mycelia sterile group. Petit Bonanjo 1 showed the highest number of isolates (76) followed by Saint Richard and Foret Bar (43 and 42 isolates respectively), and Petit Bonanjo 1 (37 isolates). Twenty-nine isolates were found at Château and Grand Hangar, while at Grand Boabab 2, 30 isolates were found, and 13 at Centre Equestre. From the 299 pure fungal isolates obtained at the end of the purification process, 76 fungal isolates were not identified although pure cultures were obtained, of which nine belonged to Centre Equestre, nine to Forêt Bar, six to Grand Baobab 2, two to Grand Hangar, 24 to Petit Bonanjo 1, 15 to Petit Bonanjo 2, and 11 to Saint Richard (Table 5.8). The highest number of genera was found at Petit Bonanjo 1 and Grand Hangar with 12 species each, followed by Grand Baobab 2, Petit Bonanjo 2 and Saint Richard with 11 species respectively. At Château, Centre Equestre and Forêt Bar, three, five and nine species were identified respectively (Table 5.8).

Table 5.8 Fungi isolated from water hyacinth leaf in the Wouri Basin during the dry season (1: Centre Equestre; 2: Chateau, 3: Foret Bar, 4: Grand Baobab 2, 5: Grans Hangar, 6: Petit Bonanjo 1, 7: Petit Bonanjo 2, 8: Saint Richard).

Fungal isolates	Location of isolation	Countries from which the isolates have previously been reported
Aspergillus niger Tiegh.	1, 2, 3, 4, 5, 7, 8	Nigeria
Epicoccum nigrum Link	4, 6	India, Mexico, South Africa
Alternaria eicchorniae Nag Raj & Ponnappa	6	Bangladesh, Egypt, Ghana, India, Indonesia, Kenya, Nigeria, Thailand, USA, Uganda, South Africa, Zimbabwe
Paecilomyces sp. = *Purpureocillium lilacinum* (Thom) Luangsa-ard, Houbraken, Hywel-Jones & Samson	1, 5, 6, 8	
Pythomyces chartarum (Berk. & M.A. Curtis) M.B. Ellis	5	
Phoma sp.	7	Brazil, India, Peru, USA, Uganda, South Africa
Lasiodiploidia theobromae (Patouillard) Griffon & Maublanc	1, 5, 8, 3, 6, 4	
Nigrospora sphaerica (Sacc.) E.W. Mason	4, 8	Kenya
Beauvaria bassiana (Bals.-Criv.) Vuill.	7, 8	

Aspergillus flavus Link.	4, 6, 7	Nigeria
Myrothecium roridum	7	Nigeria
Curvalaria lunata	3	Mexico, Kenya, Nigeria, Mali
Pythium sp.	7	Ethiopia, India, USA, South Africa
Colletotrichum dematium (Pers.) Grove	7	
Cladosporium sp.	7	India, USA, South Africa
Fusarium sp. (To confirm)	6	India, Mexico, Nigeria, Peru, Sri Lanka, Uganda, South Africa, Kenya, Mali
Fusarium sp.	6	
Colletotrichum acutatum J.H. Simmonds ex J.H. Simmonds	6	
Eurotium sp.	6	South Africa
Chaetomium sp.	2, 4, 5, 3, 7, 6	Egypt, South Africa
Cladophialophora sp.	5	India, USA, South Africa
Chaetomium sp.	5	Egypt, South Africa
Fusarium sp.	5	India, Mexico, Nigeria, Pru, Sri Lanka, Uganda, South Africa, Kenya, Mali
Colletotrichum sp.	4	South Africa, Mali
Colletotrichum sp.	4	
Alternaria sp.	8	Mexico, Sri Lanka, USA, South Africa, Kenya, Mali
Acremonium zonatum (Sawada) W.Gams	1, 2, 3, 4, 5, 6, 7, 8	
Rhizoctonia sp.	8, 1, 5, 3	
Macrophomina sp.	8, 3, 5, 6	
Cenococcum geophilum Fr.	8, 3	
Aspergillus sp.	7	
Phytophthora sp.	3, 5, 6, 8	

During the dry season, the most represented genus with the highest frequency of occurrence was *Aspergillus niger* with 7.32%, followed by *Acremonium zonatum* with a frequency of occurrence of 7.03%. *Aspergillus flavus* had a frequency of 5.34%. *Paecylomyces* sp., *Rhizoctonia* sp., *Lasiodiploidia theobromae*, Phytophthora sp., *Fusarium* sp. and *Chaetomium* sp. had a frequency of occurrence ranged between 3 and 4.6%. The remaining fungi identified had a frequency of occurrence below 3 % (Figure 5.7). Although pure cultures were obtained, their morphology was not determined, or when determined, it was not as good to be identified; these species were classified as unidentified.

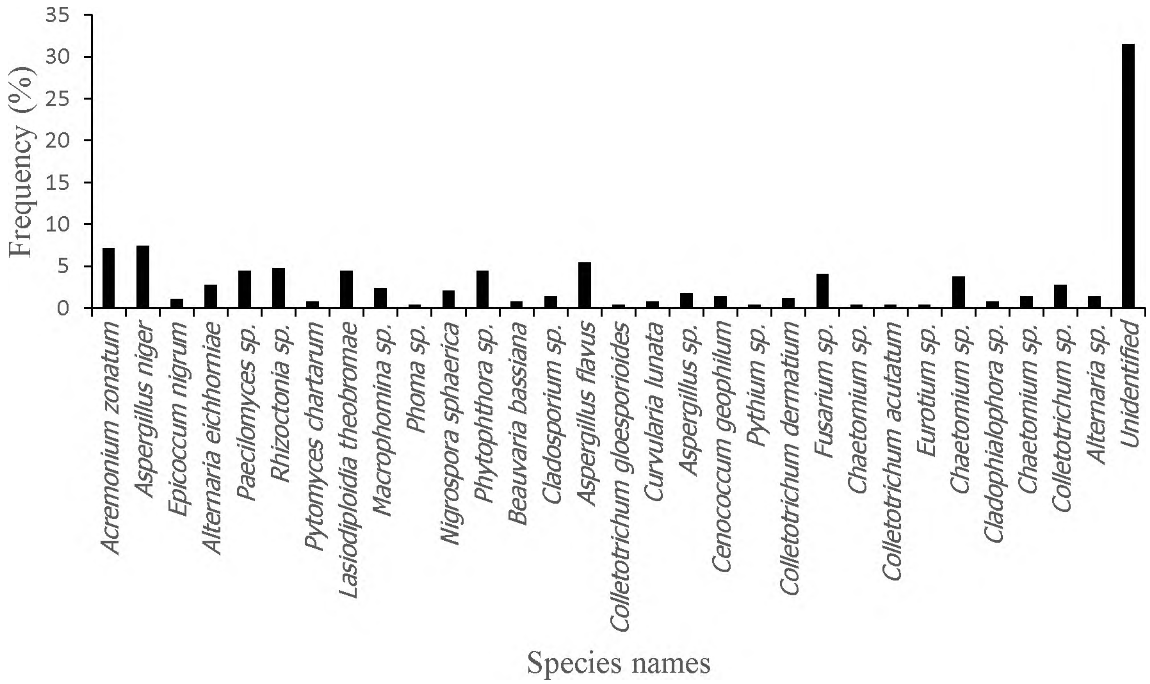


Figure 5.7 Percentage frequency of occurrence of different fungal genera found on water hyacinth in the Wouri Basin during the dry season.

A total of six species was identified during the rainy season up to the species level, while 15 species were identified during the dry season species level, with a total of nine common species found identified for the two seasons. Among these species, there were: *Aspergillus niger*, *Acremonium zonatum*, *Lasiodiploidia theobromae*, *Rhizoctoni*a sp., *Macrophomina* sp., *Phoma* sp., *Colletotrichum* sp., *Chaetomium* sp. and *Cladosporium* sp.

Five species identified during the rainy season were not identified during the dry season, while the dry season differed from the rainy season with 18 species.

5.5.4 Characteristics of some common fungi found in association with water hyacinth

Previous reports on the mycobiota of water hyacinth indicate that the genera *Fusarium*, *Curvularia*, and *Alternaria* are frequently isolated from this weed (Praveena & Naseema 2004; Evans & Reeder 2001), and that *Alternaria* and *Fusarium* are particularly common (El-Morsy

2004; Praveena & Naseema 2004; Babu *et al.* 2003). The most common diseases observed in the field and found in association with water hyacinth during the survey included the leaf spot caused by *Acremonium zonatum*, *Alternaria eichhorniae*, *Curvalaria* sp., *Colletotrichum* sp., *Fusarium* sp., *Chaetomium* sp., *Pithomyces chartarum*, *Epicoccum nigrum*, to a lesser extend *Myrothecium roridum* and *Nigrospora* sp. The listed fungi are described below.

5.5.4.1 Pithomyces chartarum

Colonies of *Pithomyces* are fast growing on general fungal media. The surface colour of the colony is pale to dark brown and the reverse is dark brown (Figure 5.8 (A, A')). *Pithomyces* colonies have a cottony texture and the sporulation is slow. The spores are multicellular and deeply pigmented. Distinctive features are the presence of both transverse and longitudinal divisions, called septa. The shape of the spores varies from barrel-shaped, to ellipsoid, to club-shaped. *Pithomyces chartarum* spores are multicelled and brown. *Pithomyces chartarum* is characterized by hand grenade-shaped spores with longitudinal septa and usually three transverse septa (Figure 5.8, B). Spores of *Pithomyces* may be confused with younger spores of *Alternaria* and *Ulocladium*.

5.5.4.2 Epicoccum nigrum

The surface colour of the colony of *Epicoccum nigrum* is dark and the reverse of the plate is brown (Figure 5.8 (C, C')). *E. nigrum* spores (Figure 5.8, D) are multicellular, spherical, with a dark-brown outer wall with both transverse and vertical division on mature spores. The produced pigment also diffuses into the agar, leading to a dark-red colour.

5.5.4.3 *Colletotrichum* sp.

The colonies of *Colletotrichum* species isolates were dense, aerial, initially white or cream white (Figure 5.9 I), becoming white-green as the cultures aged on PDA (Figure 5.8 E). The reverse of the plate colony was white to white-grey (Figure 5.8 E', Figure 5.9 J). The cultures developed black acervuli around the centre of the colony (5.8 E). No setae were observed. Mycelium was hyaline (Figure 5.9 K). Conidia were hyaline, aseptate, and fusiform, rarely cylindricall, with obtuse apices and tapering basis (Figure 5.8 F).

5.5.4.4 Alternaria eichhorniae

Growth on Potato Dextrose Agar (PDA) was fast. The colony was almost cottony with a light-dark colour at the front plate, while the back was dark (Figure 5.8 G, G'). The colony did not color the PDA. The mycelium was found to be aerial, velvety to cottony in the middle. *Conidiophores* emerged from the stomata of the host in bundles of 4–8, unbranched or branched, erect and golden-brown to brown in colour for most part of their length, tending to be subhyaline towards the tip (Figure 5.8 H, H'). Conidia were in chains of 3–4, ovate-obclavate obpyriform, with 4–10 transverse septa and 1–4 longitudinal septa and are yellow to golden-brown. The symptoms found on water hyacinth in the Wouri Basin were similar to those described by Nagaraj and Ponnapa (1970).

5.5.4.5 *Fusarium* sp.

In culture, the fungus was initially peach to buff but later becoming brown (Figure 5.9 L, M). When mature, the colony coloured the plate which becomes brownish. At first, conidia were sparse and produced from simple lateral phialides on aerial mycelium. After some days conidia were more abundant with production of compact penicillately branched and septated conidiophores. The conidia were falcate with a well-developed pedicellate foot cell and attenuated apical cell that bent inwards, exaggerating the normal curvature of the spore (Figure 5.9 N).

5.5.4.6 *Chaetomium* sp.

Pale yellow to a grey on PDA, the colony of *Chaetomium* sp. is circular, and the reverse is brown (Figure 5.9, O, P). The growth was relatively rapid. Hyphae was hyaline septate (Figure 5.9 R). Ascoma (Perithecia) are spherical to ovoidal to obovoidal with numerous hairs, usually unbranched, flexsulose, undulating or coiled with a brownish colour.

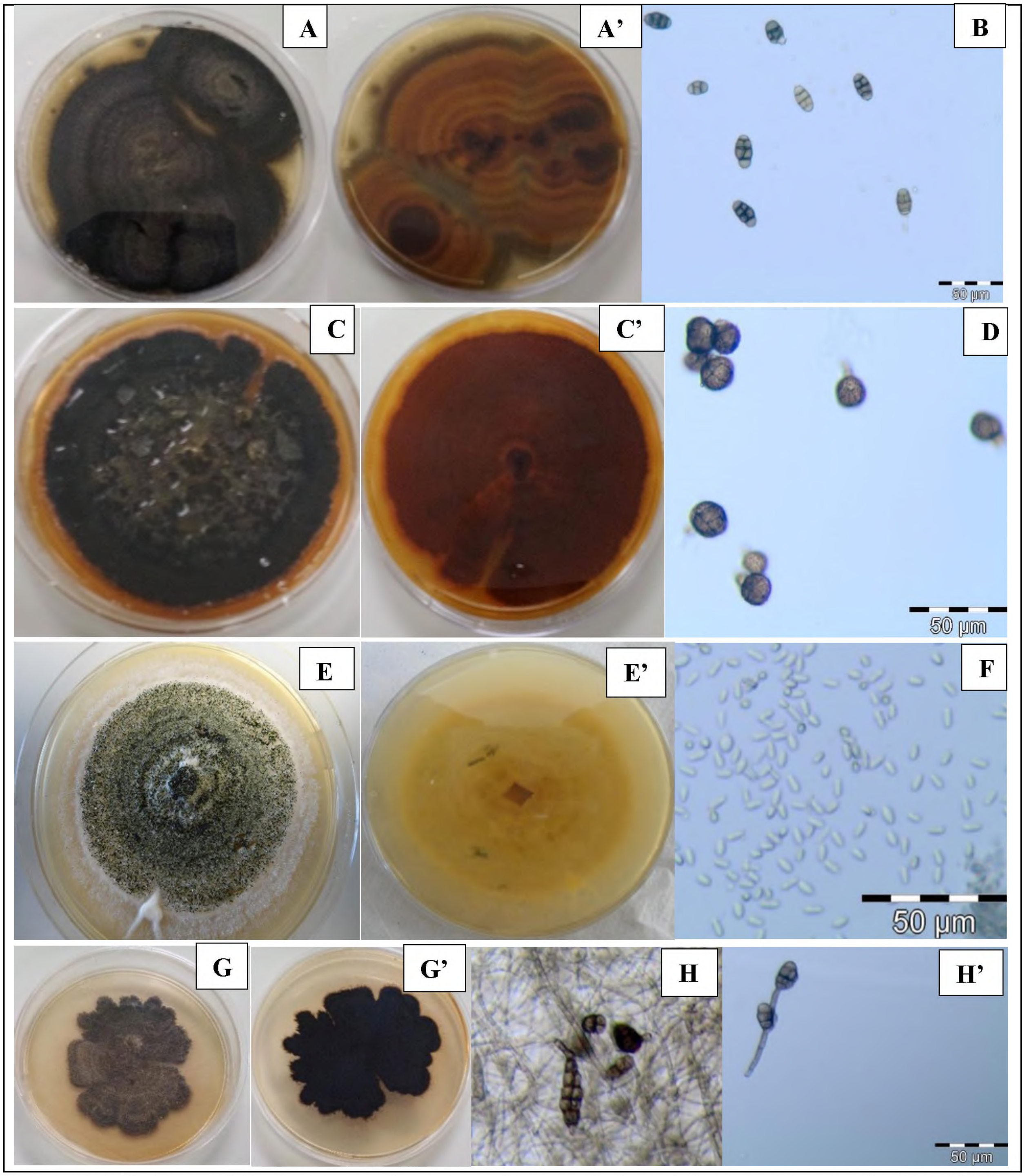


Figure 5.8 Colony of *Pythomyces chartarum* (Front of plate (A) and reverse of plate (A')), *Epicoccum nigrum* (Front of plate (C) and reverse of plate (C')), *Colletotrichum* sp. (Front of plate (E) and reverse of plate (A')), and *Alternaria eichhornia* (Front of plate (A) and reverse of plate (E')) on PDA. Light micrograph of the development stage of *Pythomyces chartarum* (image B), *Epicoccum nigrum* (image D), *Colletotrichum* sp. (image F) and *Alternaria eichhorniae* (image H and H') under the light microscope (x100).

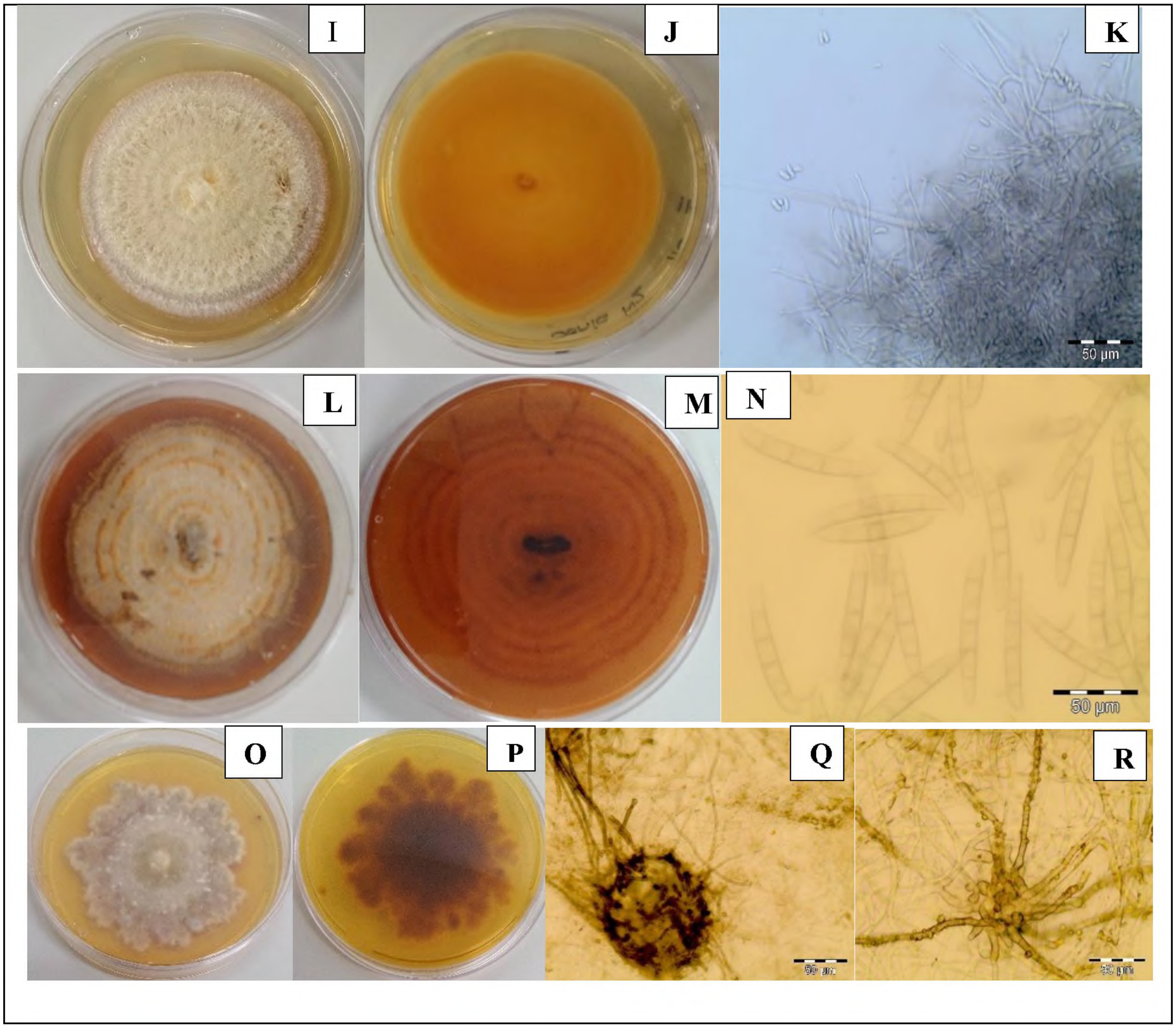


Figure 5.9 Colony of *Colletotrichum sp.* (Front of plate (I) and reverse of plate (J)), *Fusarium sp.* (Front of plate (L) and reverse of plate (M)), and *Chaetomium sp.* (Front of plate (O) and reverse of plate (P)) on PDA. Light micrograph of the development stage of *Colletotrichum sp.* (image K), *Fusarium* (image N), and *Chetomium sp.* (image Q and Q') under the light microscope (x100).

5.5.4.7 Curvularia pallescens

Colonies on PDA spread quickly. They are woolly at the centre, developing concentric zones. The colony was slightly green-grey, and the reverse was brown-dark (Figure 5.10 S, and Figure 5.10 S'). Conidiophores are simple, rarely branched, straight or sometimes geniculate near the apex, brown, variable in length, up to 5–6 µm wide. Conidia are smooth-walled, pale brown, mostly 3-septate, ellipsoidal to fusiform, usually slightly curved (Figure 5.10 U). The mycelium was hyaline, and non–septated (Figure 5.10 T).

5.5.4.8 Myrothecium roridum

In culture, the fungal colony reached 40 mm diameter on PDA after 7 days. Initial colonies of isolates were white, floccose mycelium and developed dark green to black concentric rings (Fig. 5.10 V, V'). Conidiophores branched repeatedly two to three times. Conidiogenous cells in whorls of three to seven on ultimate branches were hyaline, cylindrical (Figure 5.10 W'). Conidia were hyaline and cylindrical with both ends rounded, occasionally one blunt end (Figure 5.10 W). All characteristics were consistent with the description of *Myrothecium roridum* Tode ex Fr. (Seebold *et al.* 2005; Mangandi *et al.* 2007).

5.5.4.9 *Nigrospora* sp.

The colony was white, floccose, with a woolly reverse dark and white in colour (Figure 5.10 X, X'). The culture develops black spore clusters with time. The mycelium is immersed within the outer tissues of the host and is composed of hyaline, branched, septate hyphae Figure 5.10 Y). The hyphae penetrate the epidermis and produce on its surface clusters of short branched, pale-brown swollen conidiophores, bearing singly at their apices depressed globose shining black aleuriospores (Figure 5.10 Y, Y'). The spores are globose when viewed from the end and elliptical from the side. Certain spores showed a small hyaline drop attached to the spore (Figure 5.10 Y').

5.5.4.10 *Acremonium* sp.

Cultures on PDA were creamy-white to slightly pinkish, felted to somewhat floccose; the reverse colourless at first but becoming somewhat brownish-tinged with age (Figure 5.10 Z, Z'). *Acremonium* produces septate hyphae from which erect, unbranched and tapering phialides extend. Most phialides (but not necessarily all) have a basal septum which delimits them from the hyphae proper.

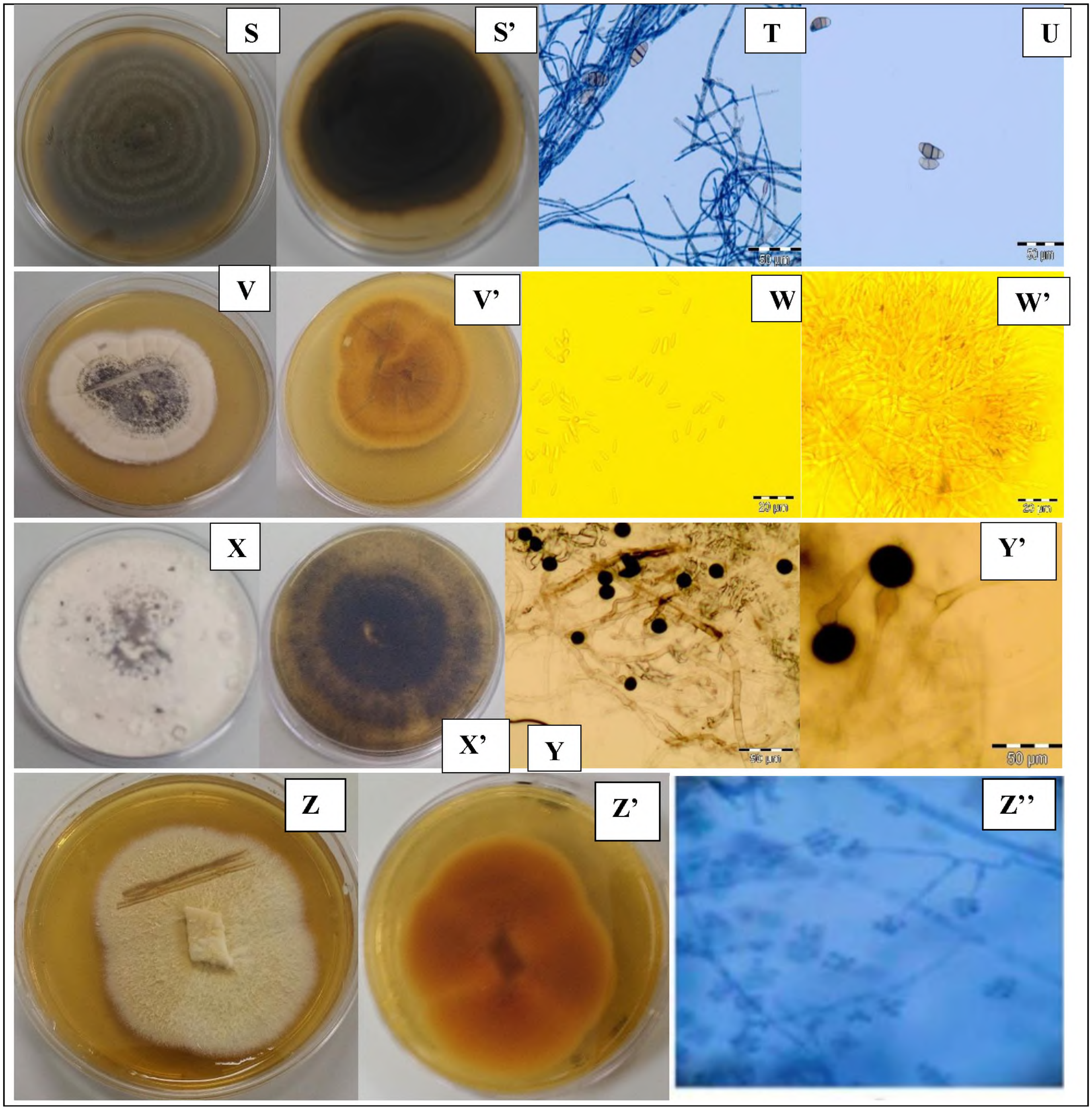


Figure 5.10 Colony of *Curvalria pallescens* (Front of plate (S) and reverse of plate (S')), *Myrothecium roridum* (Front of plate (V) and reverse of plate (V')), *Nigrospora sphaerica* (Front of plate (X) and reverse of plate (X')) and *Acremonium zonatum* (Front of plate (Z) and reverse of plate (Z')) on PDA. Light micrograph of the development stage of *Curvalaria pallescens* (image T and U), *Myrothecium roridum* (image W and W'), *Nigrospora sphaerica* (image Y and Y') and *Acremonium zonatum* (image Z'') under the light microscope (x100).

Conidiophores were erect and conidia formed singly at the apices of the conidiophore cells, often becoming aggregated into dense slimy heads. Conidia were simple and colorless. Conidia are oblong (2–3 X 4–8 µm) are usually one-celled, however, bicellular conidia may occur (Figure 5.10 Z'').

5.6 Discussion

Amongst the different factors on which the success of integrated management programme rely, is a need for a good knowledge of the hydrological and nutrient status of the system, the extent of the infestation, the climate of the area and the usage of the water body. So in order to minimize some problems associated with the introduction of new control agents such as lack of specificity, poor establishment rate, to name few, it is important to survey local areas to find indigenous or native biological control agents. To our knowledge, this is the first study looking at the fungi associated with water hyacinth in the Wouri Basin, and in Cameroon. It is, therefore, the first time that such extensive survey of phytopathogenic fungal isolates on water hyacinth has been conducted. Fungal pathogens have been shown to be the best effective biocontrol agents (El-Morsy *et al.* 2006; Shabana 2005; Vincent 2001). Therefore, in order to identify pathogens that can help control the weed, diseased water hyacinth leaves were collected in major selected areas of the Wouri Basin (Cameroon). To date, although the whole Wouri Basin was surveyed, samples have only been collected in selected sites chosen at the beginning of this study (Chapter 2). These surveys revealed that there is a rich diversity of fungal pathogens associated with water hyacinth in Cameroon. A total of 66 fungal isolates were identified in various genera during the rainy season, while 223 fungal isolates were identified in various genera as well, during the dry season. Isolation of fungi from diseased water hyacinth plants in the Wouri Basin revealed the occurrence of several fungal species, most of which have been isolated from water hyacinth species in water bodies worldwide (Shabana *et al.,* 1995; Evans and Reeder 2001, Martinez *et al.,* 2001; Evan *et al.* 2001). These include *Alternaria eichhorniae, Fusarium oxysporum, Myrothecium roridum, Phoma sp.* and *Pythium sp.* which are ubiquitous fungal genera. Among these genera, both *Alternaria* and *Fusarium* include many species or strains that may be pathogenic towards several crops (Babu *et al.* 2003; EL-Morsy 2000). Indeed, Nag Raj and Ponnappa (1970), Shabana (1997), Shabana *et al.* (2000) have extensively studied the species *A. eichhorniae* as potential biocontrol potential agents against water hyacinth. Nag Raj and Ponnappa (1970), Shabana *et al.* (1995a) noted that *A. eichhorniae* is host-specific to water hyacinth and therefore capable of severely damaging and suppressing this weed (Shabana *et al.* 1995a, 1995b, 1995c), therefore the potential for mycoherbicides should be explored. Most of the fungi identified during this study were new species for Cameroon. With the exception of *Aspergillus flavus*, *Fusarium oxysporum* and *Phytophtora* sp. which have been identified on other species (MINEPDED 2014), all the others were new genera for Cameroon and especially for water hyacinth. In addition, based on the morphology, genera *Chaetomium strumarium*, *Colletotrichum gloesporioides*, *C. acutatum*, *C. dematium*, *Curvalaria pallescens* and *Pytomyces chartarum* can be considered as a new species for Africa. However, molecular characterization and DNA analysis need to be done at a species level to confirm these results.

There was an increase in the number of fungal species isolated from the survey carried out during the dry season over that carried out during the rainy season. These results were contrary to the results found by Kusewa (2002) in Lake Victoria, Kenya where the number of fungal species isolated during the rainy season were greater than those isolated during the dry season. During her study, Kusewa found ten additional species which were isolated from the rainy season survey and attributed this to the fact that temperature and relative humidity favour fungal growth during the rainy season more than during the dry season. However, studies carried out by Charudattan (2005) and Babu *et al.* (2003) have shown that environmental factors such as temperature, water activity, RH (Relative humidity) and UV radiations influenced the efficacy of weed biocontrol agents under field conditions. Hence, in his study, Dagno (2011) found that water activity (a_w) emerged as a crucial determinant of germination for all three strains (*Fusarium sacchari*, *Cadophora malorum*, and *Alternaria* sp.,), their germination being fastest at $a_w = 0.96$ (reaching 100% at 25°C within 24 h) and slowest at $a_w = 0.88$. At high water activity, their conidia could germinate fast over a wide range of temperatures, from 15 to 35°C. At $a_w = 0.96$ and 25°C, for example, it took only 4 h for 35–60% of the viable conidia to germinate, depending on the organism studied. Based on his study, the results from the current study can be explained. Although during the dry season, the Wouri Basin is subject to the movement of tide with a fluctuation of water happening every six hours in general, the relative humidity of the air throughout the year is high and constant between 70–80% from December to May (2014–2016), and between 81–87% from June to November (2014–2016) (Appendices II, Meteorological data table from the Littoral Regional Delegate of Transport). The three strains need high humidity to germinate and penetrate the plant cell host (Dagno 2011). Moreover, the range of temperature which allows the fungi to germinate are within the range of temperature found in Cameroon, especially in the Wouri Basin (Chapter 2, l diagram of temperature).

The low natural levels of disease severity in some sites (Centre Equestre, Chateau) may be due to the fact that water hyacinth leaves are known to produce phenolic compounds that resist to fungal disease (Martyn and Cordy 1983). It could mean that though the fungi were pathogenic to water hyacinth, the inoculum densities in the field were too low to cause severe disease.

During this study, the presence of the weevils species, although it was not tested through laboratory observations of the weevils to determine the presence or no of any spores, it was assumed *Neochetina* species specifically in this case, had no effect on the spread of pathogens. This could be explained by the fact that, newly introduced in the area, the population of insects was not yet well developed enough to contribute in the dissemination of pathogen. However, now that the weevils are present in these sites, their impact on the control of water hyacinth mat should be investigated. Indeed, as showed by Sutton *et al.* (2016) in their study, under high nutrient conditions, unsterilised *Megamelus. scutellaris* (phloem-feeding bug) reduced water hyacinth daughter plant production by 32%, lengths of the second petiole by 15%, chlorophyll content by 27% and wet weight biomass by 48%, while also increasing leaf chlorosis 17-fold. They found that the most common species associated with this planthopper were *Alternaria* Nees, with three species obtained from eight isolates. *Alternaria eichhorniae* Nag Raj & Ponappa was the most abundant species within this genus, with five isolates, followed by *A. tenuissima* (Nees ex Fr.) Wiltshire with two isolates and lastly *A. alternata* with a single isolate (Fr.) Keissler. The remaining isolates comprised *Fusarium moniliforme* Sheldon with three isolates, *Cladosporium* sp. with two isolates and single isolates from the genera *Acremonium* (Link ex. Fr) and *Ulocladium* Preuss. Moreover, Venter *et al.* (2013) found that pathogens associated with chewing insects such as the weevil *N. eichhorniae* can nonetheless significantly reduce rates of photosynthesis in water hyacinth leaves.

These results may contribute to the amangement of water hyacinth in Cameroon, as the mechanical removal of water hyacinth is the only method option still undertaken in Cameroon. These pathogens constitute an important contribution to the integrated control of water hyacinth. Therefore, these results will be of great importance for Cameroon and several other countries in West Africa where this weed represents a major environmental and economic problem; but also worldwide where intensive research are conducted to the development of appropriate mycoherbicide to manage this plant.

5.7 Conclusion

From the present study it may be concluded that there are several species of fungi found in association with water hyacinth in the Wouri Basin, Cameroon, the majority of which are pathogenic to water hyacinth. Although extensive research have been carried out worldwide to manufacture these host-specific pathogens as bioherbicides for the management of water hyacinth, they need to be supplemented with other control options, and used in combination with different native fungal pathogens for a specific region (den Breeyen 1998, Ray *et al.* 2008), and the release of insect biocontrol agents (Charudattan *et al.* 1978, Denoth *et al.* 2002, Moran 2005, Yamoah *et al.* 2011).

However, as the identification process was done through the morphology and using several books and related articles, before any final decision can be made, it is important to undertake molecular characterization though DNA analysis to confirm the identity of these pathogens and therefore confirm that a species is specific to a region.

6 Chapter 6. Distribution of biological control agents (N*eochetina eichhorniae* and *Neochetina bruchi*) of water hyacinth in the Wouri Basin

6.1 Introduction

Invasive Alien Species (IAS), grow rapidly and threaten the native biota because they lack natural enemies in their introduced area (Gao & Li 2006). In order to manage the issues caused by these weeds, different methods of control have been used, and attention has focused on the use of biological control agents or natural enemies (arthropods, fungi or bacteria). Several ecologists have proposed introducing natural enemies which occur in the native ranges of weeds to control them in their introduced ranges (Harley *et al.* 1984; Charudattan 1986; Cilliers 1987; Harley 1990). These biological control agents have the potential to restrain the growth and propagation of weeds (Gao & Li 2006). According to Perkins (1973), these biological agents are effective because, through the constant stress they cause to the plant, they decrease the reproductive capacity and abundance of the plant. Biological control of weeds has a long history since the first agent was released in India 200 years ago (Johnston & Tyrone 1914).

In African countries which do not have enough resources to apply all the control methods available and have a limited number of effective tools to do so, biological control was recommended as "the only cost-effective, permanent and environmentally-friendly method" for control of water hyacinth (Greathead & de Groot 1993). Within these countries, several arthropod species have been released for the biological control of some notorious aquatic weeds including *P. stratiotes*, *E. crassipes*, *S. molesta*, and submerged weeds which have been successfully or partially managed by biological control agents around the world (Table 6.1).

Table 6.1 Example of aquatic weeds managed fully or partially by biological control agents in Africa. Data modified from Winston *et al.* (2014), Navarro & Phiri (2000), Charudattan (2001), Ajuonu *et al.* (2003), Mbati & Neuenschwander (2005) and Coetzee *et al.* (2011).

Weeds	Agents (s) most responsible for success	Countries where managed partially or fully in Africa
Azolla filiculoides	*Stenopelmus rufinosus* (weevil)	South Africa
Eichhornia crassipes	*Cercospora piaropi* (pathogen)	South Africa
	Cornops aquaticum (Grasshopper)	South Africa
	Eccritorasus catarinensis (Mirid)	Ghana, South Africa
	Neochetina bruchi (Weevils)	Benin, Burkina Faso, Egypt, Ghana, Kenya, Malawi, Nigeria, Republic of Congo, South Africa, Rwanda, South Sudan, Sudan, Tanzania, Uganada, Zimbabwe
	Neochetina eichhorniae (Weevils)	Benin, Egypt, Ghana, Kenya, Malawi, Nigeria, Republic of Congo, South Africa, Rwanda, South Sudan, Sudan, Tanzania, Uganda, Zimbabwe,
	Niphrograpta albiguttalis (Moth)	South Africa, South Sudan, Sudan
	Orthogalumna terebrantis (Mite)	South Africa, Zambia
Pistia stratiotes	*Neohydronomous affinis* (Weevil)	Benin, Botswana, Congo Republic, Ghana, Ivory Coast, Kenya, Senegal, South Africa, Zambia, Zimbabwe
Salvinia molesta	*Cyrtobagous salviniae* (Weevils)	Bostwana, Ivory Coast, Fiji, Ghana, Kenya, Mauritania, Namibia, Republic of Congo, Senegal, South Africa, Zambia, Zimbabwe
	Cyrtobagous singularis (Hustache, Erirhinidae) (Weevils)	Botswana, Zambia

Started in 1975 (Wright 1980), biological control of water hyacinth involves the use of host-specific insects, moths or pathogens which are natural enemies of the weed and are imported from the point of origin of the weed. Among different agents released to manage the spread of water hyacinth, the weevils *Neochetina eichhorniae* and *Neochetina bruchi* (Deloach & Cordo 1976 a,b; Center *et al.* 1982) are the two species that have provided the best results for biological control. Marked successes with biological control agents have been reported from many parts of the world, Louisiana, USA (Goyer & Stark, 1984); Mexico (Gutierrez *et al.*, 1996), Papua New Guinea (Julien & Orapa, 1999) and Africa, notably Lake Chivero, Zimbabwe (Chikwenhere & Phiri, 1999), Lake Victoria, Kenya (Ochiel *et al.*, 1999), and Benin (Ajuonu *et al.*, 2003; de Groote *et al.*, 2003). However, due to certain circumstances, it was not successful or took longer than expected in some countries. These countries include Bangalore (Visalakshy & Jayanth 1996), South Africa (Hill & Cilliers 1999), Nigeria (Navarro & Phiri 2000) and other countries where the success of biological control is variable.

The first release was in the USA in 1975 (Wright 1980), using *N. eichhorniae* and *N. bruchi*. In Africa, the first country to have initiated biological control of water hyacinth was Sudan, where three biological control agents were released: *N. eichhorniae*, *N. bruchi* and *Niphograpta* (*Sameodes) albiguttalis* (Beshir & Bennett 1985). *Neochetina eichhorniae* was the first to be released in May 1978, and since then, the success of biological control in this country has been spectacular, especially in the Jebel Aulia Dam (Beshir & Bennett 1985). Indeed, after two years, *N. eichhorniae* was well established, and from 1982, no accumulation of water hyacinth was apparent in contrast to the large accumulation (up to 11,300 ha) which had occurred annually since 1960 and required constant herbicide treatment (Beshir & Bennett 1985).

However, despite the fact that *N. bruchi* and *N. eichhorniae* have been most successful wherever they have been released, they were not successful in all circumstances and several other biological control agents have been considered (Cordo 1996, 1997; Julien *et al.* 1999; Hernandez *et al.* 2004). The failure is often caused by many factors which work in complex ways and therefore influence insects and plant population. For example, abiotic environmental factors like temperature, moisture, light, tidal fluctuation of water, weather (winter) and wind can be listed (White 1997; Hill & Cilliers 1999). To date, eight arthropods have been released for the biological control of water hyacinth including the new cryptic species from Peru of *Eccritotarsus*. (Harley 1990; Julien 2001; Ajuonu *et al.* 2003; Coetzee *et al.* 2011; Paterson *et al.* 2016). These biological agents include the two mottled weevils *N. eichhorniae* and *N. bruchi*, the two water hyacinth moth species *N. albiguttalis* and *Xubida infusella*, a mite *Orthogalumna terebrantis*, the grasshopper *Cornops aquaticum* (Brüner) and a mirid *Eccritotarsus catarinensis*, with the most successful being both *Neochetina* spp. (Julien *et al.* 1999; Julien 2001; Chapter 1). The most recent agents are the planthopper *Megamelus scutellaris*, which was released in South Africa in October 2013, and the new cryptic species of *Eccritotarsus* from Peru which is under taxonomic description (Paterson *et al.* 2016).

These arthropods affect water hyacinth in two ways: the direct removal of tissue followed by the decomposition of tissue surrounding the feeding area (Perkins 1973). Second, stress produced causes a loss of energy, which might otherwise be channelled into the production of daughter plants, to be redirected to the production of new tissue and defense leading to a decrease in the overall growth of the plant.

Similarly to what was seen in Nigeria, where some of the weevils (*Neochetina* sp.), released in Benin spread to the Badagry Creeks (Navarro & Phiri 2000), it was assumed that the agents released in the countries surrounding Cameroon would have spread here, although Cameroon had never initiated biological control. These agents include the weevils *N. eicchorniae* and *N. bruchi* released in Benin, Republic of Congo and Nigeria, the moth *N. albiguttalis* and the mirid *E. catarinensis* released in Benin.

6.2 Objectives

6.2.1 General objective

The aim of this study was therefore to determine the distribution of biological control agents of water hyacinth in the Wouri River Basin, Cameroon

6.2.2 Specific objectives

The specific objectives consisted to assess the mean number of weevil per areas investigated, to characterise their imact on water hyacinth mat, and finally to determine if there was any correlation between insect damages (feeding scars) and the presence of pathogens.

6.3 Material and Methods

During the first field trip, which took place between June and October 2014, and the second field trip between November 2015 and April 2016, the entire Wouri Basin was surveyed by boat and car to assess any presence of the biological control agents, their distribution and impact on water hyacinth. This included the ten sites chosen for a long-term study (Chapter 2) in Douala IV, other areas located in Douala IV (Bonendale, Mabanda areas, Pillar) and Douala V (Cassablanca, Bonaloka, Mbangue, Mbanya, Bonamouang, Bonangando, Yassem 1 and 2, Mbakoko Mbangue, Lendi), and the Fiko River in the Moungo division, in the municipality of Bonalea, located in the Littoral Region.

6.3.1 Sampling procedures

At each site surveyed, water hyacinth plants were checked carefully to detect any presence of feeding scars in the case of weevils, or any sign of depigmentation of the leaf caused by any other biological control agents. When the signs of damage caused by the agents were found in a particular areas, ten individual water hyacinth plants were randomly collected and, using a data sheet prepared in advance, the following parameters were recorded: for the insects, the parameters recorded were: the biological control agents species found on the plant, the number of larvae and petioles mined, and the presence/absence pupae. For the plants, if any of the biological control agents were found, the following parameters were recorded: the number of feeding scars on leaf 2 in the case of *Neochetina* species, the percentage leaf area damage on leaf 5 for the mite, the percentage of leaf damage on leaf 4 for the mirid and the approximate number of adults per plant. The presence or absence of pathogens was also assessed on each plant (Table 6.2). General comments included a description of the weather on the collection day i.e. wind, rainfall, sunlight, temperature, the collection date.

Due to the high cost of one trip by boat in the Wouri Basin, one survey per trimester in reason of two surveys per season was done (Chapter 2).

6.4 Data analysis

According to Levene's test for homogeneity of variance and Kolmogorov-Smirnov test for normality, none of the parameters measured during this study fulfilled the requirements of parametric statistics. Therefore non-parametric statistics were performed. Data were analysed in STATISTICA (v. 13). The analyses used with this software were tests of differences. A Kruskal-

Wallis ANOVA test was performed to test for differences in insects parameters between sites, months, and season at each sampling event at a confidence interval of 0.05 (Fowler *et al.* 2005).

Table 6.2 Data sheet used during the survey to record the insect's parameters and damage by insect and pathogens to water hyacinth plant.

SITE NAME: Bonassama Vallee……..

DATE …………………………..…………

- *AGENT DATA:*

	WEEVILS:					
Plant	**No. of *N. eichhorniae* adults**	**No. of *N. bruchi* adults**	**No. of feeding scars on leaf 2**	**No. of larvae**	**No. of petioles mined**	**Pupae Pres / abs**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

	MITE:	**MOTH:**			**MIRID:**		**PATHOGEN**
Plant	**% of leaf area damage on leaf 5**	**Pres / abs**		**No. of petioles mined**	**% of leaf area damage on leaf 4**	**Nymphs Pres / abs**	**Pres /abs**
		larvae	**pupae**				
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

ADULT MIRIDS:	
Pres / abs at site	**Approx. No. per plant**

General Comments include description of weather today and generally preceding collection date, i.e. wind, rainfall, sunlight, temperature, etc: ____ .

6.5 Results

6.5.1 Insects associated with water hyacinth in the Wouri Basin

During the survey of the entire Wouri Basin over the two seasons (dry and rainy), signs of leaves damaged by weevils (feeding scars), larval feeding damage and petioles mined were recorded on the leaves of water hyacinth plants. The species found were the both *Neochetina* species (Figure 6.1).

It is important to note that, during the rainy season (June-October 2014), the weevils were not found in any of the ten sites chosen for a long-term study at the beginning of the survey. The weevils were found in other areas, such as the municipality of Bonalea (Fiko River), at Bonendale and Pillar in Douala IV, at Yassem 1 and 2, Lendi, Bonangando, Bonamouang, Mbangué and Bonaloka in Douala V (Table 6.3).

However, during the dry season (November 2015–April 2016), besides the sites where the weevils were found during the rainy season, weevils and signs of feeding scars on the leaves were found at Cassablanca, Mbakoko Mbangué, and Mbanya in Douala V, while in Douala IV, they were found at Château, Petit Bonanjo 1 and 2, which were three of the ten sites selected at the beginning of the survey (Table 6.4).

In all these areas, leaves damaged by pathogens were also found associated with leaves damaged with feeding scars (Figure 6.2, Table 6.3, and Table 6.4).

Only *N. eichhorniae* was found at Bonendale, Bonaloka, Mbakoko Mbangue, Mbanya, Pillar, Petit Bonanjo 1 and Petit Bonanjo 2, while both *Neochetina* species were found in the remaining sites (Table 6.3 and Table 6.4).

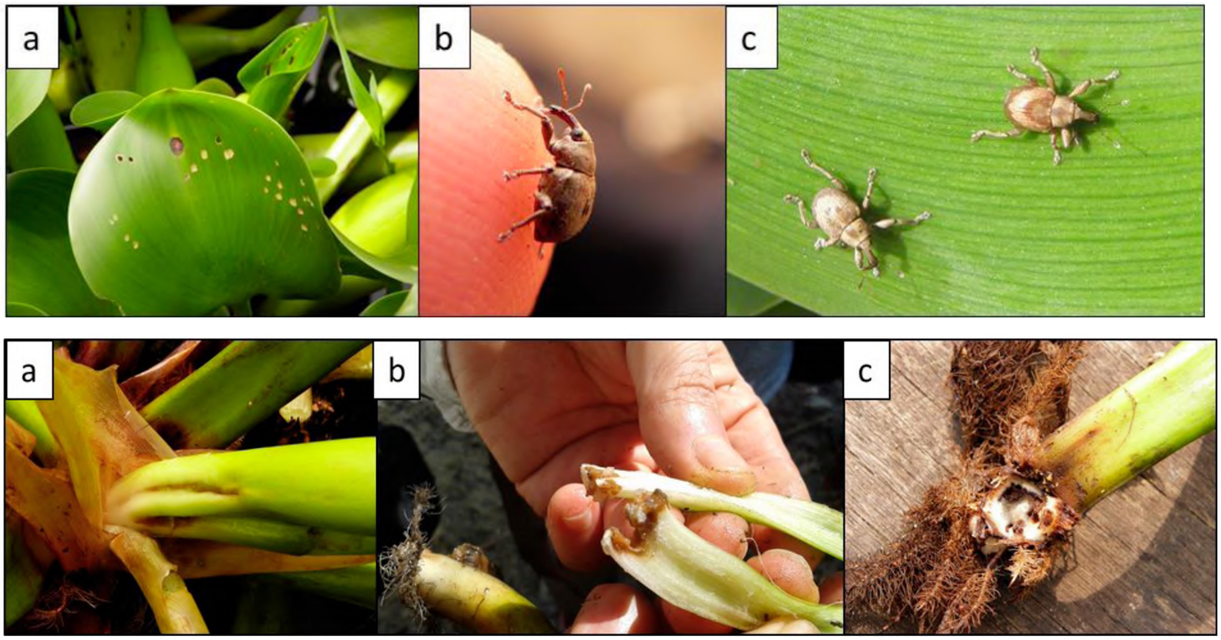


Figure 6.1 (a) The adult feeding damage of the two weevils *N. eichhorniae* and *N. bruchi*, (b and c). The adult weevils were collected from the Wouri River (Picture above), and *Neochetina* weevil larval feeding damage (Picture below). a) Feeding damage externally visible, b) petiole damage and c) feeding on the crown of the water hyacinth plant, where most damage to the plant is caused.

Figure 6.2 Leaves presenting the feeding scars of the weevils *Neochetina* species ○ and the pathogens ○ at Bonangando (a), Yassem (b) and Fiko (c).

Table 6.3 Different sites where biological control agents (*N. eichhorniae* and *N. bruchi*) were found during the rainy season.

Season	Location	Biological control agents		Pathogens not identified (Absence/ Presence)
		Neochetina eichhorniae	*Neochetina bruchi*	
Rainy season (between June and October 2014)	Fiko	✓	✓	✓
	Lendi	✓	✓	✓
	Bonendale	✓	x	✓
	Yassem 1	✓	✓	✓
	Yassem 2	✓	✓	✓
	Mbangue	✓	✓	✓
	Bonamouang	✓	✓	✓
	Pillar	Feeding scars on leaves, but no adults found		✓
	Bonangando	✓	✓	✓
	Bonaloka	Feeding scars on leaves, but no adults found		✓

6.5.2 Population dynamics of insects and pathogens on water hyacinth

6.5.2.1 Rainy season

During the rainy season and especially in June, Fiko presented the highest number of *N. eichhorniae* with an average of 0.4 adults per plant, the highest number of feeding scars (20.2), number of larvae (0.7) and petioles mined (2.6) respectively (Table 6.5). It was followed by Bonangando, and Bonendale. The highest number of *N. bruchi* was found at Mbangue and Bonangando (Table 6.5). During this month, no sign of pupae was found in any of these sites.

Table 6.4 Different sites where biological control agents (*N. eichhorniae* and *N. bruchi*) were found during the dry season.

Season	Location	Biological control agents		Pathogens (Absence/ Presence)
		Neochetina eichhorniae	*Neochetina bruchi*	
Dry season (between October 2015 and April 2014)	Fiko	✓	✓	✓
	Lendi	✓	✓	✓
	Bonendale	✓		✓
	Yassem 1	✓	✓	✓
	Yassem 2	✓	✓	✓
	Mbakoko Mbangue	✓		x
	Mbangue	✓	✓	✓
	Cassablanca	✓		x
	Bonamouang	✓	✓	✓
	Mbanya	✓		x
	Chateau	✓	✓	x
	Petit Bonanjo 1	✓		x
	Petit Bonanjo 2	✓		x
	Pillar	✓		✓
	Bonangando	✓	✓	✓
	Bonaloka	✓		✓

In October, while Fiko, Lendi, Bonendale, Yassem 1, Yassem 2 and Mbangue had similar numbers of *N. eichhorniae* with an average of 0.3 and 0.2 respectively, the highest record of *N. eichhorniae* was found at Bonangando with an average of 0.6 adults per plant. *N. bruchi* was also found at Fiko and Yassem 1, with an average of 0.4 each, while at Yassem 2, only an average of 0.1 adults of *N. bruchi* was found (Table 6.5). The number of feeding scars was high at Fiko and Yassem 1, with 36 and 38.8 of average per plant respectively; it was followed by Bonangando (19.7), Yassem 2 (9.3) and Bonendale (6.2). The remaining sites had a low number of feeding scars ranging between 5 and 0.7 on average, per plant. Although no sign of larvae was found at Bonendale and Bonaloka, the remaining sites showed almost the same average number of larvae, with the lowest found at Yassem 2 and Bonendale which each had 0.1 average number of larvae per plant (Table 6.5). The highest number of petioles mined was found at Fiko and Yassem 1 with an average of 3.4 and 1 respectively (Table 6.5). Although, no pupae in any of these sites was found in June, in October, they were recorded at Bonangando and Mbangue with an average of 0.7 and 0.3 pupae per plant respectively (Table 6.5).

6.5.2.1.1 Kruskal-Wallis ANOVA test of each of the parameters recorded between month and sites during the rainy season

The parameters used in this statictical analysis were from insects in their different life stage. These insect parameters were used as their life may differ from region to another one and also according to the conditions or weather prevailing in the area surveyed. A study carried out in the semi arid zone of Nigeria by Hamadina *et al.* (2015) showed the entire life cycle of *N. bruchi* lasted for 79 days while for *N. eichhorniae* lasted for more than three months (average of 98 days).

The Kruskal-Wallis test of the different parameters recorded during the rainy season showed no significant difference in the number of *N. bruchi*, number of larvae, number of petioles mined at any of the sampling event between months, while a significant difference was found in the number of *N. eichhorniae*, the number of feeding scars and the number of pupae (Table 6.6). However, with exception of the number of *N. bruchi* which was not significantly different between sites, the other paramters showed a significant difference between sites at each of the sampling events (Table 6.6).

Table 6.5 The H-test statistic and p-value for the Kruskal-Wallis test performed on insesct parameters recorded between all the sites sites and the different months when the Wouri Basin was surveyed during the rainy season. The numbers in brackets indicate the degrees of freedom and the total sample size. The values in **bold** indicate significant differences.

Insect parameters	Source of variation			
	Sites (9, 200)	**p value**	**Months (1, 200)**	**p value**
Number of *N. eichhorniae*	21.69	**0.01**	4.41	**0.03**
Number of *N. bruchi*	15.97	0.07	0.82	0.37
Number of feeding scars	83.81	**0.000**	8.30	**0.004**
Number of larvae	17.21	**0.045**	3.54	0.60
Number of petioles mined	103.29	**0.000**	0.15	0.70
Number of pupae	21.47	**0.01**	5.10	**0.02**

Table 6.6 Mean number of *Neochetina eichhorniae*, *Neochetina bruchi*, number of feeding scars, number of larvae, number of petioles mined, and number of pupae found in the different sites in June and October, during the rainy season.

Months	Location	Mean ± SD No of *N. eichhorniae*	Mean ± SD No of *N. bruchi*	Mean ± SD No of feeding scars on leaf 2	Mean ± SD No of larvae	Mean ± SD No of petioles mined	Mean ± SD Pupae
June 2014	Fiko	0.4±0.22	0	20.2±2.48	0.7±0.37	2.6±0.4	0
	Lendi	0	0	1.2±0.42	0	0	0
	Bonendale	0.1±0.1	0	1.1±0.60	0	0	0
	Yassem 1	0	0	6.7±3.06	0	0.6±0.34	0
	Yassem 2	0	0	8.9±3.59	0	0	0
	Mbangue	0	0.3±0.21	0.9±0.80	0	0.7±0.47	0
	Bonamouang	0	0	0	0	0	0
	Pillar	0	0	0	0	0	0
	Bonangando	0.3±0.21	0.3±0.21	7.1±2.19	0	0.7±0.47	0
	Bonaloka	0	0	15.4±3.61	0.2±0.13	0	0
October 2014	Fiko	0.3±0.15	0.4±0.16	36±3.28	0.3±0.15	3.4±0.52	0
	Lendi	0.2±0.13	0	5±2.54	0.4±0.22	0.2±0.2	0
	Bonendale	0.2±0.13	0	6.2±1.84	0	0	0
	Yassem 1	0.3±0.15	0.4±0.31	38.8±11.01	0.3±0.21	1±0.52	0
	Yassem 2	0.2±0.13	0.1±0.1	9.3±5.02	0.1±0.1	0.1±0.1	0
	Mbangue	0.3±0.21	0	5.3±2.12	0.2±0.13	0.3±0.21	0.3±0.21
	Bonamouang	0	0	1.4±1.4	0.2±0.2	0	0
	Pillar	0	0	0.7±0.47	0	0	0
	Bonangando	0.6±0.34	0	19.7±3.94	0.1±0.1	0.3±0.21	0.7±0.42
	Bonaloka	0	0	2.7±1.09	0	0	0

6.5.2.2 Dry season

Compared to the ten sites where the presence of weevils and signs of damage on the leaves were found during the rainy season, during the dry season, the presence of weevils was recorded at six more sites.

In November, the number of *N. eichhorniae* was high at Bonamouang with an average of one adult weevil per plant sampled, while the lowest number of *N. eichhorniae* was found at Petit Bonanjo 2 (0.1) (Table 6.7). No weevils were found at Fiko, Lendi, Yassem 1, Cassablanca, and Pillar. The highest number of *N. bruchi* in October was found at Fiko and at Bonamouang with an average of 0.3 adult weevils per plant, while at Mbangue the lowest number of weevil *N. bruchi* was recorded (0.1). The weevil was not found at the remaining sites (Table 6.7). The mean number of feeding scar was very high at Fiko (74.1), Bonaloka (70.2), Bonangando (34.8) and at Château (25.2) (Table 6.7). The lowest number of feeding scars was recorded at Cassablanca. Bonamouang showed the highest number of larvae (1.1), while at Fiko, an average of 2.5 petioles mined was found per plant in November (Table 6.7).

In April, the highest number of *N. eichhorniae* was recorded at Fiko, while the highest number of *N. bruchi* was recorded at Yassem 2 and Château (Table 6.7). As for the number of feeding scars, number of larvae and the number of petioles mined, they were all high at Yassem 2 (Table 6.7). The highest number of pupae was recorded at Bonamouang with an average of 0.3 per plant sampled (Table 6.7).

During the dry season, at each of these sites, although the number of *N. eichhorniae* adults reached 1 at Bonamouang, Fiko and Yassem, it remained very low in other sites, with adults of *N. eichhorniae* ranging between 0.1 and 0.8 per plant, and between 0.1 and 0.6 for *N. bruchi*. However a slight increase was noted during the dry season compared to the rainy season where it was very low.

Table 6.7 Mean number of *Neochetina eichhorniae*, *Neochetina bruchi*, number of feeding scars, number of larvae, number of petioles mined and number of pupae found in the different sites in November and April during the dry season.

Months	Location	Mean ± SD No of *N. eichhorniae*	Mean ± SD No of *N. bruchi*	Mean ± SD No of feeding scars on leaf 2	Mean ± SD No of larvae	Mean ± SD No of petioles mined	Mean ± SD Pupae
November 2015	Fiko	0	0.3±0.21	74.1±20.10	0.8±0.29	2.5±0.48	0
	Lendi	0	0	6.2±1.99	0	0	0
	Bonendale	0.2±0.13	0	4.7±2.59	0.2±0.13	0	0
	Yassem 1	0	0	4.2±2.24	0	0	0
	Yassem 2	0.1±0.1	0	18±6.59	0.2±0.13	0.3±0.21	0
	Mbakoko Mbangue	0	0	6±2.33	0	1±0.39	0
	Mbangue	0.2±0.13	0.1±0.1	9.7±2.16	0	1.9±0.74	0.8±047
	Cassablanca	0	0	1.1±0.64	0	0	0
	Bonamouang	1±0.60	0.3±0.21	3.7±1.98	1.1±0.60	0.8±0.47	0.1±0.1
	Mbanya	0.3±0.21	0	0.8±0.8	0	0.7±0.47	0
	Chateau	0.4±0.22	0	25.2±4.24	0.9±0.35	1.8±0.63	0
	Petit Bonanjo 1	0.1±0.1	0	10.7±2.74	0.1±0.1	0.1±0.1	0
	Petit Bonanjo 2	0.2±0.13	0	8.8±3.53	0.2±0.13	0	0
	Pillar	0	0	0.7±0.47	0	0	0
	Bonangando	0.8±0.47	0	34.8±10.75	0	1.9±0.74	0.8±0.47
	Bonaloka	0	0	70.2±4.09	0	0.1±0.1	0.3±0.15
April 2016	Fiko	1±0.42	0	55.4±11.90	0.4±0.22	2.4±0.54	0
	Lendi	0.1±0.1	0.1±0.1	15.2±5.58	0.1±0.1	0.3±0.21	0
	Bonendale	0	0	9.6±4.96	0.2±0.2	0.2±0.2	0
	Yassem 1	0.3±0.21	0	13.8±4.44	0.2±0.13	0.5±0.27	0
	Yassem 2	1±0.52	0.6±0.31	99±14.27	3.2±0.85	6.8±0.71	0

Months	Location	Mean ± SD No of *N. eichhorniae*	Mean ± SD No of *N. bruchi*	Mean ± SD No of feeding scars on leaf 2	Mean ± SD No of larvae	Mean ± SD No of petioles mined	Mean ± SD Pupae
April 2016	Mbakoko Mbangue	0.3±0.15	0	27.2±7.90	0.4±0.16	1±0.47	0
	Mbangue	0.5±0.27	0	11.2±3.29	0.6±0.34	3.6±1.25	0.1±0.1
	Cassablanca	0.3±0.15	0	11.8±5.36	0	0.2±0.13	0
	Bonamouang	0.5±0.34	0	17.6±4.13	0.1±0.1	0.2±0.2	0.3±0.21
	Mbanya	0.1±0.1	0	1.6±0.64	0	0	0
	Chateau	0.2±0.13	0.5±0.22	23.8±4.80	0.7±0.3	1.2±0.49	0.2±0.2
	Petit Bonanjo 1	0.2±0.13	0	15.8±2.74	0.1±0.1	0.1±0.1	0
	Petit Bonanjo 2	0.3±0.15	0	17.2±4.50	2.5±0.34	2.5±0.45	0.1±0.1
	Pillar	0.3±0.21	0	7.9±3.62	0	0.2±0.13	0
	Bonangando	0.7±0.42	0	28.7±10.18	1.1±0.55	3.6±1.25	0.1±0.1
	Bonaloka	0.5±0.22	0	34.7±5.83	0.8±0.33	1.6±0.6	0

6.5.2.2.1 Kruskal-Wallis test of each of the parameters recorded between month and sites during the dry season

With exception of the number of *N. bruchi* and the the number of pupae which has showed no significant difference between months, a significant difference was found in the number of *N. eichhorniae*, number of feeding scars, the number of larvae, and the number of petioles mined during the dry season (Table 6.8). Although no significant difference was found in the number of *N. eichhorniae* between sites, a significant difference was noted in the number of *N. bruchi*, the number of feeding scars, the number of larvae, the number of petioles mined and the number of pupae between sites during the dry season (Table 6.8).

Table 6.8 The H-test statistic and p-value for the Kryskal-Wallis test performed on insescts parameters recorded between all the sites sites and the different months when the Wouri Basin was surveyed during the dry season. The numbers in brackets indicate the degrees of freedom and the total sample size. The values in **bold** indicate significant differences.

Insect parameters	Source of variation			
	Sites (15, 320)	**p value**	**Months (1, 320)**	**p value**
Number of *N. eichhorniae*	16.50	0.35	10.26	**0.001**
Number of *N. bruchi*	28.71	**0.02**	0.53	0.47
Number of feeding scars	100.29	**0.000**	25.76	**0.000**
Number of larvae	71.78	**0.000**	14.63	**0.0001**
Number of petioles mined	103.10	**0.000**	11.74	**0.0006**
Number of pupae	40.11	**0.0004**	1.14	0.3

6.5.2.3 Kruskal-Wallis test between seasons and months for each of these parameters

No significant difference was recorded in the number of *N. bruchi* between seasons, whilst a significant difference was noted between seasons for the other parameters (Table 6.9). As for the number of *N. eichhorniae*, *N. bruchi*, number of feeding scars, number of larvae, number of petioles mined and the number of pupae, a significant difference was found at each sampling event between sites (Table 6.9).

Table 6.9 The H-test statistic and p-value for the Kruskal-Wallis test performed on insescts parameters recorded between all the sites sites and both seasons when the Wouri Basin was surveyed. The numbers in brackets indicate the degrees of freedom and the total sample size. The values in **bold** indicate significant differences.

Insect parameters	Source of variation			
	Seasons (1, 640)	p value	Sites (15, 640)	p value
Number of *N. eichhorniae*	16.43	**0.0001**	33.12	**0.004**
Number of *N. bruchi*	1.34	0.25	32.62	**0.005**
Number of feeding scars	94.50	**0.000**	165.29	**0.000**
Number of larvae	35.54	**0.000**	64.41	**0.000**
Number of petioles mined	49.71	**0.000**	180.22	**0.000**
Number of pupae	5.89	**0.015**	62.94	**0.000**

6.6 Discussion

Of the eight biological control agents which have been released around the world to manage water hyacinth, only two *Neochetina* species were found in the Wouri Basin, specifically *N. eichhorniae* and *N. bruchi*. The presence of the weevils in Cameroon, although Cameroon has not yet initiated biological control, can be explained by the fact that countries surrounding Cameroon, have released these agents to control the spread of water hyacinth in their countries. These countries include: Nigeria which has released both *Neochetina* species, Benin which has released both *Neochetina* species and the moth *N. albigutallis,* and Congo which has released both *Neochetina* species (Julien 2000, Navarro & Phiri 2000, Mbati & Neuenschwander 2005). Biological control in these countries has proved to be a very cost efficient control method. Indeed, in Benin, De Groote *et al.* (2003) studied the economic impact of biological control of water hyacinth and found that if well adapted, biological control can cheaply be exported to many countries to improve the life of million people. The results of this study (De Groote *et al.* 2003), showed that, before the release of biological control agents, the economic loss due to water hyacinth was estimated at US$2151 per household, while the impact of biological control was US$783 per household. Moreover, while extrapolated, by taking in account the 39000 households present in the studied region, a total economic loss due to water hyacinth was estimated at US$83.9 million especially in fishing (64%) and in fish trade (24%). These losses were reduced with an increase of almost US$30.5 million, mostly from fishing (72%) and trading food crops (17%) after the release of the weevils *N. eichhorniae* and *N. bruchi*, increase tht they attributed entirely to the reduction in water hyacinth cover, and therefore, associated it to the benefit of biological control.

Although present in Cameroon, the population of these weevils was small and isolated, with an average of 0.1 adult weevils in sites where they were present during the rainy season, and an average of 0.3 adult weevils in all the sites investigated during the dry season which showed to do not have a great impact on the plant morphology. The species which was most common was *N. eichhorniae*. These results are similar to the field study carried out by Apabey (2012) who showed that, the population of the *Neochetina* weevils in Ghana, was really affected in the Tano Lagoon during the rainy season, for which reason he proposed augmentative release of the weevils regularly during the rainy season.

The small number of adult weevils can be associated first with the small number of feeding scars, larvae, pupae and petioles mined recorded during this study. Indeed, the higher the weevil density, the greater the impact of the weevils will be on the plants. In this case, with respect to the surface area covered by water hyacinth in these sites, only few plants showed the feeding scars of weevils, and the plants were still healthy, and no real impact was noticeable. During the rainy season, an average of less than ten feeding scars were counted at Lendi, Bonendale, Yassem 2, Mbangue, Bonamouang and Bonaloka, while during the dry season, sites with less than ten feeding scars included Bonendale, Cassablanca, Mbanya, Pillar, Petit Bonanjo 1 and Petit Bonanjo 2.

Second, the scarcity of weevil population can also be attributed to the tidal fluctuation of water occuring in the Wouri Basin. Hill & Cilliers (1999) found that one of the biggest impediments to the successful control of water hyacinth included catastrophic reduction of the weevil populations by periodic or annual floods. However, during the current field work a slight difference in the abundance of the weevil population was noticed between the different sites surveyed. In sites where water hyacinth plants were always floating, the agents appeared to be better established than in sites which are subjected to a constant tidal fluctuation of water, and where, during low tide, roots of plants were in contact with sediment. The sites where tidal fluctuation of water occurs regularly are : Château, Petit Bonanjo 1, Petit Bonanjo 2 and Bonendale in Douala IV, Mbanya in Douala V. These observations could explain why during the first survey between June and October 2014, no weevils were found in the ten selected sites for long-term study at the beginning of the survey, where they were only found during the dry season. Similar results were found in the Tano River (Ghana). There, Akpabey (2012) found that in sites where the flooding regimes occured, a very low number of adults weevils per plant was recorded.

Although recorded in the Wouri Basin, the number of adult weevils found per plant was stillbelow the number of weevils required per plant to get effective control. According to post-releases studies carried out around the world, this number should be ranged between 5 and 7 adult weevils in average per plant. Haag (1986) in his study in the Richardson pond (USA), found that after winter, the population of the weevils increased from an average of 1.6 to 4.6 adults of *N. eichhorniae* per plant leading to the death of all plant by late April 1985. Similarly, field studies conducted by Jayanth (1988), showed that the collapse of water hyacinth in India was the result of the presence of five to seven adults per plant. In Bangalore, Mexico, Visalkshy and Jayanth (1996) found that under field conditions, successful control of water hyacinth was reached in water bodies where the plants were free floating with an average of 5.8 *N. eichhorniae* adults per plant and six *N. bruchi* per plant. Moreover, Ochield *et al.* (2001) showed that the success of water hyacinth control on Lake Victoria, on the Kenyan shore four years after the introduction of the weevils was due to the high number of weevils adults per plant. The adult weevils varied from zero to 32 per plant with an average of six adults per plant leading to the reduction of the weed coverage by up to 80 %.

At Fiko, which is one of the sites where the weevils were better established in the Wouri Basin compared than at other sites, a difference in surface area covered by water hyacinth was noted between data recorded during the rainy season and the dry season. The surface of water which could not been seen during the first survey in 2014, was visible during the second survey in 2016. However, the reduction of water hyacinth mats which has led to the appearance of water could not be assigned with certainty to the work of the weevils *Neochetina* species alone. The pathogens were found associated with leaves presenting the feeding scars of the weevils, however, leaves damaged by pathogens were also found and collected in sites where the agents were not present (Chapter 5). Besides, it could not be confirmed whether the pathogens were present because of the weevils, or the dispersion was greater in the presence of insects.

6.7 Conclusion

The results gathered during this field work, raised several other questions which need to be answered and developed further. These questions were: what impact could the tidal fluctuation of water have on the population growth of the *Neochetina* species; what role do the weevils play in term of pathogen dispersion, and finally, what is the impact of weevils on the reduction of the water hyacinth mat. Moreover, although assumed that the weevils were drained with water hyacinth through water currents from Nigeria, it is relevant to note that the release sites in Nigeria and the Congo are all rather far away and not in the same river systems (Neuenschwander *p. com.*). Therefore a follow up would certainly be highly recommended every two years for example. Furthermore, a mass rearing facility of the weevils should be built up in order to start their release in specific locations which are not too musch disturbed by tides.

7 Chapter 7. The influence of a tidal regime on the population dynamics of two biological control agents on water hyacinth

7.1 Introduction

Neochetina eichhorniae is the primary biological control agent presently used against water hyacinth around the world. The adults feed on the epidermis of the leaves, producing discreet feeding scars, and lay their eggs beneath the leaf and petiole epidermis; while the larvae, which is the damaging stage in the 3rd instar, makes a tunnel in the petiole and often in the meristematic tissue in the crown of the plant. The result is a decrease in the leaf length and petiole thickness together with an increase in the leaf mortality and an overall reduction in plant biomass (Forno 1981, Center & Van 1989, Center 1985). All this leads to the disruption of water hyacinth leaf dynamics through the death of the plant when leaf mortality exceeds leaf production (Center & Van 1989; Van & Center 1994).

Recorded in the Wouri Basin, the impact of the weevils *Neochetina* species was not quantifiable, especially in areas which were subjected to tidal fluctuation of water (Chapter 6). Indeed, although present in the Wouri Basin, the weevils were not present in all ten tributaries selected at the beginning of the survey (Chapter 2), and where they were found, they were scarce.

These different observations led to the following hypothesis: the exposure of the roots to tidal movement, the manual removal of water hyacinth throughout the Wouri-Basin reduces the pupation success by the weevils; and therefore affects the growth of the population of weevils in the Wouri-Basin.

7.2 Aim and objectives

7.2.1 General objective

So, to understand the results gathered in the previous chapter (chapter 6), the aim of this study was to determine the impact of tidal fluctuation of water on the pupation success of the weevil *N. eichhorniae*.

7.2.2 Specific objectives

It was to assess the growth of population under different treatments, and also to assess if the fluctuation ofwater has an impact on the damage caused by the weevil.

7.3 Material and Methods

After the first survey in Cameroon between June and October 2014, several experiments were set up in South Africa to mimic as closely as possible the natural conditions occurring in the field.

7.3.1 Experimental set up

To assess the impact of tidal movement on the pupation success of the larvae and thus the population growth of the weevil, two different experiments were carried out in a greenhouse at Waainek, Grahamstown, South Africa. Each of these experiments trials were conducted inside three large recirculating hydroponic systems or tanks. The system ran in parallel and two of the three tanks comprised a series of twelve 15litre buckets, the third containing no buckets but worked as a supply tank or a collection tank (Figure 7.1).

The experimental tanks consisted of tubs of 110cm by 90cm, and 46cm high, filled with 911litres of borehole water and covered with a fine mesh sleeve with a mesh diameter of 0.5mm. The fertilizer multicote six month formula was used to introduced total nitrogen at a rate of 50.5mg/l N L^{-1} (N:P:K:Mg ratio of 15:3:12:7) and approximately 6 g of commercial iron chelate (13%Fe) was added to the reservoir. The nutrient levels for this experiment are classed by Holmes (1996) as hypertrophic and are the upper levels for water hyacinth growth (Reddy *et al.* 1989, 1990). A gravity-driven flow rate of water circulating through the system was approximately 40-60 l min^{-1}. A pump returned water from the tanks containing plants to the supply tank. Before each bucket used for the experiment was placed in a designated tank, several holes were made at the bottom of each, after which they were filled with mud to one third the height of the bucket. The mud was added to obtain sedimentation and silt coverage of root hairs similar to that in the field situation when there is no water.

Figure 7.1 Photo of the experimental set up used during the two experiments carried out in South Africa. (a) the tidal tank, (b) reservoir and (c) theriver tank.

From the two tanks where buckets were included, one system had always water 24/24h; in the other system, the movement of the tide was mimicked using a timer, so that plants had water for six hours, and after six hours, the water was drained out of the system to the supply tank, leaving the plant without water and the root hairs lying directly on the mud. The tidal system plot design was to simulate the natural condition as closely as possible. The tank where the plants were always floating was called “river”, while the tank where plants were subjected to tidal changes was called “tidal”.

Twenty-four water hyacinth plants of similar size (leaves, 6–7, petiole length, 20.17 cm (±0.66SD); fresh weight, 104.9 g (±15.11SD), dry weight, 7.5 g (±1.04SD) , which had been grown under the same conditions, were collected from insect–free stock ponds in the tunnel. All the dead material and daughter plants were removed and each plant was washed in fresh water. After washing, individual plants of uniform size were transferred to each bucket in each of the two tanks and each bucket was immediately covered with the fine mesh sleeve to prevent insects entering or leaving. The mesh sleeve fitted snugly around the brim of the tubs and extended 1 metre above the water surface. The plants were given 14 days for acclimation to the conditions of the experiment before any larvae or insects were released or plant parameters recorded. During the acclimation time, the plants were sprayed with the acaricide Kirchhoffs Ludwig's "Insect spray" to minimize the chance of red spider mite (*Tentranychidae*) and aphid contamination which contains as active ingredients garlic juice extract, canola oil, natural pyrethrum (pyrethrins) and piperonyl butoxide. The plants were washed down with fresh water prior to the inoculation of larvae or insects.

The daily maximum and minimum water temperature inside each experimental tank were recorded using a continuous Thermochron iButton (DS1922L#F5 Maxim/Dallas iButton Products; temperature range from -40 °C to +85 °C, an accuracy of ±0.5 °C from -10 °C to +65 °C, and a sampling rate from 1s to 273 hours). Three data loggers were introduced into each system, the river (free-floating) and the tidal system. The daily maximum and minimum temperature for tunnel air in the green-house was also recorded using a iButton (DS1923L#F5 Maxim/Dallas iButton Products; temperature range from -20 °C to +85 °C, an accuracy of ±0.5 °C from -10 °C to +65 °C, 0 to 100% RH, and a sampling rate from 1s to 273 hours) which was placed in the greenhouse to record conditions under which the plant grows and see if they were similar to those encountered in the field in tropical and subtropical areas. There was a general downward trend in the temperature data as the experiment ran from late summer into early winter (Figure 7.2).

The first experiment was carried out between March 2015 and June 2015, while the second experiment was carried out between end of August 2015 and October 2015. For each of these experiments, third instar larvae and adult weevils of *N. eichhorniae* were sourced from New Year's Dam in Alicedale, Eastern Cape, South Africa (S: 33°18'6.84'' E: 26°6'45.36''), where the weevil had been released to control water hyacinth. Plants damaged by the weevils were collected in the dam and placed in big buckets filled with water and brought to Waainek.

For the first experiment, carried out between March and June 2015, after the first two weeks of acclimatation to which plants were subjected, third instar larvae were removed from the plants collected at New Year's Dam and inoculated into the lower part of the petiole of each test plant. Once the larvae had migrated into the petiole, the plant was replaced in its bucket. The larvae were inoculated on Friday 20th March 2015, and two days acclimatation allowed to the larvae before the timer in the tidal system was set up for six hours without and with water.

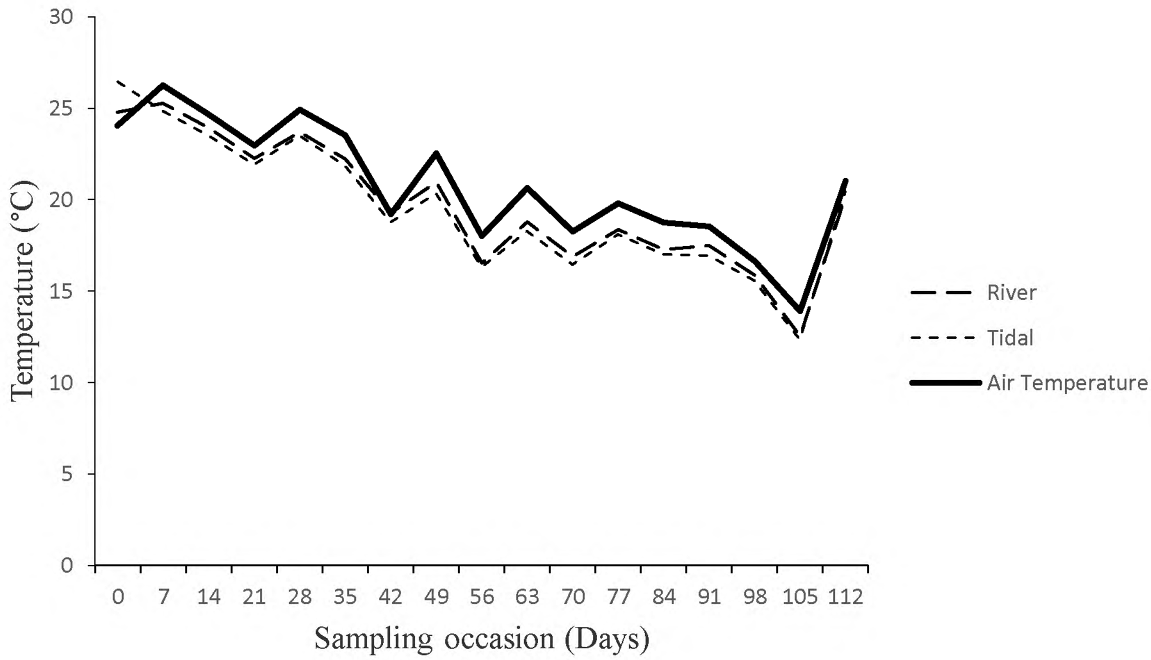


Figure 7.2 Average weekly temperature (water and air) recorded in the green house for the duration of the experiment.

To ensure that all larvae inoculated at the beginning of the experiment had the chance to emerge as adults, each trial was stopped at 14 weeks, which is maximum development time of a single generation of weevils, as determined from literature (Chapter One).

The life stage for *N. eichhorniae* from larvae to pupae varies between 56 and 58 days (Hamadina *et al.* 2015), although Cordo (1976) reported longer durations of 75-90 days for the larval stages of *N. eichhorniae* in Argentina. The pupal stage to adult emergence varies from 26 to 28 days (Hamadina *et al.* 2015) with an entire life cycle duration from eggs to adults of up to 120 days (DeLoach & Cordo 1976a); these rates vary still further with location.

For the second experiment, the same system was used, but this time with adult weevils of *Neochetina* species. The importance to use both *N. eichhorniae* was to assess the performance and impact that tidal condition might have on either biological control agent. Before the insects were introduced to the system, plants were left for a 14 days period of acclimatation to the conditions of the experiment. The experimental treatments consisted of a single insect species per bucket, resulting in two treatments and one control where no insects were released. The tubs were arranged in a randomized block design to minimize any confounding factors associated with position in the tunnel (Figure 7.3). As with the larvae, the adults were collected from damaged plants at the New Year's Dam. The *Neochetina* weevils arrived two weeks before the experiment, the species were separated and kept in plastic containers, the containers were cleaned and leaves were replaced daily to ensure no food shortage.

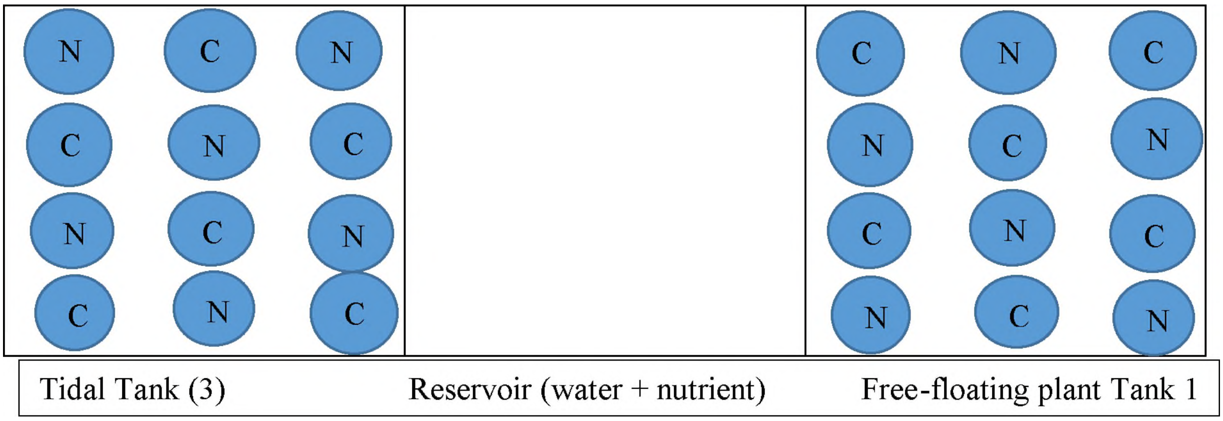


Figure 7.3 Design of experiment using adult biological control agents. C = Control without insect, N = *Neochetina eichhorniae*.

As in the first experiment, at Week 0, each bucket had one plant each of similar size and weight (leaves, 5–6, petiole length, 17 cm (±0.29SD); fresh weight, 103.49 g (±6.17SD), dry weight, 4.09 g (±0.23SD).

For each treatment containing the weevils, two adult weevils of *N. eichhornia* were introduced at a 1:1 sex ratio (one male and one female). The density of one pair of adult insects per plant was representative of several local stands of water hyacinth where the weevils are well establishedin Cameroon, but also to ensure that the plants in the experimental tubs did not collapse before the end of the experiment due to weevil herbivory. Each bucket in each of the two water tanks was immediately covered in the fine mesh sleeve to prevent insects entering or leaving.

7.3.2 Data collection

7.3.2.1 Plant parameters

For each experiment the plant parameters were recorded at the beginning and at the end of the experiments; these parameters included the length of the longest petiole, the length of the second leaf, the number of leaves, the number of ramets, with a ramet being defined as a plant with one open leaf (excluding the primary leaf) (Center & Spencer 1981), the leaf surface area for the second leaf, and the maximal root length.

7.3.2.2 Leaf turnover

The leaf turnover was only assessed for the first experiment which used larvae, at Waainek and was therefore measured by labeling the youngest leaf (10^{th} April 2015) and recording the position of that leaf on the next sampling event, then moving that label back to the youngest leaf.

7.3.2.3 Plant biomass

The biomass of the plants was taken for the whole plant, separating the plant into above water, below water and dead organic matter and weighed separately at the end of the experiment for both the experiments carried out at Waainek. Samples were dried at 70 °C for 72 hours or to a constant weight for larger plants, and shoot and root dry weights were recorded.

As we were just interested at the population growth of the weevils during the second experiment, the plant's biomasses were not assessed.

7.3.2.4 Insect parameters

- ***Neochetina eichhorniae***

Adult feeding scars were counted on both the upper and underside of leaf two. At any sampling time, when the main plant presented a ramet with a second leaf, the number of feeding scars were also counted on the second leaf. The total number of petioles mined by the larvae was recorded. Since plants were not destructively sampled during the experiment larval mining of the petioles could only be recorded once it was externally visible on the petiole. The mean number of feeding scars was evaluated by adding up all feeding scars present on the second leaf of the main plant and the daughter plant and then dividing it by the number of second leaves counted.

At the end of each experiment, the total number of adult insects from these plants, plus next-generation larvae, pupae were counted.

7.3.3 Water parameters

In the first experiment, water parameters were measured weekly as for the plant parameters in each of the tanks used. The parameters measured were: temperature, pH, conductivity, salinity, TDS, nitrate and ammonium.

7.4 Statistical analysis

All the data were analyzed on STATISTICA (v. 13). According to the Levene test for homogeneity of variances, Kolmogorov-Smirnov test for normality and Mauchly sphericity test, all the plant parameters except the number of leaves did not fulfil the assumptions and requirements of an ANOVA for repeated-measures. A Kruskal-Wallis ANOVA test was performed to test for differences in plant parameters between treatment (control or *Neochetina*), and system (tidal or river) at each sampling event at a confidence interval of p=0.05 (Fowler *et al.* 2005).

The biomass parameters measured fulfilled the Levene's test for homogeneity of variances and the Kolmogorov-Smirnov test for normality requirements of a one-way ANOVA. Therefore a one-way ANOVA was performed on the biomass parameters to test for differences between them. To test whether there was any significant difference between the two treatments in the first experiment, an independent sample t-test was performed.

Concerning the number of feeding scars, the number of leaves damaged by the weevils and the number of petioles, a Tukey HSD post-hoc test was conducted at a confidence level of p=0.05 (Fower *et al.* 2005) to determine the statistical differences for the effects of time and treatment (river, tidal).

7.5 Results

7.5.1 Plant parameters

The plant growth parameters of water hyacinth for the first experiment were not affected by the different treatments (river or tidal) once the adults emerged and started to feed on the plant (Table 7.1). When data were compared from the beginning (Week 0 (W0)) to the end (Week 12 (W12)) for the river and tidal treatment, there were no significant differences between these treatments (river or tidal) for the length of the second leaf petiole. However, the longest leaf petiole, number of leaves, the maximum root lengths, and number of ramets had increased significantly between time (at the beginning of the experiment (W0) and at the end for plants in the river and tidal tanks (Figure 7.4, Table 7.1). It is important to note that at the beginning of the experiment, the plant parameters for each treatment were the same.

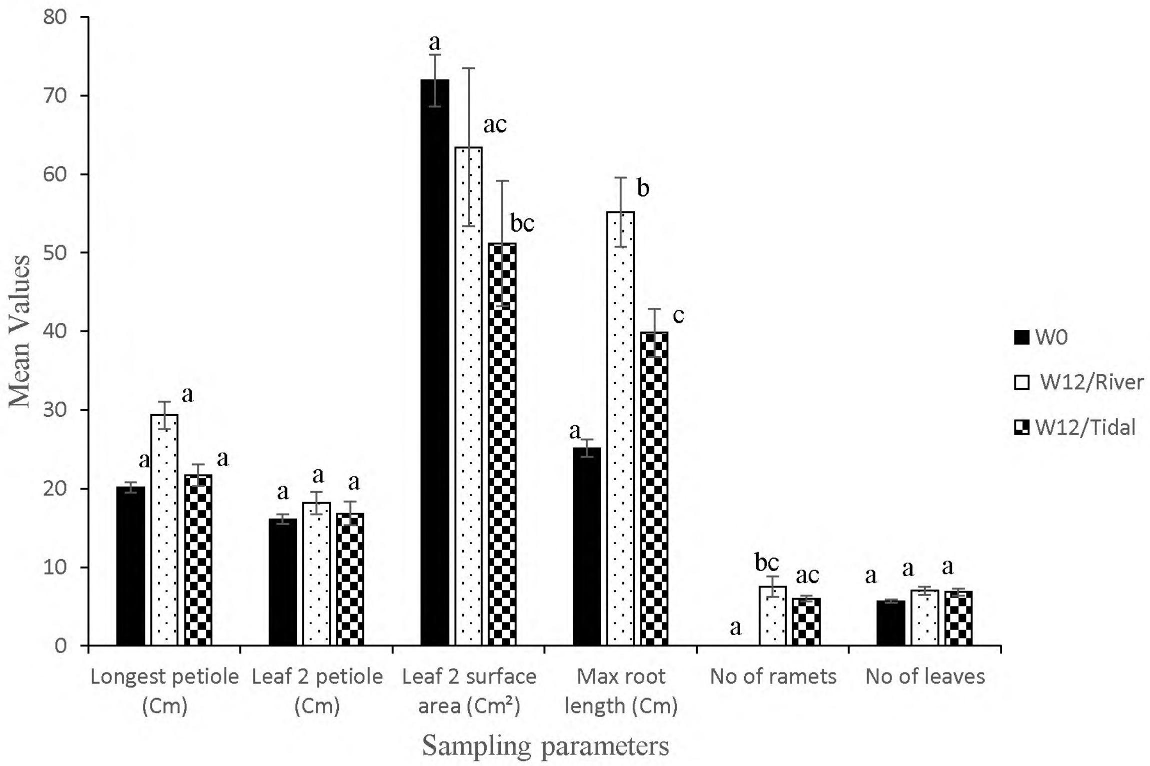
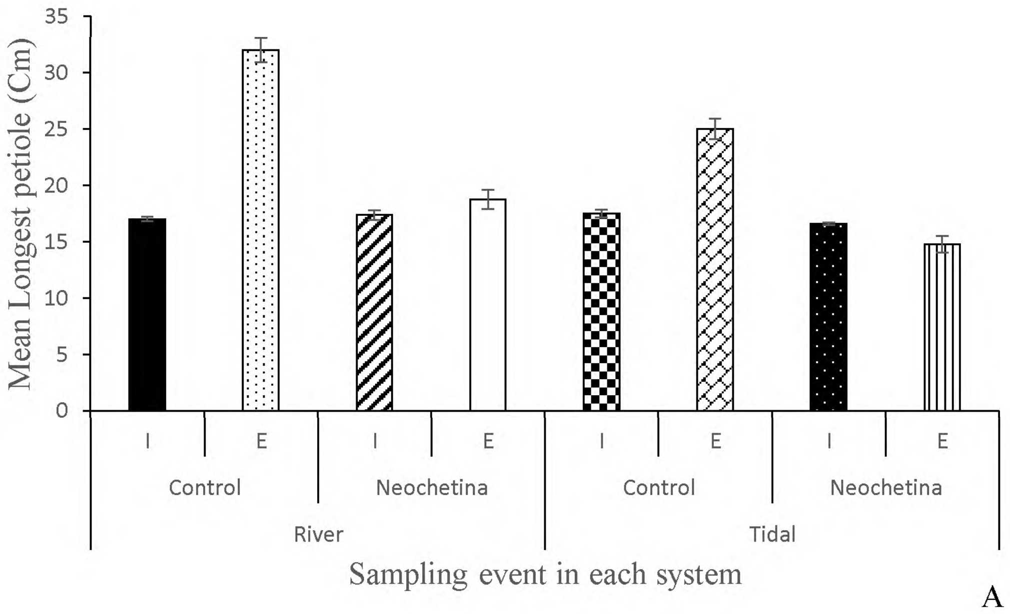


Figure 7.4 Plant parameters at the beginning and at the end for each treatment (river, tidal).

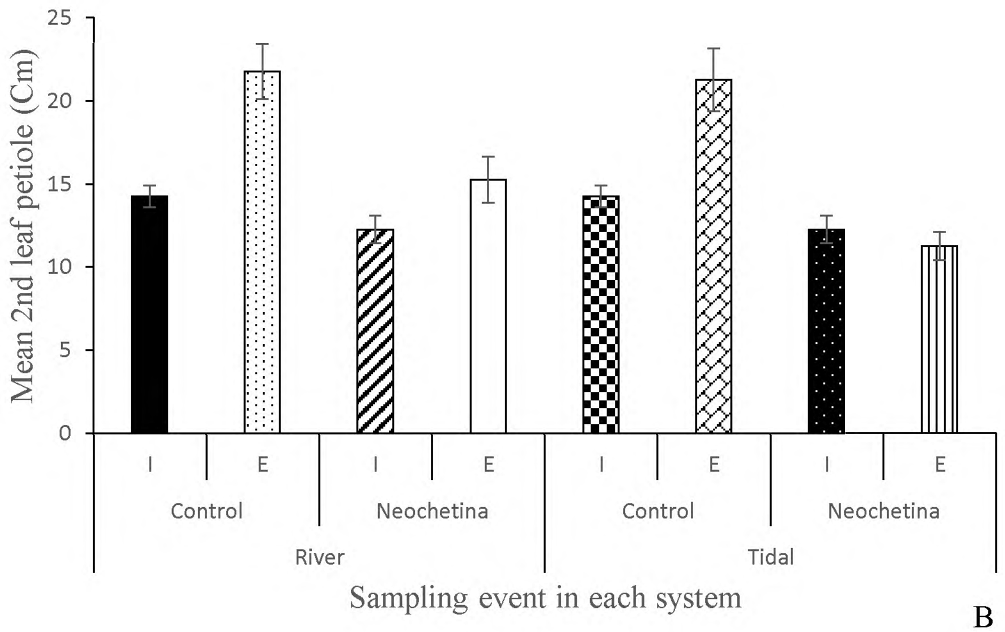
Table 7.1 The H-test statistic and p-value for the Kruskal-Wallis test performed on plant parameters recorded between system (river and tidal) and time (beginning and end of the experiment. The numbers in brackets indicate the degrees of freedom and the total sample size. The values in **bold** indicate significant differences.

Plant growth parameters	**Source of variation**			
	System **(1, 24)**	**p-value**	Time **(1, 24)**	**p-value**
Longest petiole	2.74	0.09	6.44	**0.01**
Leaf 2 petiole	0.17	0.68	2.30	0.13
Leaf 2 surface area	0.44	0.50	4.35	**0.03**
Max root length	0.70	0.40	17.40	**0.000**
Number of ramets	0.096	0.76	19.88	**0.000**
Number of leaves	0.91	0.34	13.57	**0.0002**

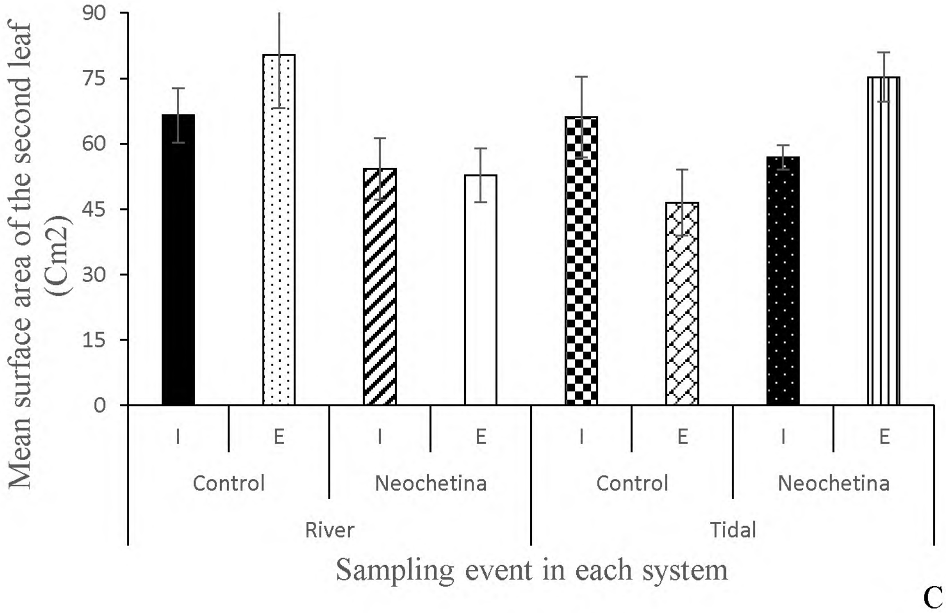
At the end of second experiment, plant parameters measured in the control (C), and *N. eichhorniae* (N) treatments were compared between them and between systems (river, tidal). The results from the Kruskal-Wallis test showed that none of the plant paramters (the longest petiole (LP) and the length of the second leaf (L2P), the number of leaves, the secod leaf surface area, the number of ramets and the max root length were affected by the system (river and tidal) as no significant difference was found (Table 7.2, Figure 7.5). However, a significant difference was found in the longest petiole, the second leaf petiole and the number of leaves between treatments (C, N), while no significant difference was recorded in the surface area of the second leaf, the max root length and the number of ramets (Table 7.2, Figure 7.5). When data were compared between the beginning and the end of the experiment (time), although no significant difference was found in the surface area of the second leaf, there was a significant difference in the longest petiole, the leaf of the second petiole, the max root length, the number of ramets and the number of leaves (Table 7.2, Figure 7.5).



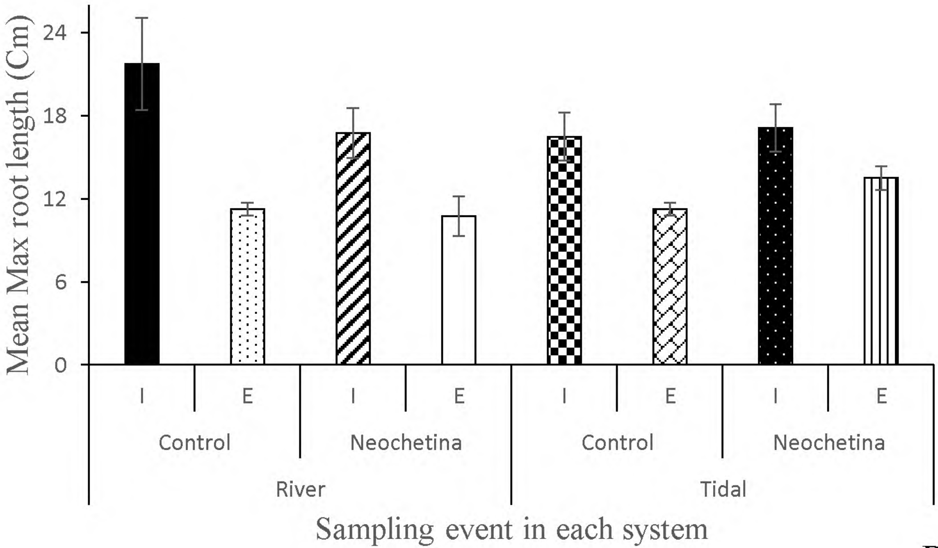
Mean Longest petiole (Cm)
0
5
10
15
20
25
30
35
I
E
I
E
I
E
I
E
Control
Neochetina
Control
Neochetina
River
Tidal
Sampling event in each system
A



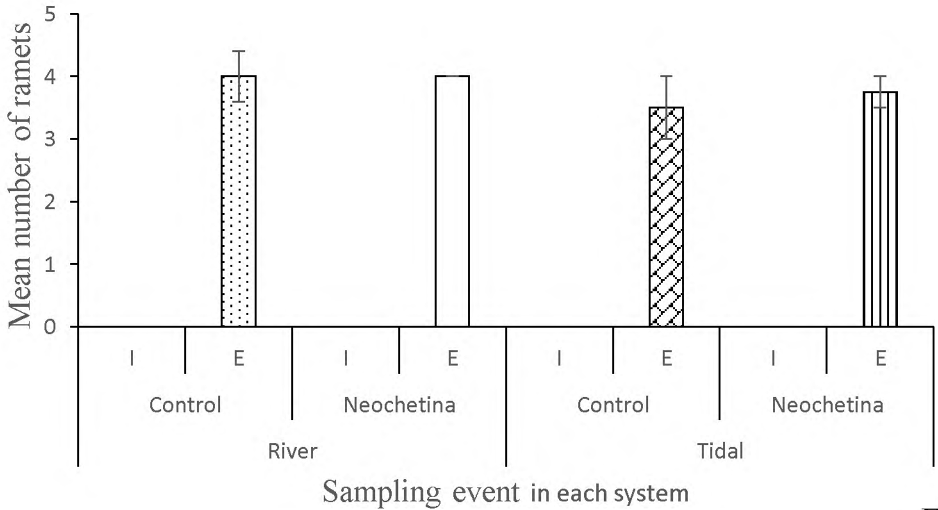
Mean 2nd leaf petiole (Cm)
0
5
10
15
20
25
I
E
I
E
I
E
I
E
Control
Neochetina
Control
Neochetina
River
Tidal
Sampling event in each system
B


Mean surface area of the second leaf (Cm2)
90
75
60
45
30
15
0
I
E
I
E
I
E
I
E
Control
Neochetina
Control
Neochetina
River
Tidal
Sampling event in each system

C


Mean Max root length (Cm)
24
18
12
6
0
I
E
I
E
I
E
I
E
Control
Neochetina
Control
Neochetina
River
Tidal
Sampling event in each system

D


Mean number of ramets
5
4
3
2
1
0
I
E
I
E
I
E
I
E
Control
Neochetina
Control
Neochetina
River
Tidal
Sampling event in each system

E

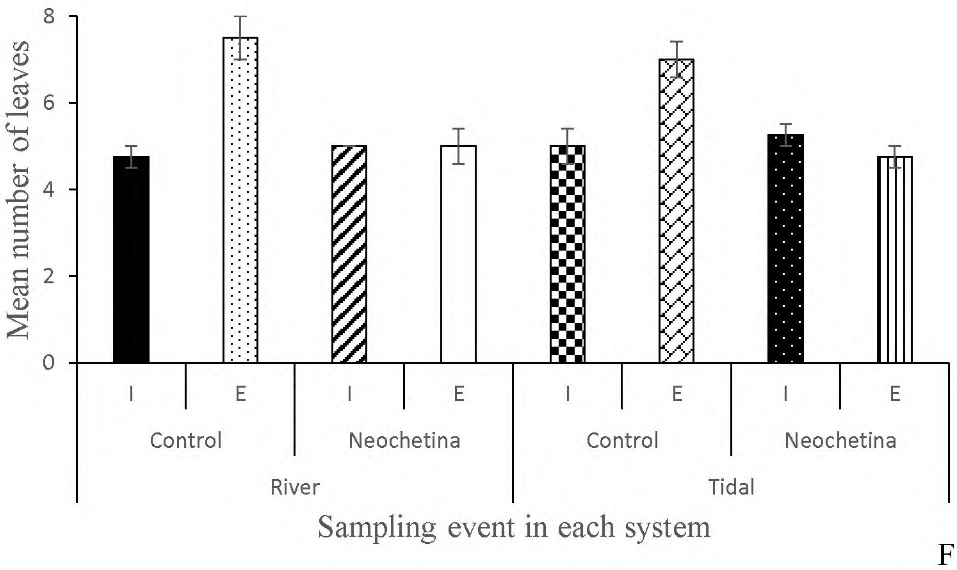


Figure 7.5 Different plant parameters recorded at the beginning (I) and the end (E) of the experiment in each system (river, tidal) per treatment (control, and *Neochetina eichhorniae*) (A: Mean Longest petiole; B: Mean second leaf petiole; C: Mean surface area second leaf petiole; D: Mean root length; E: Mean number of daughter plant; F: Mean number of leaves).

Table 7.2 The H-test statistic and p-value for the Kruskal-Wallis test performed on plant parameters recorded between system (river and tidal) treatment (Control and *Neochetina eichhorniae*) and time (beginning and end of the experiment). The numbers in brackets indicate the degrees of freedom and the total sample size. The values in **bold** indicate significant differences.

Plant growth parameters	**Source of variation**					
	Sites **(1, 48)**	**p-value**	Treatment **(1, 48)**	**p-value**	Time **(1, 48)**	**p-value**
Length longest petiole	2.96	0.85	5.68	**0.02**	13.91	**0.002**
Leaf 2 petiole	1.41	0.23	9.56	**0.002**	14.49	**0.001**
Leaf 2 surface area	0.20	0.66	0.15	0.69	1.49	0.22
Max root length	0.97	0.33	**0.42E-3**	0.98	25.13	**0.00**
Number of ramets	0.63	0.43	0.15	0.70	41.46	**0.00**
Number of leaves	0.71	0.40	4.83	**0.02**	13.81	**0.002**

7.5.2 Plant biomass

The plant biomass of water hyacinth were not affected by the different treatments (river or tidal) once the adults emerged and started to feed on the plant. When data were compared from the beginning (Week 0 (W0)) to the end (Week 12 (W12)) for the river and tidal treatment, there were no significant differences between these treatments (river or tidal) for the dry root biomass and dry shoot biomass (Figure 7.6). However, there was a significant difference between the wet biomass for the whole plant, and the fresh biomass of the shoot (Figure 7.6) at the beginning of the experiment (W0) and at the end for plants in the river and tidal tanks. Between the beginning and the end of the experiment, a significant difference was noted in the the fresh root biomass, death biomass (Figure 7.6) for each treatment. It is important to note that at the beginning of the experiment, the plant biomass for each treatment were the same.

Figure 7.6 Wet and dry biomass of water hyacinth from the beginning (W0, where the plants in both groups had the same characteristics) until the end of the experiment for each group (river and tidal).

7.5.3 Leaf turnover

Initially, the leaf turnover in the river treatment was high, with in each bucket one leaf every week, and it started to decline between sampling weeks with an average of 0.5 leaves per week (i.e in the 12 buckets present in the river tank, the leaf turnover was noted in six buckets) (Figure 7.7). In the tidal treatment, the average leaf turnover was similar for the entire duration of the experiment, with 0.5 leaves per weak, although in some buckets the leaf turn over happened at least once a week (Figure 7.7). Recording the leaf turn over started from 17 April 2015 (W1), date when the feeding scars were seen for the first time in each treatment, and continued until the end of the experiment on 5 June 2015.

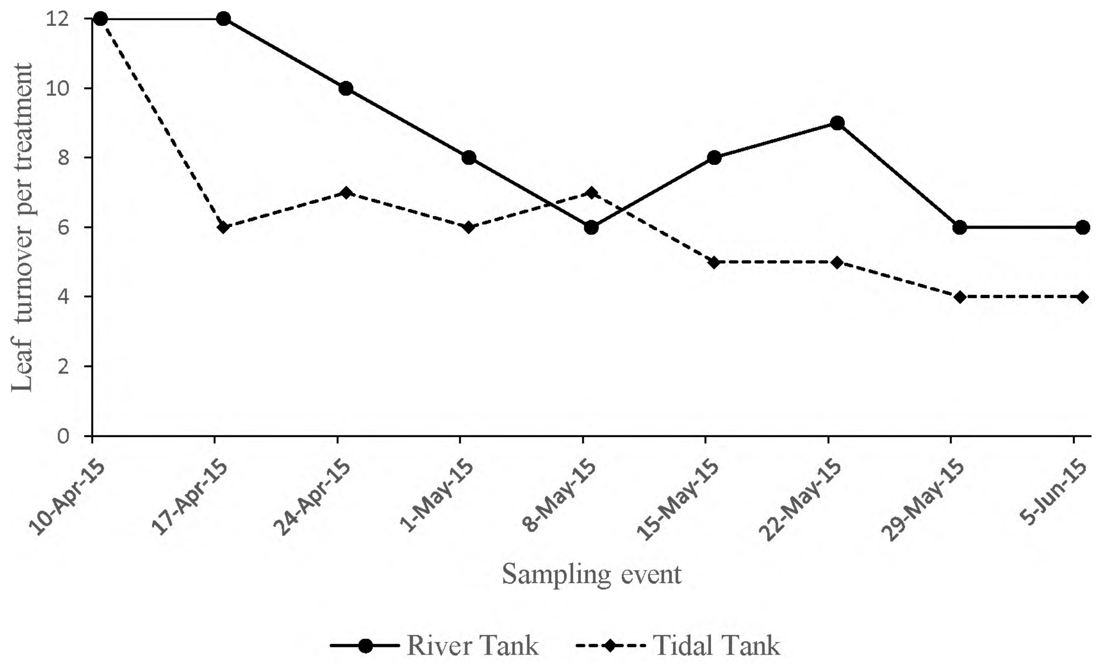


Figure 7.7 Number of water hyacinth leaf turnover at each sampling event for each treatment (17 April 2015–5 June 2015).

7.5.4 Shoot /root ratio

A mean shoot/root ratio of the dry biomass between the river and the tidal treatments was estimated at the end of the first experiment. The mean shoot/ratio of the tidal treatment was associated with a numerically smaller mean shoot/root ratio (S/R = 1.48, SD = 0.19) than the mean shoot/root ratio of the river treatment which had the highest value (S/R = 2.07, SD = 0.26). The results from the t-test showed that there was no statistically significant difference between the two ratios ($t_{(10)} = 1.85$, p-value = 0.09).

7.5.5 Insect Parameters

During the first experiment in both treatments (twelve buckets per treatment, river and tidal) where the larvae were inoculated, larvae pupated in eight buckets per treatment and eclosed into adults. As they started to feed on the plant, almost the same number of feeding scars was recorded in the river treatment with an average of 13.76 feeding scars per week (Figure 7.8) and in the tidal treatment with an average of 11.6 feeding scars per week (Figure 7.8).

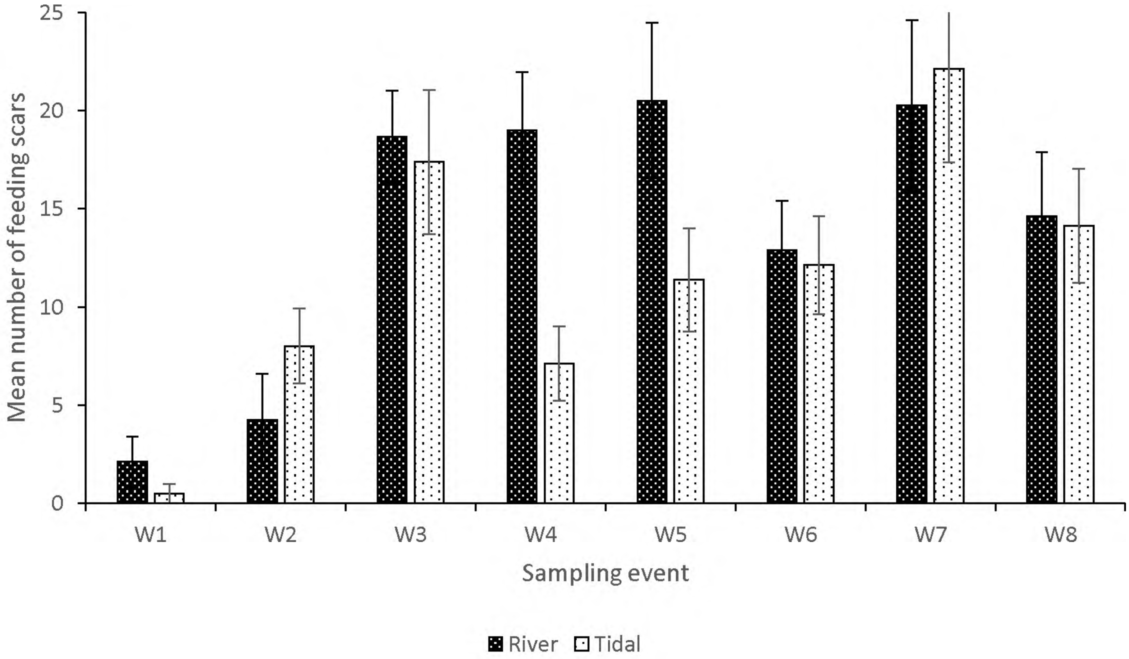


Figure 7.8 Mean number of feedings recorded each week in the river and tidal treatment for a period of eight weeks after the adults emerged (W1 = 17 April 2015, W8 = 05 June 2015).

In the second experiment where the impact of tidal fluctuation of water was assessed on the growth population of insects used, results were taken for *N. eichhorniae*.

Observation of the number of feeding scars on each second leaf per bucket, per treatment showed that, in the river treatment, the number of feeding scars increased with time up to an average of 35 feeding scars on the second leaf at the end of the experiment (Figure 7.9), while those in the tidal treatment increased progressively until the third week of sampling when a slight decrease in W4 and increase in W5 of the mean number of feeding scars was observed. After W5, the mean number of feeding scars decreased regularly until the end of the experiment (Figure 7.9).

As regard to the percentage damage of the total number of leaves by feeding scars, in both river and tidal treatments, percentage damage increased progressively until the end of experiment attaining 100 % damage of the total number of leaves.

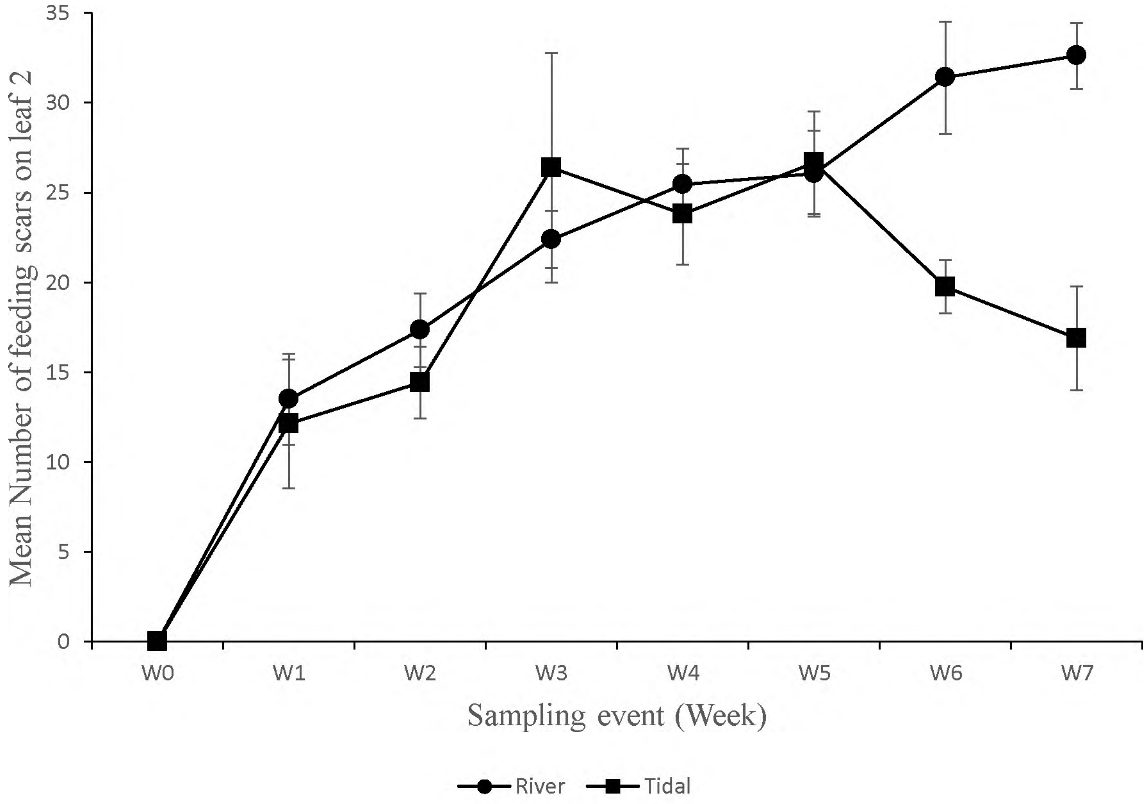


Figure 7.9 Mean number of feeding scars on the second leaf, per treatment (river, tidal) during the weeks of sampling.

The number of petioles mined was also evaluated at the end of the experiment, with the river treatment presenting the higher number of mined petioles (3.5, SD=±0.23) than the tidal, which showed only 0.25 mined petioles (SD = ±0.25).

An ANOVA of the total number of leaves damaged, the number of feeding scars on the second leaf and the petioles mined by *N. eichhorniae* in each system over time showed that in the second experiment, there was a significant difference between the value recorded between the system, time, and the combined effect of time x system (Table 7.3; 7.4; 7.5).

Table 7.3 Summary of the ANOVA test of significance for effect of time and treatment (river, tidal) on the number of leaves damaged by the weevil *Neochetina eichhorniae*. Values in bold are significant

Effect	SS	DF	MS	F	P
Intercept	9312.25	1	9312.25	2546.94	**<0.05**
Treatment	90.25	1	90.25	24.68	**<0.05**
Time	2597.50	7	371.07	101.49	**<0.05**
Treatment X Time	56.50	7	8.07	2.21	**0.04**
Error	175.50	48	3.656		

Table 7.4 Summary of the ANOVA test of significance for effect of time and treatment (river, tidal) on the number of feeding in the second leaf by the weevil *Neochetina eichhorniae*. Values in bold are significant.

Effect	SS	DF	MS	F	P
Intercept	23836.14	1	23836.14	793.56	**<0.05**
System	205.62	1	205.62	6.85	**0.012**
Time	4794.58	7	684.94	22.80	**<0.05**
System X Time	617.22	7	88.17	2.94	**0.012**
Error	1441.77	48	30.04		

Table 7.5 Summary of the ANOVA test of significance for effect of time and treatment (river, tidal) on the number of petiole mined by the weevil *Neochetina eichhorniae*. Values in bold are significant.

Effect	SS	DF	MS	F	P
Intercept	3.52	1	3.52	122.73	**<0.05**
System	2.64	1	2.64	92.18	**<0.05**
Time	21.11	7	3.02	105.27	**<0.05**
System X Time	21.92	7	3.14	109.64	**<0.05**
Error	1.37	48	0.029		

7.5.6 Water parameters

TDS, conductivity and salinity presented the same trends for the duration of the sampling weeks of the experiment with a slight increase of these parameters over the period (Figure 7.10). As the experiment was carried out from late summer into early winter, the temperature data showed a sawtooth curve, with the minimum temperature recorded at the end of the experiment in June (10.93°C). The pH was almost constant for the full duration of the experiment with a maximum of 8.06 (it's bore water) recorded on 17 April 2015, and a minimum value of 5.56 in May (29 May 2015) (Figure 7.11). Ammonium and nitrate both decreased progressively until the end of the experiment, when the minimum value of 0.23 mg/l and 0.47 mg/l were recorded for nitrate and ammonium, respectively (Figure 7.11).

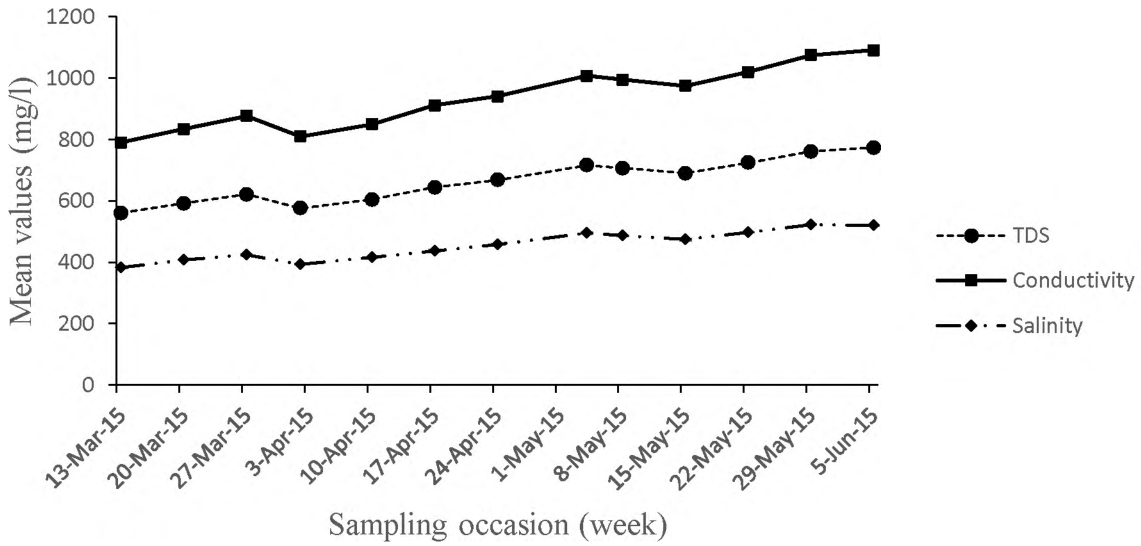


Figure 7.10 The mean conductivity, TDS, and salinity of water samples collected in each of the tanks for the duration of the experiment (13 March 2015–05 June 2015).

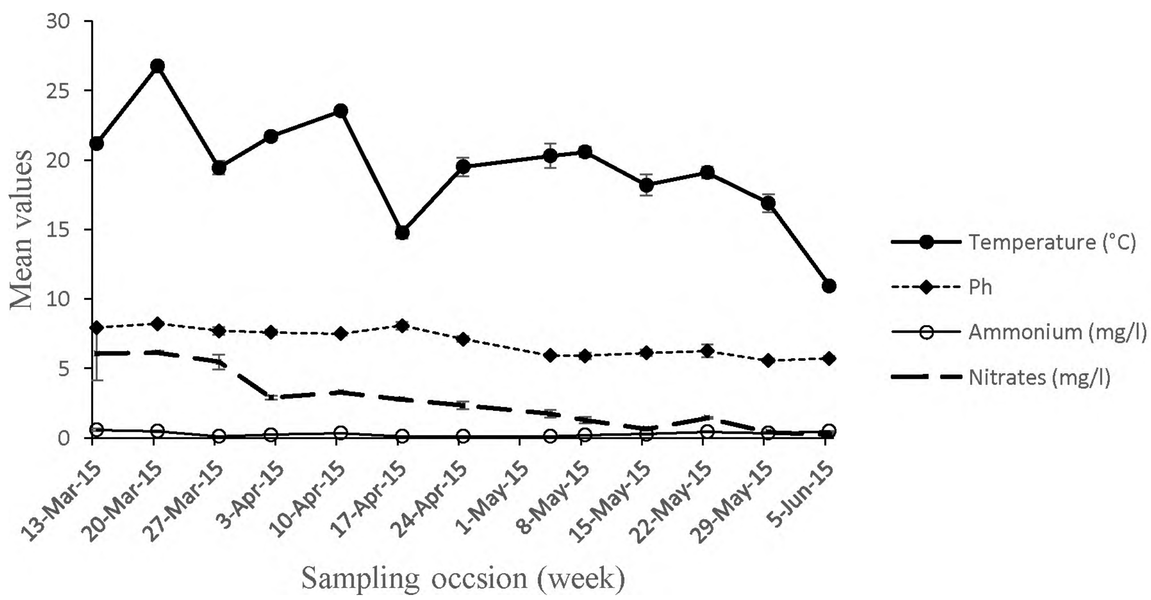


Figure 7.11 The mean temperature, pH, nitrate and ammonium of water samples collected in each of the tanks for the duration of the experiment (13 March 2015–05 June 2015).

7.6 Discussion

The hypothesis tested here, was that, tidal fluctuation reduced the pupation success of the weevil, and this was the reason why the weevils, were not well established in the Wouri Basin. However, from the results of the first experiment with the third instar larvae of *N. eichhorniae*, there was no difference between the tidal treatment and the river treatment in the numbers of larvae which pupated and eclosed as adults. As reported by Deloach and Cordo (1976a), fully grown larvae of *N. eichhorniae* and *N. bruchi* emerge from the plant and form cocoons by entangling nearby root hairs into balls, and they then pupate inside. In both treatments (river and tidal), the same number of larvae (eight) which pupated and then emerged as adults was obtained. The same results were obtained by Visalakshy and Jayanth (1996) and Ajuonu (unpub.). Visalakshy and Jayanth (1996) found that although silt was an issue for pupation, once pupae on plants with silted roots had formed a cocoon, they could survive to adults as larvae on free-floating plants, and no difference in survival was noted in the two different conditions. The current results can be explained by the results found by early observations made by (Deloach & Cordo1976b) and Visalakshy and Jayanth (1996). They found that, in free-floating roots, pupal cocoons could be located as far as 10.5 cm from the base of the plant while in silt-covered plants, cocoons could be collected only up to 3 cm from the base. In the roots of free-floating plants, 30% pupated near the base (within 1 cm), 50% at 1±5 cm and 20% at 5±11 cm. In contrast, in silt-cove red roots, 70% pupated near the base (0±1 cm) and 30% at 1±3 cm (Visalakshy and Jayanth 1996).

The similar results obtained in the pupation of weevils between the tide and river systems, suggested that something else was the cause of lack of weevils in the Wouri Basin, especially in the tidal sites, which led to the second study. In the second experiment, although the number of feeding scars increased in all treatments, in both river and tidal systems, meaning that there were still live weevils during the course of the experiment, a significant difference was noted between the river and tidal systems in the mean number of feeding scars and mean number of mined petioles. The difference in the feeding scars in the tidal system can be explained by the repeated drought (when the tide was "out") and flooding (tide was "in") which might have had an impact on the physiology of the insects, and therefore affecting their capacity to feed on the plant. This was shown by the considerable difference between the river and tidal treatments in the number of mined petioles. Mined petioles are the result of larvae which, in their different growth stages as they tunnelled the petiole of the plant.

Wright and Center (1984) developed a formula based on the feeding scars to to determine indirectly the number of *N. eichhorniae* weevils on a population of water hyacinth. The formula is:

$$I = 0.0366S^{0.775}$$

where I is the number of weevils and S the number of feeding scars.

Using this fomula, The average number of feeding scar on leaf two at the end of the experiment for the river treatment was 32.6, which gives a result of 0.55 weevils per plant, while in the tidal treatment, the average number of feeding scars was 16.9, giving a result of 0.33 weevils per plant, which is less than the number of weevils inoculated. The inoculation density of insects at the beginning of the experiment was one pair of weevils per plant and per bucket where *N. eichhorniae* was released. However, the number of daughter plants has to be taken into account. When the insects were released after fourteen days of acclimation, each experiment had two daughter plant and, at the end of experiment, the mean number of daughter plants in both river and tidal treatment was four, which means that, the insects released at the beginning were still all alive in the river treatment while in the tidal treatment, one weevil might have died or was weak. This could also be explained by the stress they weevils went through, due to the regular drought and flood of water in the system during the low and high tide.

Visalakshy and Jayanth (1996) showed that the difference in the number of adults comes from the fact that, in silt-covered plants, most cocoons were found attached to the newly sprouted root hairs, which were free from silt. So, when mature larvae were released into slits made on the petioles, 20 % and 70% adult emergence was obtained from silt-covered and free-floating plants, respectively. Again, no mortality of pupae was observed. However, the fully grown larvae may have died because pupation sites were not available or the larvae were unable to form pupal cocoons in silt-covered roots. Moreover, as shown by Center *et al.* (1999a), Hill and Cilliers (1999), one of the challenges to successful biological control in areas which are subjected to tidal fluctuation is the periodic flooding which flushes out plants as well as established weevils, leading to the loss of insects released, or to their catastrophic reduction, and therefore, a slow process of multiplication, which could be the case of theWouri Basin especially during the rainy season where plants are flushed out(Chapter 2).

In the second experiment (river system) where plants always had water, a constant increase in the number of feeding scars, mined petioles and therefore, population of insects was noted which led to the decline of plant parameters such as surface area of the second leaf, and the number of ramets. These results were similar to the study carried out by Akpabey (2012) who noted that, in heavy infestations, the meristematic tissues (new leaves and daughter plants) are destroyed, resulting in less overall productivity and growth. As damage increases, plant growth rate is reduced and the production of new leaves and new stolons is reduced. Plant size (height, weight, size of leaves, size of stolons) declines. According to Bownes (2009), herbivory suppresses daughter plant production, albeit by different agents, whereas plants not subjected to herbivory will continue to reproduce vegetatively. The stress produced causes a loss of energy, which might otherwise be channelled into the production of daughter plants, to be redirected to the production of new tissue, leading to a decrease in the overall growth of the plant (Perkins 1973).

At the end of this study, which aimed to assess the influence of the tidal fluctuation of water on the population dynamic of biological control agents on water hyacinth, it appeared that the population growth of the agents released was affected by the tidal regime of water during these experiments (although the exact mechanism is still unclear), which can therefore explain the scarcity of biological control agents *N. eichhorniae* and *N. bruchi* in the Wouri Basin, especially in sites subjected to the tide. These results also explained the slow success of biological control in areas where the river is subjected to tidal fluctuation, necessitating a longer period of time for the control to be fulfilled. So, in Cameroon, and especially in the Wouri Basin, in order to manage water hyacinth mats, the *Neochetina* weevils should be reared until appropriate numbers are obtained before they are released, and further, in addition to the weevils other biological control agents that only attack the leaves should be considered as alternatives.

8 Chapter 8: General discussion and conclusion

8.1 Introduction

Globally, invasive aquatic species have caused numerous threats in all countries where they have been introduced, either accidently or deliberately as products to support agriculture, forestry, horticulture and recreation. In many of these countries, the economic and environmental costs of managing waterweeds, and in particular, water hyacinth, are too far-reaching to be calculated accurately (Neuenschwander *et al.* 2003, Wise *et al.* 2007). Water hyacinth can invade different types of environments, despite manual remova in Cameroon as well as, and as in other African countries. The fact that Cameroon is still in the primary stages of managing water hyacinth, prompted the development and realization of this study in order to provide a baseline for the management of this scourge and other aquatic invasive species.

The current study was undertaken in order to investigate the main factors which promote the development and proliferation of water hyacinth in the Wouri Basin with implications for its biological control. To answer the different questions and issues which were raised, several objectives were assigned to the study: the description of the selected area; the impact of biotic and abiotic factors on the growth of water hyacinth; a socio-economic survey to assess the impact of this aquatic invasive plant on the lives of riparian communities; the impact on aquatic plant biodiversity; the fungi associated with water hyacinth in the Wouri Basin; the status and distribution of biological control agents in the Wouri Basin, and finally, the assessment of some experimental studies of biological control of water hyacinth with the weevils under tidal and river conditions. This study is the first carried out in Cameroon to investigate such a broad range of impacts, as well as the first to introduce the potential for biological control of water hyacinth in Cameroon.

The level of pollution encountered in the Wouri Basin during both the dry and rainy seasons offers water hyacinth provides adequate conditions for its proliferation and spread (Chapter 2), leading to serious economic, social and environmental threats. Of the different impacts observed, the impact on plant biodiversity was the most significant. However, few studies have considered the biodiversity of areas surveyed before and after the invasion of aquatic invasive weeds, and especially water hyacinth, and even fewer have therefore measured the biodiversity recovery. Comparing sites without water hyacinth and sites with water hyacinth revealed the presence in both habitats of other invasive species, both floating (sites with water hyacinth) and rooted (site without water hyacinth) (Chapter 3). This component of the study also showed that habitats rich in water hyacinth were poor in diversity, while habitats without water hyacinth were rich in diversity, thus raising awareness on the importance of monitoring invasive aquatic weeds along the Wouri Basin, and the importance of selecting the correct control management options to implement for all invasive aquatic weeds.

As the surface areas of the Wouri Basin have been progressively invaded by water hyacinth, fishing and water transportation have been the main activities affected. In the surveyed areas, the number of fishermen involved in fishing activities has decreased by 68 % since the appearance of water hyacinth. Similarly, the number of people involved in water transportation has also decreased, with a loss of income of around USD$200 per month, especially during the rainy season. Furthermore, because of the infestation of water ways, motorboats required more maintenance, which is not usually covered, even by increased cost of transportation. However, because of a lack of regional and national statistical data in these fields, it was difficult to calculate a real estimate of the total losses recorded in these different sectors (Chapter 4).

The significant increase in human disease, was explained by the constant floods which occur in all the surveyed areas at least five times a year, especially during the rainy season. Although estimations were made of the total losses suffered by riparian communities living along these rivers, it is important to extend this research to all the areas invaded by the plant, in order to provide a national report on the loss of income per year due to the invasion of water ways, and thus to devise a comprehensive strategy to deal with socio-economic concerns associated with water hyacinth. In her study, Da Fatima (2013) points out the importance of putting a coordinating mechanism in place to manage water hyacinth and other invasive weeds to ensure that a common approach is adopted, not only in one river, but in all the rivers invaded by aquatic weeds in every country. The date of introduction of water hyacinth into Cameroon was an unexpected discovery, based on the information gathered during this survey, and proved to be much earlier than the date proposed by previous studies. The evidence suggests that, water hyacinth has been present in Cameroon for more than 30 years, which is supported by the date of the first collection of water hyacinth by R. Letouzey, 12 April 1971 in the Sangha River, of Ouessa (eastern part of Cameroon), (National Herbarium).

8.2 Impact of biological control

According to Van Driesche *et al.* (2010) and Morin *et al.* (2009), the benefits of biological control of weeds and the evaluation of its success are essential to justify the continued use of biological control for conservation. Although slow or inadequate in some countries, there are examples of successful control of invasive species: first, through the use of classical biological control by means of arthropods, in which another alien species is introduced to attack the invasive; and second, through the use of pathogens as mychoherbicides that damage the invasive plant (Chapter 5 and Chapter 6). When properly executed, these are safe approaches which has led to the successful control of water hyacinth in several countries.

Several fungi occurring on the leaves of water hyacinth in the Wouri Basin were identified. Field results showed that the naturally induced severity of disease in the field was relatively low, especially on plants during the rainy season. Where disease symptoms were present, they occurred mainly on the leaf lamina and petioles. None were observed on the rhizome. Although the use of mycoherbicide for water hyacinth is still unknown in Cameroon, this study was not only a benchmark which provides basic information on the presence of pathogens damaging water hyacinth in the Wouri Basin, but it also provides an opportunity to study the role of the pathogens in the decline of water hyacinth mats in Cameroon.

Surprisingly, two agents, *N. eichhorniae* and *N. bruchi* were found in the Wouri Basin. They were negatively influenced by tidal fluctuation of water, which then affected the development of larvae and their pupation success. In these cases, successful control, which takes two to three years in normal conditions, can take up to eight years in tidal areas (Visalakshy and Jayanth 1996). So, to improve and enhance the activities of biological control agents in the Wouri Basin, it is recommended that the weevils are reared until they reach a significant number, and redistributed in areas with a low weevil population and that the weevilsare reintroduced every year.

8.3 Constraints to water hyacinth management

Water infestation calls for well-understood national policy management. In October 2010, a strategic plan for biodiversity (2010–2020) was adopted with the goal of identifying IAS and pathways, controlling and eradicating priority species, and managing pathways in order to prevent further invasion (UNEP 2012).

Although national efforts for the management of water hyacinth proliferation in the Wouri River and other regions invaded have been undertaken both at the administrative and local levels, there is still a need to understand and initiate adequate management measure to solve these issues. Because there is no comprehensive strategy for the management of water hyacinth proliferation, water hyacinth is still an important constraint. The Wouri River Basin in particular, has been a hot-spot for years, and several attempts to fight the weed have been unsuccessful. A meeting of experts in Africa and the Middle East regions, under the auspices of the International Development Research Centre (IDRC) through its People's Land and Water Programme (PLaW) initiative (IDRC's PLaW), investigated several constraints to water hyacinth management in the region (Navarro, 2001) and classified them into three main groups, namely institutional, technical and financial.

According to Navarro (2001), the institutional constraints are the most common, wide-spread, and are typical of problems found in developing, resource poor countries. These have to do with problems of organization and bureaucracy across the many units within a country sometimes even within one ministry that deals with the weed. Most of the time, these units work without coordination or communication, often with different or conflicting objectives, and with limited access to information and resources. The effective participation of riparian communities in campaigns to control the weed is sometimes impeded by the unnecessary bureaucracy of responsible institutions which slows the initiation and implementation of programmes for water hyacinth control.

The lack of an appropriate integrated strategy for water hyacinth control in Africa was considered a technical constraint to water hyacinth management. When combined with institutional limitations, technical problems also include:

- Difficulties in identifying lead organizations with relevant structures to effectively coordinate control efforts, and ensure the full participation of key stakeholders;

- Lack of regional efforts to ensure collaboration and interaction of key players and the harmonization of efforts to control water hyacinth on a whole-catchment basis; and

- Lack of back-up services for techniques such as mechanical control.

According to Cho Mujingni (2012), financial problems emanate from the very belief that efforts to control and manage water hyacinth are inadequately funded and not sustainable. This undermines efforts, even when governments and other agencies make funds available.

One of greatest impediments in the fight against water hyacinth proliferation in Cameroon is the absence of a national strategy policy for the fight. This has rendered many local efforts unsuccessful. Although money from the government is redistributed to municipal councils for the management of water hyacinth and other invasive aquatic species in the whole country, lack of skills of government departments, stakeholders, municipal councils and local community involved in the fight, means that the end result is that funds allocated for this purpose are lost and only little work is done.

8.4 Implication for policy

Because of the inherent dangers of water hyacinth and other aquatic invasive species, wareness must be raised among local communities and stakeholders, managers and policy makers. From the various meetings which took place while in Cameroon for the fieldwork, the major ministries or institutions currently addressing a national strategy for the control of the proliferation of water hyacinth, including aquatic invasive weed problem in Cameroon, are: the Ministry of Economic Planning and Regional Development (MINEPAT) in collaboration with the Ministry of Environment; Nature Protection and Sustainable Development (MINEPDED); the Ministry of Forestry and Wildlife (MINFOF); the Ministry of Transport (MINTP); the Ministry of Fisheries and Animal Husbandry (MINEPIA); the Ministry of Scientific Research (MINRESI); the Territorial Administration (Councils), including the Douala City Council (CUD), and NGOs.

Despite all the meetings and workshops held each year to investigate what was done previously by mandated NGOs or councils, and including a plan of action proposed for next year, nothing has really changed; first, because since 2010 when these annual gatherings were instituted, Cameroon was still using manual removal which has been unsuccessful because removal is often uncoordinated and not done properly, leaving portions of the weed to be covered again before the next cycle of removal. Second, even when good proposals are raised, they are never executed**.** So, as proposed by Cho Mujingni (2012), the responsibility for water hyacinth control should be organized by the Prime Minister, Head of Government, through an order, designating the various ministries in charge of the management of water hyacinth, including authorities of the Port of Douala. The Heads of the Ministries so designated in collaboration with heads of decentralized administrative units such as the governor of the region and authorities of the port, must appoint representatives who should meet in order to establish a Water Hyacinth Management Committee (WHMC) on the basis of a proposed plan known as the PIMIMEF strategy (Figure 8.1).

Regular meetings should be held by the WHMC in order to design appropriate methods. The choice of methods must be based on the level of infestation, knowledge of the weed's principal nursery sites, and the effect of control on the environment and on major economic activities carried out on the river. Biological control combined with manual removal could be the most appropriate solution. One of the best approaches for Cameroon would be to involve riparian communities in a process of controlling the weed by training communities in the different techniques of control (especially biological control) as is done in South Africa and around Lake Victoria where communities are involved in rearing and distributing the weevils to control the plant (Wilson *et al.* 2007). This proposition meets the key elements listed by Jones and Cilliers (1999) and Jones (2001) for the best integrated management approach to the control of water hyacinth in South Africa which includes among others: the appointment of one individual or organization to drive the control programme, the involvement of all interested and affected parties on the river, the division of the river system into management units and the implementation of appropriate control methods for each these management units.

Communities here in Cameroon consist of mayors of municipal councils, chiefs of the villages, experts with technical knowledge of the various control methods from Cameroon and other countries.

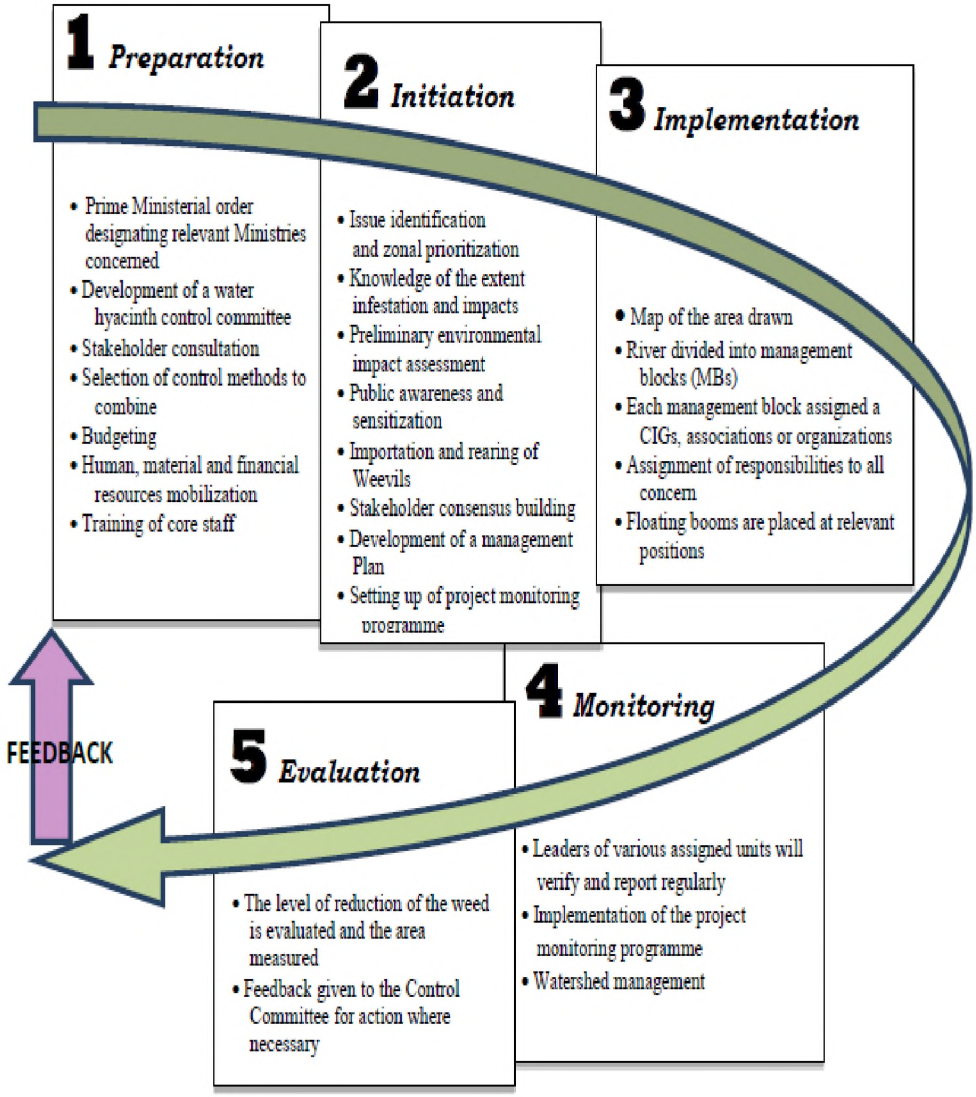


Figure 8.1 The PIIMEF strategy for the integrated control of water hyacinth in the Wouri River Basin (Source: Cho Mujingni 2012).

Similarly, different ways of communication, such as workshops, seminars, campaigns, newspaper articles, radio and television programmes (such as documentaries on water hyacinth) must be used to break the silence and to spread the message; and sufficient funds must be allocated to achieve the goal. Control or management of water hyacinth has become especially necessary for Cameroon and the Wouri Basin in that, if nothing is done, the national economy will face additional pressure due to the increased cost of treatment, an increase in the cost of fish as fish catches diminish, and the increased cost of water-borne diseases.

As applied in South Africa (Jones 2001; Hill & Coetzee 2008), Cho Mujingni (2012), proposed the implementation of a management plan consisting of management blocks (MBs) depending of the level of infestation of water hyacinth (Figure 8.2). After modification by adding the results of the current study, this management plan should consider the release of biological control agents, and the use of pathogenic fungi in MB1, MB2, MB3 and MB6, the choice being based on the extent of water hyacinth infestation in and around the areas where the infestation has led to complete blockage of these creeks.

In MB4, MB5, MB7 and MB8, manual removal should continue, because, even if large mats exist in these areas, their removal may be counteracted by many economic activities, notably fishing and sand extraction, which could be a hindrance to the biological method, and also because this waterway is the main transport route to some villages upriver which are not accessible by land, for example, Bwene.

Both biological and manual removal should be carried out in MB9, which is off the Port of Douala where many quays have been severely infested by water hyacinth in some areas and where there are large and small patches in other areas. The quay which is most heavily affected is the fishing port, where the presence of wrecks has rendered a huge portion of the quay non-functional and provided an opportunity for the proliferation of water hyacinth.

Each of the management units should be assigned to various groups for monitoring and reporting. Groups involved should include fishermen's associations, sand extractors' associations, and NGOs, with each group having leaders. Leaders of groups assigned to particular MBs should work with their members to regularly verify and monitor the progress in weed reduction in their assigned blocks, and report to the WHMC. Groups should be made up of members who live close to their assigned management blocks for easy access and regular monitoring.

Another mapping exercice should be carried out at the end of the programme to determine the extent of water hyacinth.

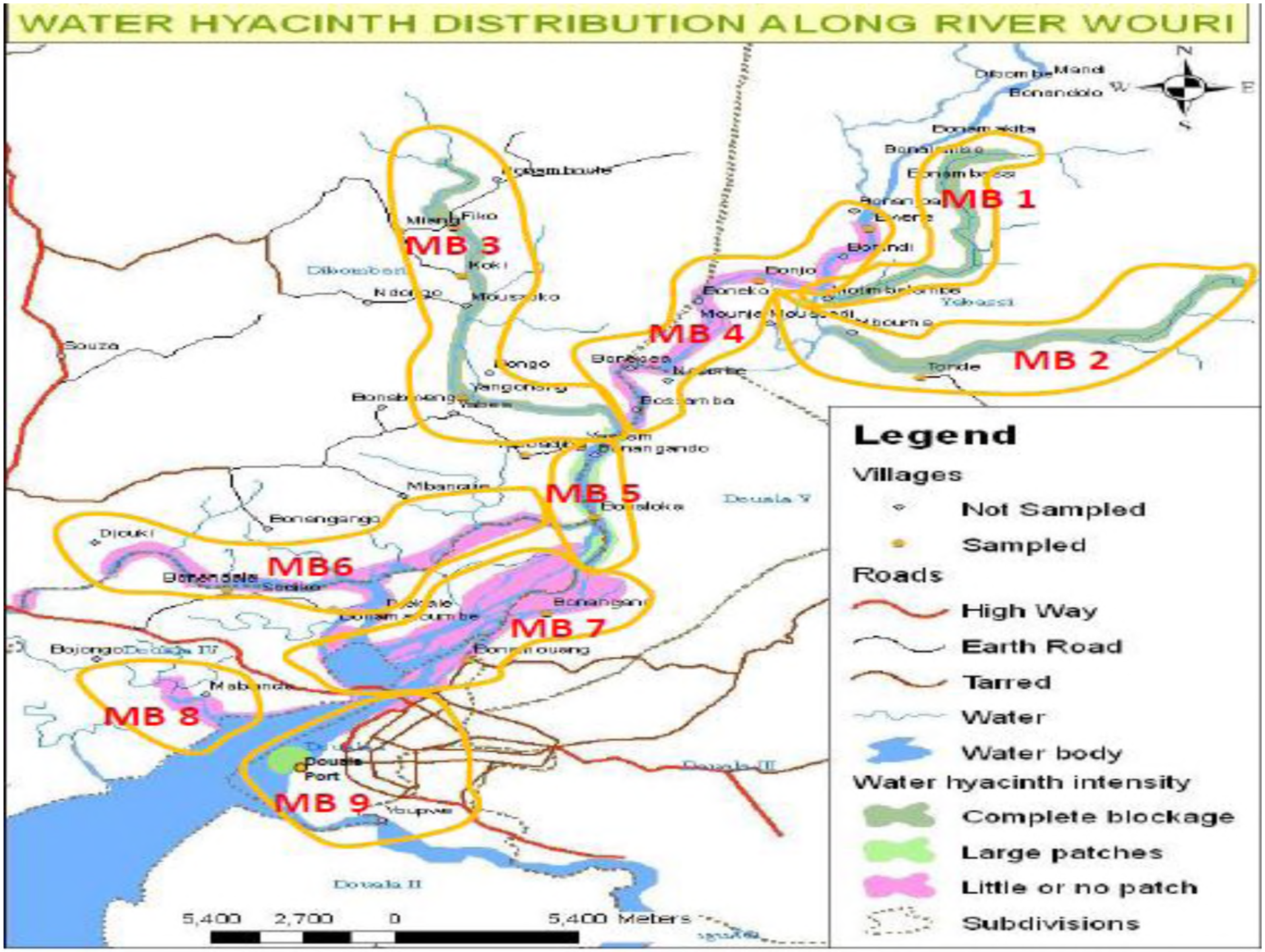


Figure 8.2 Management blocks (MBs) for Water hyacinth control in the Wouri River Basin (Source: Cho Mujingni 2012).

Further, to be sure that the control method proposed for each management block is suitable for the area selected, that it will work and will be followed properly, the ten point's plan summarized by Hill and Coetzee (2008) in their study of "Integrated control of water hyacinth for Africa" should be addressed. This plan comprises the following activities:

- Identify of the weed;
- Map the extent of the weed in order to quantify the total area covered by the weed, in this case water hyacinth, and to calculate the cost of control;
- Identify the cause of the infestation such as nutrient enrichment. As, Hill and Olckers (2001), and Hill (1999) point out, any management plan for water hyacinth must include aspects of nutrient control. Therefore, understanding the nutrient status of the aquatic ecosystem and its correlation with water hyacinth growth will determine the type of control required, the time taken to achieve control and finally the level of control that is likely to be achieved;
- Consult interested and affected parties, such as riparian communities living around the affected areas;
- Appoint a lead agency or champion which will coordinate and document all control efforts;
- Ascertain an acceptable level of control, which is one of the very important step in the integrated management plan;
- Consider control options to determine which control options to implement between manual clearance, biological control or integrated management control for each site; these will vary according to the initial level of water hyacinth infestation;
- Implement control options chosen according to a set of norms and standards determined by a the relevant health and safety environmental regulations for the river, district, region where they will be applied;
- Monitor control options which will help to draw a quantitative assessment of the level of success achieved, and therefore help in the calculation of a cost/benefit analysis for water hyacinth (Van Wyk & Van Wilgen 2002);

- Evaluate the plan and adjust accordingly based on information from regular meetings between stakeholders, scientists and the lead agency or champion to adjust the management plan whenever necessary.

8.5 Conclusion and recommendations

This study has highlighted the fact that both biotic and abiotic factors contribute to the proliferation and development of water hyacinth in the Wouri Basin, coupled with the incoming pollutants from various industries, houses, hotels and shops located along the rivers. In both the dry and rainy seasons, water hyacinth finds appropriate conditions for rapid growth: temperature, conductivity, nitrates, ammonium, and in some cases, pH. Nutrient supply therefore plays a greater role in determining growth and biomass accumulation of water hyacinth than the amount of light the plants receive. As suggested by the results gathered during this study, to call water hyacinth "the world's worst aquatic weed" is not an overstatement. Its proliferation in Africa, and especially in Cameroon, causes severe socio-economic and environmental problems for riparian communities wherever it is found in the country, including the Wouri Basin.

It is unrealistic to think that biological control will solve all water hyacinth problems on its own, and hence it is necessary to develop integrated management strategies. This means selecting the most appropriate control techniques available and implementing them so that they complement each other in time and space, as the best objective should be to obtain the best level of affordable, sustainable control while considering environmental aspects. Thus, biological control should be the base component of all strategies. It is important to note that, although it is difficult to carry out accurate economic assessments, control of invasive species, especially water hyacinth, can deliver positive benefits if carried out effectively; benefits which will be worth the effort. This can be done through the addition or inundative releases of *Neochetina* species at sites where they are already present, or by using a combination of other compatible insect control agents, and fungi pathogens such as *Acremonium zonatum*, *Alternaria eichhorniae*, *Colletotrichum* sp. which have proved to be highly pathogenic to water hyacinth.

However, the Cameroonian government should also consider what has been done in other African countries and learn from them. Examples are Uganda, Ghana, South Africa, Sudan, and Zambia which have implemented a number of national and regional biological control strategies. Moreover, the cases of Zambia, Malawi, Kenya, Uganda, the Congo Republic, Benin, Tanzania, Nigeria, Senegal and the Democratic Republic of Congo should be mentioned where some capacity in biological control of floating weeds has been built with successful management. The success story of the control of water hyacinth on Lake Victoria through biological control is a good example to follow.

8.5.1 Recommendations for long-term management of water hyacinth in the Wouri Basin, and further research

To manage water hyacinth in Cameroon successfully, and especially in the Wouri Basin, keeping its density to a level where it will no longer be a problem, comprehensive strategies and measures need to be taken to avoid its further proliferation and re-infestation:

- The Cameroonian government should cooperate with regional and international organizations, and research centres which have worked in other countries around Africa, and which can provide technical support and regular advice on how to manage aquatic weed in Cameroon sustainably. Some of these include the International Institute for Tropical Agriculture (IITA), the Commonwealth Scientific and Industrial Organization (CSIRO), the Centre for Agriculture and Biosciences International (CABI), the Food and Agricultural Organization of the United Nations (FAO) and the Commonwealth Science Council (CSC) (Navarro & Phiri, 2000).
- If not yet a member, Cameroon should join regional initiatives such as the Council of Ministers of ECOWAS, the Water Hyacinth Information Partnership (WHIP) through the People's Land and Water Programme (PLaW) to share information about water hyacinth with other countries in Africa and the Middle East, and learn from the experiences of countries which have succeeded in fighting the weed. Indeed, among the objectives listed by ECOWAS is the project to protect, rehabilitate and improve the biodiversity of water bodies in the regions, with a view to conserving the environment (Phiri *et al.* 2000).
- Increase resource allocation to institutions, strengthen education and create awareness, and increase human resources through the development of programmes in tertiary

education to call for more responsibility towards Cameroon's invasive alien species challenges.

Because this study was restricted to the District of Douala IV, which is one of the districts mainly impacted by water hyacinth in the Wouri Basin, and also because it was assumed that, by understanding the drivers of water hyacinth development and proliferation there, a better evaluation could be made for other localities invaded by the weed, there are shortcomings in this study. In future research, it will be important to:

- conduct field studies in different sites in all the areas and regions invaded by water hyacinth in order to compare the results;
- carry out molecular identification of fungi of water hyacinth;
- investigate the role of insects in the displacement of an other interactions with pathogens;
- conduct more surveys and isolates of fungi to determine all species found locally;
- carry out DNA identification on all promising isolates for pathogens;
- carry out host-specificity tests on promising isolates for water hyacinth control, and finally, to
- develop mycoherbicides or bioherbicides from promising pathogens as a component of integrated water hyacinth management strategy for Cameroon.

REFERENCES

Adams C. S., Boar R. R., Hubble D. S., Gikungu M., Harper D. M., Hickley P. & Tarras-Wahlberg N. (2002). The dynamics and ecology of exotic tropical species in floating plant mats: Lake Naivasha, Kenya. *Hydrobiologia,* **488:** 115–122.

Adis J., Bustorf E., Lhano M. G., Amedegnato C. & Nunes A. (2007). Distribution of *Cornops* grass- hoppers (Leptysminae: Acrididae: Orthoptera) in Latin America and the Caribbean Islands. *Studies on Neotropical Fauna and Environment,* **42**: 11–24.

Affeld K., Hill K., Smith L. A. & Syrett P. (2004). Toxicity of Herbicides and surfactants to three insect biological control agents for Cytisus scoparius (Scotch broom). In: *Proceedings of the XI International Symposium on Biological Control of Weed*, eds. J. M. Cullen, D. T. Briese, D. J. Kriticos, W. M. Lonsdale, L. Morin and J. K. Scott, April 27–May 2, 2003, Camberra, Australia, pp. 375–380

Agarwal G. P. & Hasija S. K. (1986). *Microorganisms in the laboratory: A laboratory guide of Microbiology, Mycology and Plant Pathology*. Print House, Lucknow, India. 155p.

Ainsworth G. C., Sparrow F. K. & Sussman A. S. (1973). *The fungi, an Advance Treatise. Vol. IV A: A Taxonomic Review with Keys: Ascomycetes and Fungi Imperfecti*. 621 S., 39 Abb., 78 Tafeln. New York-London. Academic Press Inc.

Ajonina N. G. (2006). Ethno biological surveys in the Douala-Edea costal atlantic region, Cameroon. *Cameroon Wildlife Conservation Society*, **8:** 7–10.

Ajuonu O., Schade V., Veltman B., Sedjro K. & Neuenschwander P. (2003). Impact of the weevils *N. eichhorniae* and *N. bruchi* on water hyacinth, *Eichhorniae crassipes in* Benin, West Africa. *African Entomology,* **11***:* 153–161.

Ajuonu O., Byrne M., Hill M. P., Neuenschwander P. & Korie S. (2007) Survival of the mirid *Eccritotarsus catarinensis* as influenced by *Neochetina eichhorniae* and *Neochetina bruchi* feeding scars on leaves of water hyacinth *Eichhornia crassipes*. *BioControl,* **52**: 193–205.

Ajuonu O., Tamo M., Neuenschwander P., Toko M., Beed F. & Hounkpe C. (2010). Invasive floating water weeds-killing life and commerce. *Technical Innovation brief*, No 3, Avril 2010.

Akinyemiju O. A. (1987). Invasion of Nigerian waters by water hyacinth. *Journal of Aquatic Plant Management*, **25**: 24–26.

Akpabey F. J. (2012). Quantification of the cross-sectoral impacts of water weeds and their control in Ghana. PhD Thesis, Rhodes University, 207p.

Albright T. P., Moorhouse T. G. & McNabb T. J. (2004). The rise and fall of water hyacinth in Lake Victoria and the Kagera River Basin, 1989 –2001. *Journal of Aquatic Plant Management,* **42**: 73–84.

Allen L. H., Sinclair T. R. & Bennett J. M. (1997). Evapotranspiration of vegetation of Florida: Perpetuated Misconceptions versus Mechanistic Processes. *Proceedings - Soil and Crop Science Society of Florida,* **56**: 1–10.

Anderson D. R. (2008). *Model based inference in the life sciences: A primer on evidence*. Springer, New York. 184 p.

Aneja K. R., Srinvas B. & Manpreet K. (1993). Evaluation of *Fusarium chlamydosporium* as a biocontrol agent of water hyacinth (*Eichhornia crassipes*) (Mart.) Solms. In: *Integrated Weed Management of Sustanaible Agriculture*. *Proceeding of Indian Society of Weed Science International Symposium*, Hisra, India, **3**: 145–149.

Anon (1947). The measurement of potato blight. *Transactions of the British Mycological Society,* **31:**140–141.

Anonymous (2000). When water hyacinth is not enough. *Water hyacinth News,* **2:**7.

Anonymous (2007) (htpp://gisp.org/publications/newsletter/GISPnewsletterfr7.pdf). Le Bulletin du GISP (GISP news). Le Programme mondial sur les espèces envahissantes (The Global Invasive Species Programme). NUMERO 7 • JANVIER 2007 • EGALEMENT DISPONIBLE EN ANGLAIS ET ESPAGNOL SUR www.gisp.org. http://www.gisp.org/publications/newsletter/GISPnewsletterfr7.pdf.

Anonymous (2011a). Water hyacinth mapping report of the Wouri–basin Douala, Littoral Region. Feasibility study for WTG project. p 13.

Anonymous (2011b). Environmental and social impact assessment for the drilling of oil and gas exploration wells within the Bomono permit, Cameroon. *Non technical summary*, Euroil Limited. P 8.

Anonymous (2010). Rapport de l'étude de la faisabilité sur la collecte, la valorisation et la gestion des déchets de la jacinthe d'eau dans le bassin hydrographique du Wouri, MINEP/WTG. P. 24.

Anonymous (2008). Cameroon fourth national report to the convention on biological diversity. 91pp.

Anonymous (2013). Water hyacinth – can its aggressive invasion can be controlled? In: *UNEP Global Environmental Alert Service (*GEAS*). Thematic focus: Ecosystem Management*. pp. 17.

APG II (2003). An update of the Angiosperm Phylogeny Group classification for the orders and families of the flowering plants: APGII. *Botanical Journal of the Linnean Society*, **141**: 399 – 436.

Ashton P. J., Scott W. E., Steyn D. J. & Wells R. J. (1979). The Chemical Control Programme Against the Water Hyacinth *Eichhornia crassipes* (Mart.) Solms on Hartebeespoort Dam: Historical and Practical Aspects. *South African Journal of Science,* **75:** 303–306.

Auld B. A., Menz K. M. & Tisdell C. A. (1987). *Weed Control Economics*. Academic Press, London, pp. 177.

Axtell N. R., Sternberg S. K. & Claussen K. (2003). Lead and nickel removal using *Microspora* and *Lemna minor*. *Bioresource Technolology*, **89**: 41–48.

Ayodo T. & Jagero N. (2012). The economic, educational and social responsibilities of elders development groups in Lake Victoria region. *Academic Research International,* **2 (3)**:610–620.

Azong Cho M. & Afangang E. E. (2011). Water hyacinth mapping report of the Wouri Basin, Douala, Littoral Region. 13 pages.

Babu R. M, Sajeena A., Seetharaman K. (2003). Bioassay of the potentiality of *Alternaria alternata* (Fr.) keissler as a bioherbicide to control water hyacinth and other aquatic weeds. *Crop Protection,* **22:** 1005–1013.

Bagnouls F. & Gaussen H. (1957). Les climats biologiques et leur classification. *Annales de Geographie*, 66e Annee, **No 355** (Mai-Juin 1957): 193–220. Stable URL: http://0-www.jstor.org.wam.seals.ac.za/stable/23443505.

Baker C. A. (1951). Pontederiaceae. *Flora Malesiana Bulletin Service,* **1(4)**: 255–261.

Balciunas J. (2004). Are mono-specific agents necessarily safe? The need for prerelease assessment of the probable impact of candidate biological control agents, with some exam- ples. In: Cullen J. M., Briese D. T., Kriticos D. J., Lonsdale W. M., Morin L., Scott J. K. (eds) *Proceedings of the XI international symposium on the biological control of weeds.* CSIRO Publishing, Melbourne, Australia, pp 252–257.

Barliwa J. S. (2009). Lake Victoria wetlands and the ecology of the Nile Tilapia, *Oreochromis niloticus* Linne., Ph.D. Dissertation, Wageningen Agricultural University, the Netherlands, pp 7-29, 1998.

Barliwa J. S., Wanda F. M. & Muyodi F. J. (2009). Impacts of Water Hyacinth and Water Quality Change on Beneficial Uses of Lake Victoria, Uganda. *13th World Lake Conference*, Wuhan, China, 1-5 November 2009.

Barreto R. W. & Evans H. C. (1996). Fungal pathogens of some Brazilian aquatic weeds and their potential use in biocontrol. In: Moran V. C. & Hoffmann H., ed., *Proceedingg of the IX International Symposium on Biological Control of Weeds*, Stellenbosch, South Africa, 19–26 January 1996. University of Cape Town, South Africa, 121–126.

Barrett S. C. H. & Forno I. W. (1982). Style morph distribution in New World populations of Eichhornia crassipes (Mart.) Solms-Laubach (water hyacinth). *Aquatic Botany,* **13:** 299–306.

Barrett S. C. H. (1977). Trystyly in *Eichhornia crassipes* (Mart.) Solms (water hyacinth). *Biotropica*, **9**: 230–238.

Barrett S. C. H. (1980a). Sexual reproduction in *Eichhornia crassipes* (water hyacinth) II: Seed production in natural populations. *Journal of Applied Ecology,* **17**: 113–124.

Barrett S. C. H. (1980b). Sexual reproduction in *Eichhornia crassipes* (water hyacinth). I. Fertility of clones from diverse regions. *Journal of Applied Ecology*, **17**: 101–112.

Barrett S. C. H. (1982). Style-morph distribution in new world populations of *Eichhornia crassipes* (Mart.) Solms-Laubach (Water hyacinth). *Aquatic Botany*, **13**: 299–306.

Barrett S. C. H. (1989). Waterweed invasions. Vast vegetative mats of the two most noxious aquatic weeds plague the world's waterways. Investigations of the water hyacinth and the Kariba weed (*Salvinia molesta*) are leading to new programs for weed control. *Scientific American*, **260**: 90–97.

Barrett S. C. H., Morgan M. T. & Husband B. C. (1989). The dissolution of a complex genetic polymorphism: the evolution of self-fertilization in Trystylous *Eichhornia paniculata* (Pontederiaceae). *Evolution*, **43 (7):** 1398–1416. DOI: 10.2307/2409456.

Bashir M. O. (1984). The establishment and distribution of natural enemies of water hyacinth released in Sudan. *Tropical Pest Management*, **30**: 320–323.

Batcher M. S. (2000). Element Stewardship Abstract for *Eichhornia crassipes* (Martius) Solms water hyacinth. The Nature Conservancy. The Global Invasive Species Initiative. Virginia, USA.

Bateman R. (2001). IMPECCA: an international, collaborative program to investigate the development of a mycoherbicide for use against water hyacinth in Africa. In: Julien M., Hill M. P., Center T. D. & Jianqing D. (eds), Biological and Integrated Control of water hyacinth, Eichhornia crassipes. *Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth*, Beijing, China, 9–12 October 2000. *Australian Centre for International Agricultural Research (ACIAR) proceedings,* **102:** 57–61.

Bates B. C., Kundzewicz Z. W., Wu S. & Palutikof J. P. (2008). *Climate Change and Water*. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210pp.

Berg A. (1961). *Role ecologique des eaux de la Cuvette Congolaise sur la Croissance de la jacinthe d´eau* (*Eichhornia crassipes*) (*Mart.) Solms*. Memoires Académie Royale des Sciences d´Outre Mer, Classe Sciences Naturelles et Medecine, ser XII, 3:1-119.

Beshir M. O. & Bennett F. D. (1985). Biological control of waterhyacinth on the White Nile, Sudan, pp. 491–496. In Delfosse E. S. (ed.). *Proceedings of the VI International Symposium on Biological Control of Weeds*. August 19–25, 1984. Vancouver, Canada, Agriculture Canada, Ottawa, Canada.

Bickel D. J. & Hernández M. C. (2004). Neotropical *Thrypticus* (Diptera: Dolichopodidae) reared from water hyacinth, *Eichhornia crassipes*, and other Pontederiaceae. *Annals of the Entomological Society of America,* **97**: 437–449.

Bini *L. M.*, Thomas S. M., Murphy K. J. & Carmago A. F. M (1999). Aquatic macrophytes distribution in relation to water and sediment conditions in Itaipu reservoir, Brazil. *Hydrobiologia,* **415:** 147–54.

Binimelis R., Wanda Born, Iliana Monterroso & Beatriz Rodríguez-Labajos. (2006). Socio-Economic Impact and Assessment of Biological Invasions. *Ecological Studies*, **193:** 331–347. Page proofs as of 9/15, 2006, by Kröner, Heidelberg.

Binimelis R., Monterroso I. & Rodríguez-Labajos B. (2007). A social analysis of the bioinvasions of *Dreissena polimorpha* in Spain and *Hydrilla verticillata* in Guatemala. *Environmental Management,* **40**: 555–566.

Biswas S., Choudhury J., Nishat A. & Rahman M. (2007). Do invasive plants threaten the Sundarbans mangrove forest of Bangladesh? *Forest Ecology and Management,* **245**:1–9.

Blackburn T. M., Pyšek P., Bacher S., Carlton J. T., Duncan R. P., Jarošík V., Wilson J. R. U. & Richardson D. M. (2011). A proposed unified framework for biological invasions. *Trends in Ecology and Evolution,* **26(7):** 333–339.

Bloom A. J., Stuart Chapin III F. & Mooney H. A. (1985). Ressource limitation in plants-An economic analogy. *Annual Review of Ecology and Systematics*, **16:** 363–392. Stable URL: http://www.jstor.org/stable/2097053.

Bock C. H., Poole G. H., Parker P. E. & Gottwald T. R. (2010). Plant disease severity estimated visually, by digital photography and image analysis, and by hyperspectral imaging. *Critical reviews in Plant Sciences*, **29(2):** 59–107. DOI: 10.1080/07352681003617285.

Bornette G. & Puijalon S. (2011). Response of aquatic plants to abiotic factors: a review. *Aquatic Sciences,* **73:**1–14. DOI 10.1007/s00027-010-0162-7.

Bornette G., Piegay H., Citterio A., Amoros C. & Godreau V. (2001). Aquatic plant diversity in four river floodplains: a comparison at two hierarchical levels. *Biodiversity and Conservation,* **10:**1683–1701.

Bownes A. (2009). Evaluation of a plant-herbivore system in determining potential efficacy of candidate biological control agent, *Cornops aquaticum*, for water hyacinth, *Eichhornia crassipes*. PhD thesis. Rhodes University, Grahamstown, South Africa. Pp.189.

Bownes A., Hill M. P. & Byrne M. J. (2010). Evaluating the impact of herbivory by a grasshopper, *Cornops aquaticum* (Orthoptera: Acrididae), on the competitive performance and biomass accumulation of water hyacinth, *Eichhornia crassipes* (Ponte- deriaceae). *Biological Control,* **53**: 297–303.

Braun-Blanquet J. (1932). *Plant sociology. The study of plant communities*. Edition McGray Hill, New York, London. p. 439.

Brendonck L., Maes J., Rommens W., Dekeza N., Nhiwatiwa T., Barson M., Callebaut V., Phiri C., Moreau K., Gratwicke B., Stevens M., Alyn N., Holsters E., Ollevier F., & Marshall B. (2003). The impact of water hyacinth (*Eichhornia crassipes*) in a eutrophic subtropical impoundment (Lake Chivero, Zimbabwe). II. Species diversity. Arch. *Hydrobiology,* **158 (3)**: 389–405.

Bruton B. D., Garcia-Jimenez J., Armengol J. & Popham T. W. (2000a). Assessment of virulence of *Acremonium cucurbitacearum* and *Monosporascus cannonballus* on *Cucumis melo*. *Plant Diseases,* **84:** 907–913.

Bureau Central des Recensements et des Etudes de Population, BUCREP (2010b). 3[è] RGPH : la Population du Cameroun en 2010. Retrieved from http://www.statistics-cameroon.org/downloads/La_population_du_Cameroun_2010.pdf

Bureau Central des Recensements et des Etudes de Population, BUCREP (2010). Rapport de présentation des résultats définitifs. Retrieved from http://www.statistics cameroon.org/downloads/Rapport_de_presentation_3_RGPH.pdf

Burton J. (2005). Water hyacinth. *Eichhornia crassipes*. *Agfact* P.7.6.43, Third edition 2005. NSW Department of Primary Industry Burton 2005.

Buzzle (2011). Water hyacinth control. Retrieved October 18th, 2014 from http://www.buzzle.com/articles/water-hyacinth-control.html.

Calvert P. (2002). Water Hyacinth: Control and possible uses. *Practical Action*, the Schumacher Centre for Technology and Development, Bourton on Dunsmore, Rugby, Warwickshire, UK.

Carr G. M. & Chambers P. A. (1998). Macrophytegrowth and sediment phosphorus and nitrogen in a Canadian prairie river. *Freshw. Biol.*, **39 (1998),** pp. 525–536.

Center T. D. & Dray F. A. (2010). Bottom-up control of water hyacinth weevil populations: do the plants regulate the insects? *Journal of Applied Ecology*, **47:** 329–337.

Center T. D. & Hill M. P. (2002). Field efficacy and predicted host range of the pickerelweed borer, *Bellura densa,* a potential biological control agent of water hyacinth. *BioControl,* **47**: 231–243.

Center T. D. & Spencer N. R. (1981). The phenology and growth of water hyacinth (*Eichhornia crassipes*) (Mart.) Solms in a eutrophic north-central Florida Lake. *Aquatic Botany,* **10**: 1–32.

Center T. D. & Van T. K. (1989) Alteration of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) leaf dynamics and phytochemistry by insect damage and plant density. *Aquatic Botany,* **35**: 181–195.

Center T. D. (1987). Insects, mites, and plant pathogens as agents of waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) leaf and ramet mortality. Journal of *Lake and Reservoir Management*, **3(1)**: 285–293

Center T. D. (1987a). Do Waterhyacinth Leaf Age and Ontogeny Affect Intra-plant Dispersion of *Neochetina eichhorniae* (Coleoptera: Curculionidae) Eggs and Larvae? *Environmental Entomology*, **16:** 699–707.

Center T. D. (1982). The Waterhyacinth weevils. *Neochetina eichhornia* and *N. bruchi*. *Aquatics,* **4 (2):** 8, 16, 18–19.

Center T. D. (1984a) Leaf life tables: a viable method for assessing sublethal effects of herbivory on waterhyacinth shoots. In: *Proceedings of the IV International Symposium on Biological Control of Weeds* (Ed. Delfosse ES), pp. 511–524. Agriculture Canada, Vancouver (CA).

Center T. D. (1984b). Dispersal and variation in infestation intensities of water hyacinth moth, Sameodes albiguttalis (Lepidoptera: Pyralidae) populations in peninsular Florida. *Environmental Entomology*, **13**: 482–491.

Center T.D. (1985). Leaf life tables: a viable method for assessing sublethal effects of herbivory on water hyacinth shoots. *Proceedings of the VI International Symposium on Biological*

Control of Weeds (ed. E.S. Delfosse), pp. 511–524. Agriculture Canada, Ottawa, Canada.

Center T. D. (1994). Biological control of weeds: water hyacinth and water lettuce. In "*Pest Management in the Subtropics: biological control-A Florida Perspective*". (D. Rosen, F. D. Bennett and J. L. Capinera, Eds.), pp. 481–521. Intercept, Andover, UK.

Center T. D., Dray F. A., Jubinsky G. P., & Grodowitz M. J. (1999a). Biological control of water hyacinth under condition s of maintenance management: Can herbicides and in sects be integrated? *Environmental Management*, **23:** 240–256.

Center T. D., Dray F. A., Jubinsky G. P. & Leslie A. J. (1999b). Waterhyacinth weevils (*Neochetina eichhorniae* and *N. bruchi*) inhibit waterhyacinth (*Eichhornia crassipes*) colony development. *Biological Control,* **15:** 39–50.

Center T. D., Steward K. K. & Bruner M. C. (1982). Control of water hyacinth (*Eichhornia crassipes*) with *Neochetina eichhorniae* (Coleoptera: Curculionidae) and a growth retardant. *Weed Science*, **30 (5):** 453–457.

Center T. D., Frank J. H. & Dray F. A. (1997). Biological control. In: Simberloff D., Schmitz D. C., Brown T.C. (Eds.), *Strangers in Paradise*. Islands Press, Washington, DC, pp. 245–266.

Center T. D., Groodwitz M. J., Cofrancesco A. F., Jubinsky G., Snoddy E. & Freedman J. E. (1997). Establishment of *Hydrellia pakistanae* (Diptera: Ephydridae) for the biological control of the submersed aquatic plant *Hydrilla verticillata* (Hydrocharitaceae) in the Southeastern United States. *Biological Control,* **8:** 65–73.

Center T. D., Hill M. P., Cordo H. & Julien M. H. (2002). Water hyacinth. In: van Driesche, R.G., Lyon, S., Blossey, B., Hoddle, M.S. & Reardon, R. (Eds) *Biological Control of Invasive Plants in the Eastern United States.* 41–64. USDA Forest Service, Morgantown, WV, U.S.A.

Chambers P. A., Prepas E. E., Bothwell M. L. & Hamilton H. R. (1989). Roots versus shoots in nutrient uptake by aquatic macrophytes in flowing waters. *Canadian Journal of Fisheries and Aquatic Sciences,* **46 (3):** 435–439. 10.1139/f89-058.

Charudattan R. (2000). Biological control of water hyacinth by using pathogens: opportunities, challenges and recent developments, pp.21–28. In: M.H. Julien, M.P. Hill, T.D. Center abd J. Ding (eds.), *Biological and integrated control of water hyacinth*, *Eichhornia crassipes*, ACIAR *Proceedings* 102.

Charudattan R. (2001b). Water hyacinth: A global menace. *Abstracts of the Third International Weed Science Congress*, **3:** 215.

Charudattan R. (2001a). Are we on top of aquatic weeds? Weed problems, control options, and challenges. In: Stirton C. H. (ed.). Weeds in a changing World International Symposium, Brighton, England, U.K., 20 November 1995, *British Crop Protection Council Monograph* No 64, Farnham (1995), pp. 20–27.

Charudattan R. (1984). Role of *Cercospora rodmanii* and other pathogens in the biological and integrated controls of waterhyacinth. In: G. Thyagarajan (ed), *Proceedings of the International Conference on Water Hyacinth*, Hyderabad, India, February 7–11, 1983. United Nations Environment Programme, Nairobi, Kenya. pp. 823–833.

Charudattan R. (1986). Integrated control of waterhyacinth (Eichhornia crassipes) with a pathogen, insects and herbicides. *Weed Science*, **34 (1):** 26–30.

Charudattan R. (1996). Pathogens for biological control of water hyacinth. In: Charudattan R., Labrada R., Center T. D. & Kelly-Begazo C. (eds), *Strategies for water hyacinth control. Rome: Food and Angriculture Organization*. Pp 189–196.

Charudattan R. (1996). Biological control of weeds. An international overview. In: V. SICONBIOL (Simposio de Controle Biologico), Foz do Iguacu, Brazil, June 9–14, pp. 270–282.

Charudattan R. (2001c). Biological control of water hyacinth by using pathogens: opportunities, challenges, and recent developments. In: Julien M. H., Hill M. P. and Jianqing D. (eds). *Proceedings of the Second meeting of global working group for the biological and integrated control of water hyacinth, Beijing*, China, 9–12 October 2000. p. 21–28.

Charudattan R. (2001d). Biological control of weeds by means of plant pathogens: significance for integrated weed management in modern agro-ecology. *BioControl,* **46:** 229–260.

Charudattan R. (2005). Ecological, practical and political inputs into selection of weed targets: what makes a good biological control target? *Biological Control,* **35:** 183-196.

Charudattan R. & Conway K. E. (1975). Comparison of *Uredo eichhorniae*, the water hyacinth rust, and *Uromyces pontederiae*. *Mycologia,* **67(3):** 653–657.

Charudattan R., McKinney D. E., Cordo H. A., Silveira-Guido A. (1976). *Uredo eichhorniae*, a potential biocontrol agent for waterhyacinth. In: Freeman, T.E. (Ed.), *Proceeding of the IV International Symposium on Biological Control of Weeds*. University of Florida, Gainsville, pp. 210–213.

Charudattan R., Perkins B. D. & Littell R. C. (1978). Effects of fungi and bacteria onn the decline of arthropods-damaged water hyacinth (*Eichhornia crassipes*) in Florida. *Weed Science*, **26**: 101–107.

Charudattan R., McKinney D. E. & Hepting K. T. (1981). Production, storage, germination, and infectivity of uredospores of *Uredo eichhorniae* and *Uromyces pontederiae*. *Phytopathology,* **71:** 1203–1207.

Charudattan R., Linda S. B., Kluepfel M. & Osman Y. A. (1985). Biocontrol efficacy of *Cercospora rodmanii* on waterhyacinth. *Phytopathology,* **75:** 1263–1269.

Charudattan R., Labrada R., Center T. D. & Kelly-Begazo C. (1995). *Strategies for water hyacinth control*. Report of a panel of Experts Meeting, Fort Lauderdale, Florida.

Charudattan R. (1986). Integrated control of waterhyacinth (*Eichhorniae crassipes*) with a pathogen, insects, and herbicides. *Weed Science*, **34 (Suppl. 1):**26–30.

Chaube H. S. & Singh U. S. (1991). *Plant Disease Management, Principles and Practices*. CRC Press, Boca Raton, FL.

Chikwenhere G. P. & Phiri G. (2001). History of water hyacinth and its control efforts on Lake Chivero in Zimbabwe. *Proc. Ist IOBC Water Hyacinth Working Group Meeting for the Biological and Integrated Control of Water Hyacinth* (Ed. Hill MP, Julien MH & Center TD), pp. 91–97. 16-19 November 1998, Zimbabwe, Plant Protection Research Institute, Pretoria (ZA).

Chikwenhere G. P. (1994). Biological control of water hyacinth (*Eichhornia crassipes*) in Zimbabwe – results of a pilot study. *FAO Plant Protection Bulletin*, **42(4)**: 185–190.

Chikwenhere G. P., Keswani C. L. & Liddel C. (1999). Control of water hyacinth and its environmental and economic impacts at Gache Gache in the eastern reaches of Lake Kariba, Zimbabwe. In: Hill, M. P., Julien, M. H. and Center, T.D. (Eds.) Biological and Integrated control of water hyacinth, *Eichhornia crassipes*. *Proceedings of the 1st Meeting of the Global Working Group for the Biological and Integrated Control of water hyacinth*, Harare, Zimbabwe, 16-19 November 1998. Plant Protection Research Institute, Pretoria, South Africa. pp: 30-38.

Cho Mujingni J. (2012). Quantification of the impacts of Water Hyacinth on riparian communities in Cameroon and assessment of an appropriate method of control: The case of the River Wouri Basin: The Case of the Wouri River Basin. Msc dissertation. World Maritime University, Malmö, Sweden. pp. 113.

Chu J. J., Jianqing Y., & Zhuang Q. J. (2006). Invasion and control of water hyacinth (Eichhornia crassipes) in China. *Journal of Zhejiang University science B*, **7 (8)**: 623–626.

Chuang Y. S., Lay C. H., Sen B., Chen C. C., Gopalakrishnan K., Wu J. H., Lin C. S. & Lin C. Y. (2011). Biohydrogen and biomethane from water hyacinth (*Eichhornia crassipes*) fermentation: effects of substrate concentration and incubation temperature. *International Journal of Hydr Energy,* **36:** 14195–14203.

Chunkao K., Nimpee C. & Duangmal. (2012). The King's initiatives using water hyacinth to remove heavy metals and plant nutrients from wastewater through Bueng Makkasan in Bangkok, Thailand. *Ecological Engineering,* **39**: 40–52.

Cilliers C. J. (1999). *Lysathia* n.sp. (Coleoptera: Chrysomelidae), a host-specific beetle for the control of the aquatic weed *Myriophyllum aquaticum* (Haloragaceae) in South Africa. *Hydrobiologia*, **415:** 271–276.

Cilliers C. J. (1987). First attempt at and early results on the biological control of *Pistia stratiotes* L. in South Africa. *Koedoe*, **30**: 35–40.

Cilliers C. J. (1991). Biological control of water hyacinth, *Eichhornia crassipes* (Pontederiaceae), in South Africa. *Agriculture, Ecosystems, and Environment,* **37**: 207–218.

Cilliers C. J, Hill M. P., Ogwang J. A. & Ajuonu O. (2003). Aquatic weeds in Africa and their control. In: Neuenschwander P, Borgemeister C, Langewald J (*eds*) *Biological control in IPM systems in Africa*. CAB International Publishing, Wallingford, UK, pp 161–178.

Ciruna K. A., Meyerson L. A. & Gutierez A. (2004). The ecological and socio-economic impacts of invasive alien species in inland water ecosystems. *Report to the Conservation on Biological Diversity on behalf of the Global Invasive Species Programme*, Washington, D.C. pp. 34.

Clarke K. R. & Warwick R. M. (2001a). A further biodiversity index applicable to species lists: variation in taxonomic distinctness. *Marine Ecology Progress Series,* **216**: 265–278, 2001.

Clarke K. R. & Warwick R. M. (2001b). *Change in marine communities: an approach to statistical analyses and interpretation.* 2nd edn. PRIMER-E, Plymouth.

Cock M., Day R., Herren H., Hill M. P., Julien M. H., Neuenschwander P. & Ogwang J. (2000). Harvesters get that sinking feeling. *Biocontrol News and Information,* **21**: 1–8.

Coetzee J. A. & Hill M. P. (2012). The role of eutrophication in the biological control of water hyacinth, *Eichhornia crassipes*, in South Africa. *BioControl* (2012), **57**: 247–261. DOI 10.1007/s10526-011-9426-y.

Coetzee J. A. & Hill M. P. (2011). The role of eutrophication in the biological control of water hyacinth, *Eichhornia crassipes*, in South Africa. *Biocontrol*, **57**: 247–261.

Coetzee J. A., Hill M. P., Byrne M. J. & Bownes A. B. (2011c). A review of the biological control programmes on *Eichhornia crassipes* (C. Mart.) Solms (Pontederiaceae), *Salvinia molesta* (Salviniaceae), *Pistia stratiotes* L., *Myripohillum aquaticum* (Vell.) Verdc. and *Azolla filiculoides* (Azollaceae) in South Africa since 1999. *African Entomology*, **19 (2):** 451–468.

Coetzee J. A., Center T. D., Byrne M. J. & Hill M. P. (2005). Impact of the biocontrol agent *Eccritotarsus catarinensis*, a sap-feeding mirid, on the competitive performance of waterhyacinth, *Eichhornia crassipes*. *Biological Control*, **32 (2005)**: 90–96.

Coetzee J. A., Byrne M. J. & Hill M. P. (2007a) Impact of nutrients and herbivory by *Eccritotarsus catarinensis* on the biological control of water hyacinth, *Eichhornia crassipes*. *Aquatic Botany,* **86**: 179–186.

Coetzee J. A., Hill M. P., Julien M. H., Center T. D., & Cordo H. A. (2009a) *Eichhornia crassipes* (Mart.) Solms-Laub. (Pontederiaceae). In. R. Muniappan, G. V. P. Reddy, and A. Raman (Eds.) *Biological Control of Tropical weeds using Arthropods* (pp. 183 – 210). UK: Cambridge University Press.

Coetzee J. A., Byrne M. J., Hill M. P. & Center T. D. (2009b). Should the mirid, *Eccritotarsus catarinensis* (Heteroptera: Miridae), be considered for release against water hyacinth in the United States of America? *Biocontrol Science and Technology*, **19(1):** 103–111.

Coetzee J. A., Hill M. P., Byrnes M. J. & Bownes A. (2011a): a review of the Biological control programmes on *Eichhornia crassipes* (Mart.) Solms (Pontedericaea), *Salvinia molesta* D. S. Mitch (Salviniaceae), *Pistia stratiotes* L. (Araceae), *Myriophyllum aquaticum* (Vell.) Verdc. (Haloragaceae) and *Azolla filiculoides* Lam. (Azollaceae) in South Africa. *African Entomology*, **19 (2):** 451–468.

Coetzee J. A., Bownes A. & Martin G. D. (2011b). Prospects for the biological control of submerged macrophytes in South Africa. *African Entomology,* **19**: 469–487.

Coetzee J. A., Jones R. W. & Hill M. P. (2014). Water hyacinth, *Eichhornia crassipes* (Pontederiaceae) reduces benthic macroinvertebrate diversity in a protected subtropical lake in South Africa. *Biodiversity Conservation,* **23:** 1319 – 1330.

Conway K. E. (1976a). Evaluation of *Cercospora rodmanii* as a biological control agent of water hyacinth. *Phytopathology,* **66:** 914–917.

Conway K. E. (1976b). *Cercospora rodmanii* a new pathogen of water hyacinth with biological control potential. *Can. J. Bot.,* **54:** 1079–1083.

Conway K. E. & Freeman T. E. (1977). Host specificity of *Cercospora rodmanii*, a potential biological control agent of water hyacinth. *Plant Disease Reporter,* **61:** 262–266.

Conway K. E., Freeman T. E. & Charudattan R. (1978). Development of *Cercospora rodmallii* as a biological control for *Eichhomia crassipes.* Pages 225-230. In *Proceedings EWRS 5th Symposium on Aquatic Weeds*, Wageningen, Netherlands.

Cook C. D. K. (2004). *Aquatic and wetlands plants of Southern Africa*. Backhuys Publishers, Leiden. The Netherlands, pp. 1–21.

Cook C. D. K. (1998). Pontederiaceae. In *Families and genera of vascular plants IV.*. ed. K. Kubitzki, Springer-Verlag, Berlin, pp. 395–403.

Cordo H. A. & DeLoach C. J. (1975). Ovipositional specificity and feeding habits of the waterhyacinth mite, *Orthogalumna terebrantis*, in Argentina. *Environmental Entomology*, **4**: 561–565.

Cordo H. A. & DeLoach C. J. (1976). Biology of the waterhyacinth mite in Argentina. *Weed Science*, **24**: 245–249.

Cordo H. A. (1996). Recommendations for finding and prioritizing new agents for biocontrol of water hyacinth. In: Charudattan R., Labrada R., Center T. D., Kelly-Begazo C. (eds.), *Strategies for Water Hyacinth Control*. Reports of a Panel of Experts Meetings, Fort Lauderdale, FL, pp. 181–185.

Cordo H. A. (1997). Biological control of water hyacinth. In: *Annual report for the 1996/1997 Southern Hemisphere Growing Season*. 24–30. South American Biological Control Laboratory, USDA-ARS, Hurlingham, Buenos Aires, Argentina.

Cordo H. A. (1999). New agents for biological control of waterhyacinth. In: *Proceedings of the First IOBC Global Working Group Meeting for the Biological and Integrated Control of Water Hyacinth* (Ed. Hill MP, Julien MH & Center TD), pp. 68–74. 16–19 November 1998, Zimbabwe. Plant Protection Research Institute, Pretoria (ZA).

Cronck J. K. & Fennessy M. S. (2001). *Wetlands Plants. Biology and Ecology*. Lewis Publishers, Boca Raton, Florida.

Cronquist A. (1988). *The Evolution and Classification of Flowering Plants*, 2nd edition. New York Botanical Garden, New York.

Cruttwell R. E. (1973). Preliminary investigations on some insects causing minor damage to water hyacinth, *Eichhornia crassipes*. Report of the West Indian Station, Commonwealth Institute of Biologi- cal Control, Trinidad.

CSIR (2004). Implementation of invasive plant prevention and control programmes in Ghana. *Report submitted to the CABI Africa Regional Centre under the PDF-B phase of the UNEP/GEF project: Removing Barriers to Invasive Plant Management in Africa*. Council for Scientific and Industrial Research, Accra, Ghana. pp. 63.

Cuda J. P., Charudattan R., Grodowitz M. J., Newman R. M., Shearer J. F., Tamayo M. L. & Villegas B. (2008). Recent advances in biological control of submersed aquatic weeds. *Journal Aquatic Plant Management*, **46**: 15–32.

Curtis J. T. & McIntosh R. P. (1950). The interrelations of certain analytic and synthetic phytosociological characters. *Ecology*, **31 (3):** 434–455.

Curtis J. T. (1959). *The vegetation of Wisconsin: An ordination of Plant Communities*. University of Wisconsin Press, Madison. 657 pp.

Da Fatima L. S. (2013). Impact and control of waterweeds in the Southern MozambiqueBasin Rivers. PhD Thesis, Rhodes University, Grahamstwon, South Africa. 219 p.

Dagno K., Lahlali R. Diourté M. & Jijakli M. H. (2012). Fungi occurring on water hyacinth [*Eichhornia crassipes* (Martius) Solms-Laubach] in Niger River in Mali and their evaluation as bioherbicides. *Journal of Aquatic Plant Management*, **50:** 25–32.

Dagno K. (2006). Évaluation des microorganismes fongiques en tant qu'agents de lute Biologique contre *Eichhornia crassipes* (Martius) Solms-Laubach dans le bassin du fleuve Niger au Mali. DEA doc. Sci. agron. Gembloux, Belgique: Gembloux Agricultural University – FUSAGx. 102p.

Dagno K. (2011). Selection, efficacy, ecological characterization and formulation of fungal control agents against water hyacinth (*Eichhornia crassipes* (Martius) Solms-Laubach) in Mali. PhD Thesis in Engineering Sciences, University de Liege, Gembloux Agro-BioTech, 120p.

Dagno K., Lahlali R., Friel D., Bajji M. & Jijakli H., (2007). Review: problems of the water hyacinth, *Eichhornia crassipes* in the tropical and subtropical areas of the world, in particular its eradication using biological control method by means of plant pathogens. *Biotechnology, Agronomy, Society and Environment Journal*, **11 (4):** 299–311.

Dagno K., Lahlalo R., Diourte M. & Jijakli M.H. (2011). Effect of temperature and water activity on spore germination and mycelial growth of three fungal biocontrol agents against water hyacinth (*Eichhornia crasspes*). *Journal of Applied Microbiology*, **110(2):** 521–528. **DOI:** 10.1111/j.1365-2672.2010.04908.x

Dagno K., Lahlali R., Diourte M. & Haissam J. (2012). Fungi occurring on waterhyacinth (*Eichhornia crassipes* [Martius] Solms-Laubach) in Niger River in Mali and their evaluation as Mycoherbicides. *Journal of Aquatic Plant Management*, **50:** 25–32.

Dattalo P. (2008). *Determining Sample Size: Balancing Power, Precision, and Practicality*. Oxford University Press, New York.

Daubermire J. (1957). *Cover Scale or Classe Methods in Bonham*. Canada, pp. 54.

De Foucault B. (1980). Les prairies du bocage virois (Basse-Normandie, France). Typologie phytosociologique et essai de reconstitution des séries évolutives herbagères. *Doc. Phytosoc., N. S.,* **5**: 1–109.

De Groote H., Ajuono O., Attignon S., Djessou R., & Neuenschwander P. (2003). Economic impact of biological control of water hyacinth in Southern Benin. *Ecological Economics,* **45 (2003):** 105–117.

de Marco P., Araujo M. A. R., Barcelos M. K. & dos Santos M. B. L. (2001). Aquatic invertebrates associated with the water-hyacinth (Eichhornia crassipes) in a eutrophic reservoir in tropical Brazil. *Studies on Neotropical fauna and Environment*, **36**: 73–80.

Debach P. (1974). *Biological control by natural enemies*. Cambridge University Press, Cambridge (GB).

Debusk T. A. & Dieberg F. E. (1989). Effects of nutrient availability on water hyacinth standing crop and detritus deposition. *Hydrobiologia*, **174**: 151–159.

DeGroot P. J. (1993). Introduction and summary. In: "*Control of Africa's floating water weeds*". Eds. Greathead A. & de Groot P.J. Commonwealth Science Council, Series no. CSC (93) AGR-18, *Proceedings* 295, pp. 187.

Della Greca M., Previtera L. & Zarrelli A. (2009). Structures of new phenylphenalene-related compounds from *Eichhornia crassipes* (water hyacinth). *Tetrahedron,* **65:** 8206–8208.

DeLoach C. J. & Cordo H. A. (1976a). Life cycle and biology of *Neochetina bruchi*, a weevil attacking waterhyacinth in Argentina with notes on *N. eichhorniae*. *Annals of the Entomological Society of America,* **69**: 643–652.

DeLoach C. J, & Cordo H. A. (1976 b). Ecological studies of *Neochetina bruchi* and *Neochetina eichhorniae* on water hyacinth in Argentina. *Journal of Aquatic Plant Management*, **14**: 53–59.

DeLoach C. J. & Cordo H. A. (1978). Life history and ecology of the moth *Sameodes albiguttalis* a candidate for biological control of water hyacinth. *Environmental Entomology,* **7**: 309–321.

den Bieman C. F. M. (1987). Host plant relations in the planthopper genus *Ribautodelphax* (Homoptera, Delaphacidae). *Ecological Entomology,* **12**: 163–172.

Den Breeÿen A. (1998). Biological control of water hyacinth using plant pathogens: Dual pathogenicity and insect interactions. *Proceedings of the X International Symposium on Biological Control of Weeds*, 4-14 July 1999, Montana State University, Bozeman, Montana, USA. Neal R. Spencer [ed.]. (2000).

Denno R. F., Cheng J., Roderick G. K. & Perfect T. J. (1994). '*Density-related effects on the components of fitness and population dynamics of planthopper' in Planthoppers*. Their Ecology and Management, eds. R. F. Denno and T. J. Perfect, New York, NT: Chapman & Hall, pp. 257–281.

Denoth M., Frid L. & Myers J. H. (2002). Multiple agents in biological control: improving the odds? *Biological Control,* **24:** 20–30.

De Poorter M., Darby C. & Mackay J. (n.d.). Marine Menace: Alien invasive species in the marine environment. International Union for Conservation of Nature's Invasive Species Specialist Group (IUCN/ISSG).

Diamond J. (2005). *Collapse, how societies choose to fail or succeed*. New York, Pengiun. 497 p.

Dieudonne A. (2006). Towards a comprehensive strategy for the effective and efficient management of industrial pollution along the Atlantic coast of Cameroon. (Doctoral Dissertation, Brandenburg University of Technology, Cottbus, Germany). Retrieved from http://opus.kobv.de/btu/volltexte/2006/32/pdf/Ph.D_thesis.pdf. 268 p.

Din N. (2007) Réalisation d'une étude des normes d'éradication de la plante dénommée « jacinthe d'eau » sur le fleuve Wouri pour le compte de la Direction des Affaires Maritimes et des Voies Navigables (DAMVN) basée à Douala. DAMVN archives.

Din N., Priso R. J., Kenne M., Ngollo D. E., Blasco F. (2002). Early growth stages and natural regeneration of *Avicennia germinans* (L.). Stearn in the wouri estuarine mangroves (Douala-Cameroon). *Wetlands, Ecology and Management*, **10 (6):** 461–472.

Din N., Saenger P., Priso R. J., Dibong D. S. & Blasco F. (2008). Logging activities in mangrove forests: A case study of Douala Cameroon. *African Journal of Environmental Science and Technology*, **2 (2)**: 22–30.

Ding J., Wang R., Fu W. & Zhang G. (2001). Water hyacinth in China: its distribution, problems and control status. In: *Proceedings of the 2ndMeeting of the Global Working Group for the Biological and Integrated Control of Waterhyacinth, Beijing, China* (Ed. Julien MH, Hill MP, Center TD & Ding J), pp. 29–32. 9–12 October 2000. Australian Centre for International Agricultural Research, Canberra (AU).

Djeuda–Tchapnga H. B., Tanawa E. & Ngnikam E. (2001). *L'eau du Cameroun*. Presses Universitaires, Yaounde, pp. 115–129.

Domsch H., Gams W. & Anderson T. H. (2007). *Compendium of soil fungi* (2nd edn). Taxonomically revised by W. Gams, Eching : IHW-Verlag. 672 p.

DPIWE (Department of Primary Industries Parks Water and Environment) (2012). The LIST (Land Information System Tasmania) LISTmap Turners Beach.

Duarte C. M., Kallff J. & Peters R. H. (1986). Patterns in biomass and cover of aquatic macrophytes in lakes. *Canadian Journal of Fisheries and Aquatic Science*, **43**: 1900–1908.

Dugast J. L. (1992). Jacinthe d'eau, la terreur des tropiques. *Science et Nature*, **27**: 60–71.

Dutartre A., Haury J. & Planty-Tabacchi A. M. (1997). Introduction de macrophytes aquatiques et riverains dans les hydrosystèmes français métropolitains : essai de bilan. *Bulletin Francais de la Pêche et de la Pisciculture*, **344-345**: 407–426.

Eckenwalder J. E. & Barrett S. C. H. (1986). Phylogenetic systematics of Pontederiaceae. *Systematic Botany*, **11**: 373–391.

Edewor J. O. (1988). Developing water hyacinth from menace status to national profitability level. In Oke, O. L., A. M. A. Irnevborc and T. A. Farri (Eds.), *Proceedings of the International Workshop on Water hyacinth. Federal Ministry of Science and Technology.* (pp. 175–178).

Edwards D. & Musil C. J. (1975). *Eichhornia crassipes* in South Africa – a general review. *Journal of the Limnological Society of Southern Africa,* **1**: 23–27.

EEA (2012). The impacts of invasive alien species in Europe. EEA Technical reports No 16/2012. Luxembourg: Publications Office of the European Union, 2012. http://www.eea.europa.eu/publications/impacts-of-invasive- alien-species.

Ellis M. B. (1971). *Dermatiaceous hypomycetes*. Commonwealth Mycological Institute Kew, Surrey, England. 608 p.

Ellis M. B. (1976). *More dermatiaceous hypomycetes*. Commonwealth Mycological Institute Kew, Surrey, England. 507p.

El-Morsy E. M. (2004). Evaluation of microfungi for the biological control of water hyacinth in Egypt. *Fungal Diversity*, **16**: 35–51.

El-Morsy E. M. (2000). Fungi isolated from the endorhizosphere of halophytic plants from the Red Sea Coast of Egypt. In: Aquatic Mycology across the Millennium (eds K.D. Hyde, W.H. Ho and S.B. Pointing). *Fungal Diversity*, **5:** 43–54.

El-Morsy E. M., Dohlob S. M. & Hyde K. D. (2006). Diversity of *Alternaria alternata* a common destructive pathogen of *Eichhornia crassipes* in Egypt and its potential use in biological control. *Fungal Diversity,* **23:** 139–158.

Elwakil M. A., Sadik E. A., Fayzalla E. A. & Shabana Y. M. (1989). Biological control of waterhyacinth with fungal plant pathogens in Egypt. In: Delfosse E. S. (ed.). *Proc. VII. Int. Symp. Biol. Contr. Weeds*, 6–11 March 1988, Rome, Italy. Ist Sper, Patol. Veg. (MAF), pp. 483–97 (1989).

EPPO (2008). *Eichhornia crassipes*. *EPPO Bulletin,* **38**: 441–449. doi: 10.1111/j.1365–2338.2008.01261.x.

Epstein P. (1998). Weeds bring disease to the East African waterways. *Lancet*, **351:** 577.

Epule T. E., Peng C., Mirielle M. W. & Mafany N. M. (2011). Well water quality and public health implications: The case of four neighbourhoods of the city of Douala Cameroon. *Global Journal of Health Science*, **3 (2)**: 75–83.

Evans H. C. & Reeder R. H. (2001). Fungi associated with Eichhornia crassipes (Water Hyacinth) in the Upper Amazon Basin and prospects for their Use in Biological Control. In: Julien M. H., Hill M. P., Center T. D. & Jianqing Ding (eds), Biological and Integrated Control of Water Hyacinth, *Eichhornia crassipes*. *Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes*, Beijing, China, 9–12 October, 2000. Australian Centre for International Agricultural Research (ACIAR) Proceedings 102: 62–70.

Evans H. C., Greaves M. P. & Watson A. K. (2001). Fungal biocontrol agents of weeds. CAB International 2001. *Fungi as biocontrol agents: Progress, problems and potential*. (eds T.M. Butt, C. Jackson and N. Magan).

Fayad Y. H. (1999). Water hyacinth infestations and control in Egypt. In: *Proceedings of the 1st Meeting of the Global Working Group for the Biological and Integrated Control of water hyacinth*, Harare, Zimbabwe, 16-19 November 1998. Hill, M.P., Julien, M.H. and Center, T.D. (Eds.) Biological and Integrated control of water hyacinth, *Eichhornia crassipes*. Plant Protection Research Institute, Pretoria, South Africa. pp: 106–110.

Feikin D. R., Tabu C. W. & Gichuki J. (2010). Does water hyacinth on East African lakes promote cholera outbreaks? *American Journal of Tropical Medicine and Hygiene,* **83:** 370 – 373.

Findlay J. B. R. & Jones D. (1996). The integrated control of water hyacinth, *Eichhornia crassipes*, in Africa based on Roundup® herbicide treatments: in *Proceedings of the IX international Symposium on Biological Control of Weeds*, pp. 435–440. V.C. Moran and J.H. Hoffmann (eds). 19–26 January 1996, Stellenbosch, South Africa. University of Cape Town.

Flack S. R. & Benton N. B. (1998). Invasive Species and Wetland Biodiversity. *National Wetlands Newsletter*, **20**: 7–11.

Focardi S., Aragno P., Montanaro P. & Riga F. (2006). Inter-specific competition from fallow deer dama dama reduces habitat quality for the Italian Roe Deer *Capreolus capreolus italicus*. *Ecography*, **29 (3):** 407–417.

Forno I. W. (1981). Effects of *Neochetina eichhorniae* on the growth of water hyacinth. *Journal of Aquatic Plant Management*, **19:** 27–31.

Forpah N. C. (2009). Cameroon prepares a National Strategy for the control of water hyacinth (exotic species). *Workshop proceedings on the elaboration of a national strategy for the control of water hyacinth in Cameroon*, 15th – 18th September 2009, Douala, Cameroon.

Fowler J., Cohen L. & Jarvis P. (2005). Practical statistics for field biology. John Wiley & Sons, Chichester.

François J. (1970). Recherches experimentales sur l´ecologie la jacinthe d´eau, *Eichhornia crassipes* (Mart.) Solms. Dissertation, Faculte Sci Agronom Gembloux, Belgium.

Freeman T. E. & Charudattan R. (1984). *Cercosporia rodmanii Conway,* a Biocontrol Agent of Waterhyacinth. Bulletin 842. Gainesville, FL: Agricultural Experiment Stations, Institute of Food and Agricultural Sciences, University of Florida, 18 pp.

Freeman T. E. & Charudattan R. (1974). Occurrence of Cercospora piaropi on water hyacinth in Florida. *Plant Disease Reporter*, **58:** 277–278.

Freeman T. E., Charudattan R. & Conway K. E. (1981). Biological control of aquatic plants with pathogenic fungi. Technical Report, U. S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, pp. 2760–1.

Fri A. N. (2010). Annual Festivals in Cameroon. *For the Interim*. Retrieved July 10th, 2012 from World Wide Web http://fortheinterim.com/annual-festivals-in-cameroon/.

Fuxa J. R. & Tanada Y. (1987). Epidemiological concepts applied to insect epizootiology. In "*Epizootiology of Insect Diseases*" (J. R. Fuxa and Y. Tanada, Eds.), pp. 3–21. Wiley, New York.

Gallina N. (2012). Description and modeling of phytoplankton with an emphasis of cyanobacteria in deep peri-Alpine lakes under warmer climatic conditions. PhD Thesis, University of Geneva, Institute of Environnent Science. 107p.

Gao L. & Li B. (2006). A potential native natural enemy of invasive aquatic weed–water hyacinth. *Biological Invasion*, **8**: 1689–1692.

Gargominy O., Bouchet P., Pascal, Jaffré T., & Tourneur J-C. (1996). Conséquences des introductions d'espèces animales et végétales sur la biodiversité en nouvelle Calédonie. *Revue d'Ecologie (Terre vie),* **51**: 375–403.

Gassmann A., Cock M. J. W., Shaw R. & Evans H. C. (2006). The potential for biological control of invasive alien aquatic weeds in Europe: a review. *Hydrobiologia*, **570**: 217–222.

Gaudet C. L. & Keddy P. A. (1988). Predicting competitive ability from plant traits: a comparative approach. *Nature*, **334**: 242–243.

GEF (2008). GEF- Country Portfolio Evaluation Cameroon. (1992-2007) 116pp.

Gichuki J., Omondi R., Boera P., Tom Okorut T., SaidMatano A., Jembe T. & Ofulla A. (2012). Water Hyacinth *Eichhornia crassipes* (Mart.) Solms-Laubach Dynamics and Succession in the Nyanza Gulf of Lake Victoria (East Africa): Implications for Water Quality and Biodiversity Conservation. *The Scientific World Journal,* Volume 2012, Article ID 106429, 10 pages.

Golan de Mera A. & De Castro E. (2003). *Heteranthera Ruiz & Pav.* (Pontederiaceae) en la Peninsula Iberica. *Anales del Jardin Botanico de Madrid*, **60 (1)**: 241–242.

Gopal B. (1987). *Water Hyacinth, Aquatic Plant*. Elsevier Science Publishers, B. V. Amsterdam, The Netherlands. 471 pp.

Gosset D. R. & Norris W. E. Jr (1971). Relationship between nutrient availability and content of nitrogen and phosphorus in tissues of the aquatic macrophytes, *Eichhornia crassipes* (Mart.) Solms. *Hydrobiologia*, **38**: 15–28.

Goudart A. (2007). Fonctionnement des écosystèmes et invasions biologiques: importance de la biodiversité et des interactions interspécifiques. Mémoire de thèse de doctorat, Université Pierre et Marie Curie, Paris VI. 216 pp.

Goyer R. A. & Stark J. D. (1984). The impact of Neochetina eichhorniae on water hyacinth in Southern Louisiana. *Journal of Aquatic Plant Management*, **22:** 57–61.

Greathead A. & DeGroot P. (Eds.) (1993). Control of Africa's Floating Water Weeds. Commomwealth Science Council, Series Number CSC (93). AGR-18. *Proceedings of a workshop held in Zimbabwe*, June 1991, 295, pp. 187.

Greenfield B. K., Siemering G. S., Andrews J. C., Rajan M., Andrews S. P. & Spencer D. F. (2007). Mechanical shredding of water hyacinth (*Eichhornia crassipes*): Effects on water quality in the Sacramento-San Joaquin River Delta, California. *Estuaries and Coasts*, **30**: 627–640.

Grime J. P. (2002). Plant strategies, vegetation processes, and ecosystem properties. Wiley, Chichester.

Guerreiro A. R. (1976). O Jacinto aquatico (*Eichhornia crassipes* (Mart) Solms) em Portugal. Paper presented at II Simposio Nacional de Herbologia, Oeiras (Portugal), 6- 7 Dec 1976.

Gue'vart E., Noeske J., Solle J., Essomba J.M., Edjenguele M., Bita A., Mouangue A. & Manga B. (2006). Synthèse. Déterminants du choléra à Douala. *Médecine tropicale,* **66 (3):** 283–291.

Guitierez E. L., Ruiz E. F., Uribe E. G. & Martinez J. M. (2000). Biomass and productivity of water hyacinth and their application in control programs. In: Hill M. P., editor. "*Proceedings of the Second IOBC Global Working Group on the Biological and Integrated Control of Water Hyacinth*", vol. 102. Beijing, China: ACIAR; p. 109–119.

Gutierrez E. L., Huerto R., Saldaña P. & Arreguín F. (1996). Strategies for water hyacinth (*Eichhornia crassipes*) control in Mexico. *Hydrobiologia*, **340:** 181–185.

Haag K. H. (1986). Effective control of water hyacinth using *Neochetina* and limited herbicide application. *Journal of Aquatic Plant Management,* **24:** 70–75.

Haller W. T. & Sutton D. L. (1973). Effect of pH and high phosphorus concentration on growth of waterhyacinth. *Hyacinth Control Journal*, **11**: 59–61.

Haller W. T., Sutton D. L., & Barlowe W. C. (1974). Effects of the salinity on growth of several aquatic macrophytes. Ecology, **55 (4):** 891–894.

Hamadina H. L., Anaso C. E. & Umar A. (2015). Life cycles of *Neochetina bruchi* Warner and *Neochetina eichhorniae* Hustache as potential biological control agents in the semi arid zone of Nigeria. *American Journal of Life Sciences*, **3(3):** 219–222.

Harley K. L. S. & Wright A. D. (1984). Implementing a programme for biological control of water hyacinth, *Eichhornia crassipes*. In: Thyagarajan, G. (ed.) '*Proceedings of International Conference on water hyacinth*" February, 1983. Hyderabad, India. UNEP, Nairobi, pp. 58–68.

Harley K. L. S. (1990). The role of biological control in the management of water hyacinth, *Eichhornia crassipes*. *Bio Control News and Information,* **11:** 11–22.

Harley. K. L. S., Forno I. W., Kassulke R. C. & Sands D. P. A. (1984). Biological control of water lettuce. *Journal of Aquatic Pest Management*, **22**: 101–102.

Harley K. L. S., Julien M. H. & Wright A. D. (1996) Water hyacinth: a tropical worldwide problem and methods for its control. *Proceedings of the Second International Weed Control Congress* **II**, 639–644. Copenhagen (DK), 1996.

Hassane Y. H. (2010). Prolifération des plantes aquatiques envahissantes sur le fleuve Niger; état des lieux de la pollution en azote et en phosphore des eaux du fleuve. Memoire de MSc, Gestion integree des ressources en eau (GIRE), International Institute for water and Environmental Engineering. Ouagadougou.

Healy A. J. & Edgar E. (1980). Flora of the New Zealand, Volume III: Adventive cyperaceous, petalous & spathaceous monocotyledons. Government Printer, Wellington, New Zealand. 220 pp.

Heard T. A. & Winterton S. L. (2000). Interactions between nutrient status and weevil herbivory in the biological control of water hyacinth. *Journal of Applied Ecology*, **37**: 117–127.

Heard T. A., Zonneveld R. & Fichera G. (2014). *Megamelus scutellaris* (Hemiptera: Delphacidae), a biocontrol agent of water hyacinth, is not sufficiently specific for release in Australia. *Biocontrol Science and Technology*, **24 (5):** 554–560.

Hejda M., Pyšek P. & Jarošík V. (2009). Impact of invasive plants on the species richness, diversity and composition of invaded communities. *Journal of Ecology,* **97**: 393–403.

Hernandez M. C., Cordo H. A. & Hill M. (2004). Studies in Argentina on two species of Tryticus (Diptera) as agents for the biological control of water hyacinth. In: Cullen J. M., Briese D. T., Kriticos D. J., Lonsdale W. M., Morin L., Scott J. K. (Eds.), *Proceeding of the XI International Symposium on Biological Control of Weeds*. CSIRO Entomology, Canberra, Australia, pp. 117–120.

Hernandez M. C., Pildain M. B., Novas M. V., Sacco J. & Lopez S. E. (2007). Mycobiota associated with larval mines of *Trypticus truncatus* and *T. sagitatus* (Diptera: Dolichopodidae) on waterhyacinth, *Eichhornia crassipes*, in Argentina. *Biological control,* **41**: 321–326.

Hernandez C. M., Brentassi M. E., Sosa A. J., Sacco J. & Elsesser G. (2011). Feeding behavior and spatial distribution of two planthoppers, *Megamelus scutellaris* (Delphacidae) and *Toasa longula* (Dictyopharidae), on water hyacinth. *Biocontrol Science and Technology,* **21 (8):** 941–952. DOI: 10.1080/09583157.2011.596624.

Hill M. P. & Cilliers C. J. (1999). A review of the arthropod natural enemies, and factors that influence their efficacy, in the biological control of water hyacinth, *Eichhornia* *crassipes* (Mart.) Solms-Laubach (Pontederiaceae), in South Africa. *African Entomology Memoir,* **No. 1:**103–112.

Hill M. P. & Julien M. H. (2004). The transfer of appropriate technology; key to the successful biological control of five aquatic weeds in Africa, In: *Proceedings of the XI International Symposium on Biological Control of Weeds* (Eds.) Cullen, J. M., Briese, D. T., Kriticos, D. J., Lonsdale, W. M., Morin, L. and Scott, J. K. pp: 370–374. CSIRO Entomology, Canberra. Australia.

Hill M. P. (1999). The world's worst aquatic weed. Weed control. Pesticide outlook April 1999. Pp.58–61.

Hill M. P. (2003). The impact and control of alien aquatic vegetation in South African aquatic ecosystems. *African Journal of Aquatic Science,* **28:** 19–24.

Hill M. P. & Cilliers C. J. (1999). A review of the arthropod natural enemies and factors that influence their efficacy in the biological control of water hyacinth *Eichhornia crassipes* (Mart.) Solms-Laubach (Pontederaceae). *South African Entomology Memoir,* **1**: 103–112.

Hill M. P. & Coetzee J. A. (2008). Integrated control of water hyacinth in Africa. In: Proeeding of the EPPO/CoE Workshop–How to manage invasive alien plants? The case study of *Eichhornia crassipes*. Mérida, Spain, 2008-06-02/04. *Bulletin OEPP/EPPO*, **38:** 452–457.

Hill M. P. & Olckers T. (2001). Biological control initiatives against water hyacinth in South Africa: constraining factors, success and new courses of action. In: *Proceeding of the Second Global Working Group Meeting for the Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes*, eds M. H. Julien, M. P. Hill, T. D. Center and D. Jianqing, October 9–12, 2000, Beijing, China. ACIAR Proceedings No 102, pp. 33–38.

Hill M. P., Cilliers C. J. & Neser S. (1999) Life history and laboratory host range of *Eccritotarsus catarinensis* (Carvalho) (Heteroptera: Miridae), a new potential natural enemy released on water hyacinth (*Eichhornia crassipes* (Mart.) Solms-Laub.) (Pontederiaceae) in South Africa. *Biological Control,* **14**: 127–133.

Hill M. P., Coetzee J., Julien M. I. C. & Center T. D. (2011). Water Hyacinth. Pp. 689–692. From Daniel Simberloff and Marcel Rejmánek, editors, *Encyclopedia of Biological Invasions*, Berkeley and Los Angeles: University of California Press, 2011.

Hill M. P., Coetzee J. A. & Ueckermann C. (2012). Toxic effect of herbicides used for water hyacinth control on two insects released for its biological control in South Africa. *Biocontrol Science and Technology*, **22 (11):** 1321–1333.

Holliday P. (1993). A dictionary of plant pathogens. Cambridge University Press. New Delhi. 369p.

Holm L. G, Plucknett D. L., Pancho J. V. & Herberger J. P. (1977). *The world's worst weed: Distribution and biology*. Honolulu: University Press of Hawaii.

Holmes S. (1996). South African Water Quality Guidelines*: Aquatic Ecosystems*. Vol. 7. Department of Water Affairs and Forestry, South Africa.

Holmes T. P., Aukema J. A., Von Holle B., Liebhold A. & Sills E. (2009). Economic Impacts of Invasive Species in Forests: Past, Present, and Future. *The Year in Ecology and Conservation Biology*, 2009: *Ann. N.Y. Acad. Sci.*, **1162:** 18–38 (2009). doi: 10.1111/j.1749-6632.2009.04446.x _c 2009 New York Academy of Sciences.

Holt J. (2011). *Weeds*. From Daniel Simberloff and Marcel Rejmánek, editors, Encyclopedia of Biological Invasions, Berkeley and Los Angeles: University of California Press, 2011.

Howard G. W. & Harley K. L. S. (1998). How do floating aquatic weeds affect wetland conservation and development? How can these effects be minimised? *Wetlands Ecology and Management*, **5**: 215–225.

Hu S. (2007). Akaike Information Criterion, 19 p. Center for Research in Scientific Computation, North Carolina, State University, Raleigh, NC.

Hudon C. (1997). Impact of water level fluctuations on St. Lawrence River aquatic vegetation. *Canadian Journal of Fisheries and Aquatic Sciences,* **54:** 2853–2865.

Hussner A., Meyer C. & Busch J. (2009). The influence of water level and nutrient availability on growth and root system development of *Myriophyllum aquaticum*. *Weed Research*, **49 (1):** 73–80. **DOI:** 10.1111/j.1365-3180.2008.00667.x

Hytec & Mary N. (2007). Mise en place d'un indice biologique spécifique aux terrains miniers en Nouvelle-Calédonie. Province Sud, Province Nord, DAVAR Nouvelle Calédonie. 120 p. + annexes.

Hytec & Mary N. (2006). 1- Synthèse des données sur la biodiversité des écosystèmes d'eau douces de la Nouvelle Calédonie. 2- Typologie et usages. Rapport final WWF NC/Conservation International. 215 p. + annexes.

Hytec & Mary N. (2010). Etude du caractère invasive de quelques espèces animals et végétales introduites dans les milieu dulçaquicoles en Nouvelles Calédonie: 1/ *Eichhornia crassipes* (jacinthe d'eau), 2/ *Hydrilla verticillata* (hydrille verticillée), 3/ *Melanoides tuberculota* (mélanoide), 4/ *Trachemys scripta elegans* (tortue de floride), 5/ *Oreochromis mossambicus* (tilapia du Mozambique), 6/ *Micropterus salmoides* (black bass à grande bouche). Province Nord, Direction du développement économique et de l'environnement, Service environnement. Province Sud, Direction de l'environnement, Service des milieu terrestres. Rapport final. 11–78p.

Jacono C. C. & Richerson M. M. (2003). *Eichhornia crassipes* (Mart.) Solms. Last accessed on 9 January 2010, http://nas.er.usgs.gov/taxgroup/plants/docs/ei_crass.html.

Jafari N. (2010). Ecological and socio-economic utilization of water hyacinth (*Eichhornia crassipes* Mart Solms). *Journal of Applied Sciences and Environmental Management*, **14**: 43–49.

Jadhav A., Hill M. P. & Byrne M. (2008). Identification of a retardant dose of Glyphosate with potential for integrated control of water hyacinth, *Eichhornia crassipes* (Mart.) Solms–Laubach. *Biological Control*, **27**: 154–158.

Jarawaza M. (1997). Water quality monitoring in Harare. In: Moyo, N.A.G. (Ed.) *Lake Chivero: A polluted Lake. Proceedings of a Workshop held in Harare. September, 1996.* pp. 27-34. University of Zimbabwe Publications. Harare, Zimbabwe.

Jayanth K. P. (1987). Suppression of water hyacinth by the exotic insect *Neochettina eichhorniae* in Bangalore, India. *Current Science,* **56 (10):** 494–495.

Jayanth K. P. (1988). Biological control of water hyacinth in India by release of the exotic weevil *Neochetina bruchi*. *Current Science,* **57 (17):** 968–970.

Jianqing D., Ren W., Weidong F. & Guoliang Z. (2000). Water hyacinth in China: its distribution, problems and control status. *In: Julien, M.H., Hill, M.P., Center, T.D., and Ding Jianqing (eds.). Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes. Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth,* Bejing, China, 9- 12 October 2000.

Jiménez M. M. & Balandra A. G (2007) Integrated control of *Eichhornia crassipes* by using insects and plant pathogens in Mexico. *Crop Protection,* **26:** 1234 –1238.

Jiofack T., Fokunang C., Guedje N., Kemeuze V.,Fongnzossie E., Nkongmeneck B. A., Mapongmetsem P. M. & Tsabang N. (2010). Ethnobotanical uses of medicinal plants of two ethnoecological regions of Cameroon. *International Journal of Medicine and Medical Sciences*, **2 (3):** 60–79.

Joffe S. & Cooke S. (1997). Management of the water hyacinth and other invasive aquatic weeds: Issues for the World Bank. Report for the Rural Development of the World Bank. 39 pp.

Johnston T. H. & Tyrone H. (1914). *Queensland: Report of the prickly-pear traveling commission*. Government Printer, Brisbane.

Jones R. W. (2000). Integrated Control of Water Hyacinth on the Nseleni/ Mposa Rivers and Lake Nsezi, KwaZulu-Natal in South Africa. *Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water hyacinth,* Beijing, China, 9–12 October 2000.

Jones R. W. (2001). Integrated control of water hyacinth on the Nseleni / Mposa Rivers and Lake Nsezi, KwaZulu-Natal, South Africa. In: *Proceedings of the 2nd Meeting of the Global Working Group for the Biological and Integrated Control of Waterhyacinth* (ed. Julien MH, Hill MP, Center TD& Ding J), pp. 123–129. Beijing, China, 9-12 October 2000. Australian Centre for International Agricultural Research, Canberra (AU).

Jones R. W. (2009). The impact on biodiversity, and integrated control, of water hyacinth, Eichhornia crassipes (Martius) Solms-Laubach (Pontederiaceae) on the Lake Nsezi – Nseleni River System. Mc Thesis. Department of Zoology and Entomology-Rhodes University. South Africa. 115p.

Jones R. W. & Cilliers C. J. (1999). Integrated control of water hyacinth on the Nseleni / Mposa Rivers and Lake Nsezi, KwaZulu-Natal (ZA). In: *Proceedings of the First IOBC Global Working Group Meeting for the Biological and Integrated Control of Water Hyacinth* (Ed. Hill MP, Julien MH & Center TD) pp. 160–167. 16-19 November 1998, Zimbabwe, Plant Protection Research Institute, Pretoria (ZA).

Joyner B. G. & Freeman T. E. (1973). Pathogenicity of Rhizoctonia solani to aquatic plants. *Phytopathology*, **63:** 681–685.

Julien M. H. & Griffiths M. W. (1998). *Biological Control of Weeds: A world Catalogue of Agents and their Target Weeds*. Fourth Edn. Wallingford, UK: CABI Publishing.

Julien M. H. & Orapa W. (2001). Insects used for biological control of the aquatic weed water hyacinth in Papua New Guinea. *Papua New Guinea Journal of Agriculture, Forestery and Fisheries*, **44**: 49–60.

Julien M. H. & Orapa W. (1999). Structure and management of a successful biological control project for water hyacinth. In: Hill, M. P., Julien, M. H. & Center, T. D. (Eds) *Proceedings of the first IOBC global working group meeting for the biological and integrated control of water hyacinth*. 16–19 Nov, Harare, Zimbabwe. pp. 123–134.

Julien M. H. & Stanley J. (1999). Recent research on biological control for water hyacinth in Australia. In: "*Proceedings of the First Meeting of the IOBC Global Working Group for the Biological and Integrated Control of Water Hyacinth*, held 16 – 19 November 1998, Zimbabwe, eds. M. P. Hill, M. H. Julien and T. D. Center. Pretoria, south Africa: Plant Protection Research Institute, pp. 52–61.

Julien M. H. (1987). *Biological Control of Weeds. A World Catalogue of Agents and their Target Weeds* (2nd Edition). CAB, Wallingford. 144pp.

Julien M. H. (2000). Biological control of water hyacinth with arthropods: a review to 2000. *In: Julien, M.H., Hill, M.P., Center, T.D., and Ding Jianqing (eds.). Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes. Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth,* Bejing, China, 9–12 October 2000.

Julien M. H. (2001). Biological control of water hyacinth with arthropods: A review to 2000. In: Julien, M. H, Hill, M. P., Center, T. D. & D. Jianqing (Eds.), *Biological and integrated control of water hyacinth, Eichhornia crassipes. ACIAR Proceedings,* **102:** 8–20.

Julien M. H., Griffiths M. W., & Wright A. D. (1999). Biological control of water hyacinth. The weevils *Neochetina bruchi* and *N. eichhornia*: biologies, host ranges, and rearing, releasing and monitoring techniques for biological control of *Eichhornia crassipes*. Monograph No 60. *Australian Centre for International Agricultural Research* (ACIAR), Canberra (AU). 87 p.

Julien M. H., Griffiths M. W. & Stanley J. N. (2001). *Biological control of water hyacinth 2. The moths Niphograpta albiguttalis and Xubida infusellus: biologies, host ranges, and rearing, releasing and monitoring techniques for biological control of Eichhornia crassipes. ACIAR Monograph No. 79,* ACIAR, Canberra. 90 pp.

Kasno, Sunjaya, Asmarina S. R. P., Okky S. D. & Her! S. H. (1999). Integrated use of *Neochetina bruchi* and *Alternaria eichhorniae* in controlling water hyacinth. *Biotropia, 13:* 1–17.

Kateregga E. & Sterner T. (2007). Indicators for an invasive species: water hyacinths in Lake Victoria. *Ecological Indiccator,* **7:** 362–370.

Kathiresan R. M. (2000). Allelopathic potential of native plants against water hyacinth. *Crop Protection,* **19**: 705–708.

Keddy P. A. & Reznicek A. A. (1986). Great lakes vegetation dynamics: The role of fluctuating water levels and buried seeds. *Journal of Great Lakes Research,* **12(1):** 25–36. *Internat. Assoc. Great Lakes Res.,* 1986. DOI: 10.1016/S0380-1330(86)71697-3.

Keiran M. & Allen E. (2004). Keeping forest pests from moving around the world. *Unasylva,* **217 (55):** 29–30.

Kent A. & Cooker P. (1994). *Vegetation description and analysis – A Practical Approach*. John Wiley and Sons Chisteter, New York.

Kent A. & Coker P. (2012). *Vegetation description and analysis – A Practical Approach*. John Wiley and Sons, New York.

Kettunen M., Genovesi P., Gollasch S., Pagad S., Starfinger U., Ten Brink P. & Shine C. (2009). Technical support to EU strategy on invasive species (IAS): *Assessment of the impacts of IAS in Europe and the EU* (final module report for the European Commission). Institute for European Environmental Policy, Brussels.

Khedr & El-Demerdash (1997) Distribution and environmental relations of aquatic plants in the Nile Delta, Egypt**.** *Aquatic Botany*, **56(1):** 75–86.

Kirchner F. & Soubeyran Y. (2007). Espèces exotiques envahissantes : vers un état des lieux global et un réseau d'action coordonné à l'échelle de toute l'outre-mer. 13[eme] forum des Gestionnaires des Espèces Exotiques Envahissantes : une Menace Majeure pour la Biodiversité - Paris-vendredi 16 Mars 2007. p 5.

Kivaishi A. K. & Mtila M. (1995). Chemical composition and in vitro degradability of whole plants and shoots of the water hyacinth (*Eichhornia crassipes*) by rumen micro-organisms. *Tanzania Veterinary Journal*, **15**: 121–129.

Knipling E. B., West S. H. & Haller W. T. (1970). Growth characteristics, yield potential and nutritive content of water hyacinths. *Proceedings, Soil and Crop Science Society of Florida*, **30**: 51–63.

Koch E. W. & Beer S. (1996). Tides, light and the distribution of *Zostera marina* in Long Island Sound, USA. *Aquatic Botany*, **53 (1996):** 97–107. doi:10.1016/0304-3770(95)01015-7

Koffi Koffi P., Zébéyou M. G. & Kouamé K. L. (1999). Biological control of water hyacinth in Cotê d' Ivoire. In: "*Proceedings of the 1[st] Meeting of the Global Working Group for the Biological and Integrated Control of water hyacinth"*, Harare, Zimbabwe, 16-19 November 1998. Hill, M.P., Julien, M.H. and Center, T.D. (Eds.) Biological and Integrated control of water hyacinth, *Eichhornia crassipes*. *Plant Protection Research Institute*, Pretoria, South Africa. pp: 14–17.

Kohji J., Yamamoto R. & Masuda Y. (1995). Gravitropic response. I. *Eichhornia crassipes* [sic] (water hyacinth). I. Process of gravitropic bending in the peduncle. *Journal of Plant Research*, **108**: 387–393.

Kusewa M. T. (2002). Natural occurrence and potential of pathogenic fungi for integrated management of water hyacinth, Eichhornia crassipes (Mart.) Solms-Lauback:

Pontederiaceae, in Lake Victoria. Unpublished Master's Thesis in Environmental Studies. School of Environmental Studies, Moi University, Kenya. p.79.

Labrada R. & Fornasari L. (2002). Lutte contre les principaux végétaux aquatiques envahissants en Afrique – Activités et succès de la FAO de 1991 à 2001. Organisation des Nations Unies pour l'alimentation et l'agriculture, Rome, 2002.

Lacap D. C., Liew E. C. Y. & Hyde K. D. (2003). An evaluation of the fungal 'morphotype' concept based on ribosomal DNA sequences. *Fungal Diversity*, **12:** 53–66.

Lana P. & Guiss C. (1992). Macrofauna–plant-biomass interactions in a euhaline salt marsh in Paranaguá Bay (Se Brazil). *–Marine Ecology Progress Series*, **80**: 57–64.

Limon L. G. (1984). Mexican Agency Studies of Aquatic Weeds. *Aquaphytes*, Fall, 1984, p.3.

Lindsey K. & Hirt H. M. (1999). *Use water hyacinth – A practical handbook of uses for the water hyacinth from across the world*. Maranium Press, Kisubi, Uganda, pp.114.

Lindsay K. & Hirt H. (2000) Use Water hyacinth: A Practical Handbook of Uses of Water hyacinth from Across the World. Retrieved October 16th, 2012.

Linkohr B. I., Williamson L. C., Filter A. H. & Leyser H. M. O. (2002). Nitrogen and phosphorus availability and distribution have different effects on root system architecture of Arabidopsis. *Plant Journal,* **29 (2002):** 751–760.

Little E. C. S. (1975). *Aquatic plants*. In: *Man-Made Lakes and Human Health*. Academic Press, London.

Lowe S., Browne M., Boudjelas S. & De Poorter M. (2000). 100 of the World's Worst Invasive Alien Species. A selection from the Global Invasive Species Database. Published by the Invasive Species Specialists Group (ISSG), a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), 12pp. Firstpublished as special lift-out in Aliens 12, December 2000. Updated and reprinted version: November 2004.

Luilo G. B. (2008). Lake Victoria water resources management challenges and prospects: a need for equitable and sustainable institutional and regulatory frameworks. *African Journal of Aquatic Science*, **33:** 105–113.

Luken J. O. & Thieret J. W. (1997) *Assessment and Management of Plant Invasions*. Springer, New York, NY.

Lyon J. G. & Drobney R. D. (1984). Lake level effects as measured from aerialphotos. *Journal of Surveying Engineering,* **110:**103–111.

Lyons R. A., Wareham K., Lucas M., Price D., Williams J. & Hutchings H. A. (1999). SF-36 scores vary by methodof administration: implications for study design. *Journal of Public Health Medicine*, **21(1):** 41–45.

MacDonald I. A. W., Reaser J. K., Bright C., Neville L. E., Howard G. W., Murphy S. J. & Preston G. (eds.) (2003). Invasive alien species in southern Africa: National reports and directory of resources. Global Invasive Species Programmes, Cape Town, South Africa.

MacKee H. S. (1994). Catalogue des plantes introduites et cultivées en Nouvelle-Calédonie. Muséum National d'Histoire Naturelle, Paris, et Service des Eaux et Forêts, Nouméa.

Magurran A. E. (1988). *Ecological diversity and its measurements*. Princeton, NJ: Princeton University Press.

Mahamadi C. & Nharingo T. (2010). Competitive adsorption of Pb2+, Cd2+ and Zn2+ ions onto *Eichhornia crassipes* in binary and ternary systems. *Bioresource Technology,* **101**: 859–864.

Mailu A. M. (2001). Preliminary assessment of the social, economic and environmental impacts of waterhyacinth in the Lake Victoria Basin and the status of control. In: Julien, M.H., Hill, M.P., Center, T.D., Ding Jianqing (Eds.), *Biological and Integrated control of waterhyacinth, Eichhornia crassipes.* Proceedings of the Second Global Working Group Meeting for the Biological and Integrated Control of Waterhyacinth. Beijing, China, 9–12 October 2000. ACIAR Proceedings, N° **102:** 130–139.

Mailu A. M., Ochiel G. R. S., Gitonga W. & Njoka S. W. (1999). Water hyacinth: An environmental disaster in the Winam Gulf and its control. In: "*Proceedings of the 1st Working Group Meeting for the Biological and Integrated Control of Water Hyacinth*". Hill M. P., Julien M. H. & Center T. D. (eds.). 16–19 November 1998, Harare, Zimbabwe. Pretoria, South Africa, *Plant Protection Research Institute*, pp.115–119.

Malecki R. A., Blossey B., Hight S. D., Schroeder D., Kok D. T. & Coulson J. R. (1993). Biological control of purple liisestrife. *Bioscience*, **43 (10):** 680–686.

Malik A. (2007). Environmental challenge *vis a vis* opportunity: the case of water hyacinth. *Environment International,* **33**:122–138.

Mallya G. A. (1999). Water hyacinth in Tanzania. In: Hill, M.P., Julien, M.H. and Center, T.D. (Eds.) Biological and Integrated control of water hyacinth, *Eichhornia crassipes. Proceedings of the 1st Meeting of the Global Working Group for the Biological and Integrated Control of water hyacinth,* Harare, Zimbabwe, 16–19 November 1998. Plant Protection Research Institute, Pretoria, South Africa. pp: 25–29.

Mallya G., Mjema P. & Ndunguru J. (2001). Water hyacinth control through integrated weed management strategies in Tanzania. In: *Biological and integrated control of water hyacinth Eichhornia crassipes*, Julien, M. H; Hill, M. P; Center, T. D and Ding Jianqin (eds.) ACIAR proceedings, **102**: 120–122.

Magandi J. A., Seijo T. E. & Peres N. A. (2007). First Report of *Myrothecium roridum* Causing *Myrothecium* Leaf Spot on *Salvia* spp. in the United States. *Plant Disease,* **91 (6):** 771–772.

Manson J. G. & Manson B. E. (1958). Water hyacinth reproduces by seed in New Zealand. *New Zealand Journal of Agriculture,* **96**: 191.

Mansor M. (1996). Noxious floating weeds of Malaysia. *Hydrobiologia,* **340 (1-3):** 121–125.

Marchante H. (2005). Invasive plant species in Portugal. In : Brunel, S. (Ed.). 2005. *Invasive. Plants in Mediterranean Type Regions of the World (Plantes envahissantes dans les régions méditerranéennes du monde). Proceedings of the International Workshop (Actes de l'atelier de travail international).* Council of Europe Publishing.

Marlin D., Hill M. P., Ripley B. S., Strauss A. J. & Byrne M. J. (2013). The effect of herbivory by the mite *Orthogalumna terebrantis* on the growth and photosynthetic performance of water hyacinth (*Eichhornia crassipes*). *Aquatic Botany*, **104**: 60–69.

Marschner H. (1995). *Mineral nutrition of higher plants,* 2nd Edn. Academic Press, London, 889 p.

Martínez M. Jiménez, Gutiérrez López E., Huerto Delgadillo R. & Ruíz Franco E. (2001). Importation, rearing, release and establishment of Neochetina bruchi (Coleoptera curculionidae) for the biological control of waterhyacinth in Mexico. *Journal of Aquatic Plant Management,* **39 (2001):** 140–143.

Martyn R. D. & Freemann T. E. (1978). Evaluation of *Acremonium zonatum* as a potential biocontrol agent of waterhyacinth. *Plant Disease Reporter*, **62**: 604–608.

Martyn R. D. (1985). Water hyacinth decline in Texas caused by *Cercospora piaropi*. *Journal of Aquatic Plant Management*, **23**: 29–32.

Martyn R. D. & Cody S. (1983). Isolation of phenol cells from waterhyacinth leaves and possible effects on growth of foliar pathogens. *Journal of Aquatic Plant Management,* **21:** 58–61.

Martyn R. D. & Freeman T. E. (1978). Evaluation of *Acremonium zonatum* as a potential biocontrol agent of waterhyacinth. *Plant Disease Reporter,* **62:** 604–608.

Masifwa W. F., Twongo T. & Denny P. (2001). The impact of water hyacinth, *Eichhornia crassipes* (Mart). Solms on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria, Uganda. *Hydrobiologia*, **452**: 79–88.

Matthews L. J. (1967). Seedling establishment of water hyacinth (*Eichhornia crassipes*). *International Journal of Pesticide Management, Part C*, **13(1):** 7–8.

Mbati G. & Neuenschender P. (2005). Biological control of three floating water weeds, *Eichhornia crassipes*, *Pistia stratiotes*, and *Salvinia molesta* in the Republic of Congo. *Biocontrol,* **50**: 635–645.

McClay A. S. & Balciunas J. K. (2005). The role of pre-release efficacy assessment in selecting classical biological control agents for weeds applying the Anna Karenina principle. *Biological Control,* **35**:197–207.

McFadyen R. E. C. (1998). Biological control of weeds. *Annual Review of Entomology*, **43**: 369–393.

McFayden R. E. C. (2000). Successes in Biological Control of Weeds. In: "*Proceedings of the X International Symposium on Biological Control of Weeds*". Ed. Spencer N.R. Montana State University, Bozeman, Montana, USA, 149pp.

McNeely J. A. (2000). *War and Biodiversity: An Assessment of Impacts*. In: *The Environmental Consequences of War*. Cambridge University Press. Cambridge, U.K.

McNeely J. A. (2001). *Global strategy on invasive alien species*. Gland, Switzerland and Cambridge, UK: World Conservation Union.

McNeely J. A., Mooney H. A., Neville L. E., Schei P. J. & Waage J. K. (eds) (2001). *Global Strategy on Invasive Alien Species*. Cambridge, U.K.: IUCN in collaboration with the Global Invasive Species Programme. Gland, Switzerland.

McVea C. & Boyd C. E. (1975). Effects of waterhyacinth cover on water chemistry, phytoplankton, and fish in ponds. *Journal of Environment Quality,* **4(3):** 375 – 378.

Mehra A., Farago M. E., Banerjee D. K. & Cordes K. B. (1999). The water hyacinth: An environmental friend or pest? A review. – *Resource and Environmental Biotechnology,* **2:** 225–281.

Melvin N. C. (1999). Noxious, invasive and alien plant species: A challenge in wetlands restoration and enhancement. *Wetland restoration information series 1*, Wetland Science Institute, Washington.

Methy M., Alpert P. & Joy J. (1990). Effects of light quality and quantity on growth of the clonal plant *Eichhornia crassipes. Oceologia,* **84**: 265–271.

Midgley J. M., Hill M. P. & Villet M. H. (2006). The effect of water hyacinth, *Eichhornia crassipes* (Martius) Solms-Laubach (Pontederiaceae), on benthic biodiversity in two impoundments en the New Year's River, South Africa. African. *Journal of Aquatic Science*, **31 (1):** 25–30.

Mille C. (2005). Possibilité de lutte biologique contre deux plantes aquatiques en Nouvelle-Calédonie. IAC-SRFP, Laboratoire d'Entomologie Appliquée, 26 Janvier 2005.

MINEPDED (2014). List of major invasive species in Cameroon. Report submitted to MINEPDED under the UNEP/GEF Cameroon Biosecurity Project: Development and Institution of a National Monitoring and Control System (Framework) for Living Modified Organisms (LMOs) and Invasive Alien Species (IAS). Yaoundé, Cameroon. Pp. 40.

Mironga J., Mathooko J. & Onywere S. (2012). Effect of Water Hyacinth Infestation on the Physicochemical Characteristics of Lake Naivasha. *International Journal of Humanities and Social Science,* **2(7):** 103–113.

Misra K. C. (1989). *Manual of Plant Ecology*. 3rd (ed). Oxford & IBH publishing Co., Pvt. Ltd., New Delhi. 193p.

Mohan Babu R., Sajeena A., Seetharaman K., Vidhyasekaran P., Rangasamy P., Som Prakash M., Senthil Raja A. & Biji K. R. (2002). Host range of Alternaria alternata–a potential fungal biocontrol agents for waterhyacinth in India. *Crop Protection*, **21 (10):** 1083–1085. DOI: 10.1016/S0261-2194 (02)00076-5.

Mooney H. A. & Hofgaard A. (1999). Biological invasions and global change. In: Sandlund O. T., Schei P. J. and Viken A. (eds.). *Invasive species and biodiversity management. Based on a selection of papers presented at the Norway/UN Conference on Alien Species, Trondheim, Norway. Population and community Biology Series*, Vol. 24, Dordrecht, the Netherlands, Kluwer Academic Publishers. Pp.139–148.

Moorhead K. K., Reddy F. R. & Graetz D. A. (1988). Water hyacinth productivity and detritus accumulation. *Hydrobiologia*, **157**: 179–185.

Moragues Botey (2005). Flora aloctona de las Islas Baleares. Ecologia de dos especies invasoras : *Carpobrotus edulis* & *Corpobrotus* aff. *acinaciformis*. Tesis Doctoral de la Universitat de les Illes Balears. 354 pp.

Moran P. J. (2005). Leaf scarring by the weevils *Neochetina eichhorniae* and *N. bruchi* enhances infection by the fungus *Cercospora piaropi* on water hyacinth, *Eichhornia crassipes*. *BioControl*, **50:** 511–524.

Morin L., Reid A. M., Sims-Chilton N. M., Buckley Y. M., Dhileepan K., Hastwell G. T., Nordblom T. L. & Raghu S. (2009). Review of approaches to evaluate the effectiveness of weed biological control agents. *Biological Control*, **51:** 1–15.

Morin L., Batchelor K. L. & Scott J. K. (2006a). The biology of Australian weeds. *Asparagus asparagoides* (L.) Druce. *Plant Protection Quarterly,* **21:** 46–62.

Morin L., Neave M., Batchelor K. L. & Reid A. (2006b). Biological control: a promising tool for managing bridal creeper in Australia. *Plant Protection Quarterly,* **21:** 69– 77.

Morris M. J. (1990). *Cercosporia piapori* recorded on the aquatic weed, *Eichhornia crassipes*, in South Africa. *Phytophylatica*, **22 :** 255–256.

Moyo P. & Mapira J. (2012). Bioremediation with the water hyacinth (*Eichhornia crassipes*): A panacea for river pollution in the city of Masvingo (Zimbabwe)? *Journal of Sustainable Development in Africa*, Vol. **14 (6):** 115–131.

Moyo P., Chapungu L. & Mudzengi B. (2013). Effectiveness of water hyacinth (*Eichhornia crassipes*) in remediating polluted water: the case of Shagashe River in Masvingo, Zimbabwe. *Advances in Applied Science Research*, **4(4):** 55–62.

Mshandete A., Kivaisi A., Rubindamayugi M. & Mattiason B. O. (2004). Anaerobic batch co-digestion of sisal pulp and fish wastes. *Bioresource Technology*, **95**: 19–24.

Muramoto S., Aoyama I. & Oki Y. (1991). Effect of salinity on the concentration of some elements in water hyacinth (*Eichhornia crassipes*) at critical levels. *Journal of Environmental Science and Health*, **A26**: 205–215.

Myers J. H. (2000). What can we learn from biological control failure? In: Spencer N. R. (Ed.), "*Proceeding of the X International Symposium on Biological Control of Weeds*". USDA – ARS, Montana, pp. 151–154.

N'dah E. & Arfi R. (1996). Macrophytes aquatiques dans les eaux "continentales" ivoiriennes. *Archives Scientifiques, Centre de Recherches Océanologique, Abidjan*, **15 (2)**: 1–25.

Nag Raj T. R. & Ponnappa K. M. (1967). Some interesting fungi of India. Commonwealth Inst. *Biological Control Technical Bulletin*, **9:**31–43.

Nag Raj T. R. & Ponnapa K. M. (1970). Blight of water hyacinth by *Alternaria eichhorniae* sp. nov. *Transactions of the Britrish Mycological Society*, **55:** 123–30.

Navarro L. A & Phiri G. (ed.) (2000). W*ater Hyacinth in Africa and the Middle East: A survey of Problems and Solutions*. International Development Research Centre, Ottawa, Canada. 140pp.

Navarro L. A. (2001). Water Hyacinth Information Partnership for Africa and the Middle East. In: *Biological and integrated control of water hyacinth, Eichhornia crassipes.* Julien, M. H, Hill, P., Center, T. D. & Jianqing, D. (Eds). *ACIAR Proceedings,* **102**: 72–76.

Ndimele P. E. & Jimoh A. A. (2011).Water Hyacinth (*Eichhornia crassipes* [Mart.] Solms.) in Phytoremediation of heavy Metal Polluted Water of Ologe lagoon, Lagos, Nigeria. *Research journal of Environmental Sciences*, **5(5):** 424–433.

Ndimele P. E. (2008). Evaluation of phyto-remediative properties of water hyacinth (*Eichhornia crassipes* [Mart.] Solms) and biostimulants in restoration of oil-polluted wetland in the Niger Delata. PhD Thesis, University of Ibadan, Nigeria.

Ndimele P. E. (2012). The Effects of Water hyacinth (*Eichhornia crassipes* [Mart.] Solms) Infestation on the Physico-Chemistry, Nutrient and Heavy Metal Content of Badagry Creek and Ologe Lagoon, Lagos, Nigeria. *Journal of Environmental Science and Technology,* **5***: 128–136.*

Ndimele P. E., Kumolu-Johnson C. A. & Anetekhai M. A. (2011). The Invasive Aquatic Macrophyte, Water Hyacinth {*Eichhornia crassipes* (Mart.) Solm-Laubach: Pontedericeae}: Problems and Prospects. *Research Journal of Environmental Sciences*, **5(6)**: 509–520.

Nelson S. G., Smith B. D. and Best B. R. (1980). Nitrogen uptake by tropical freshwater macrophytes. Technical Report by Water Resources Research Center of Guam, University of Agana (Available from National Technical Information Service, Spring-field VA 22161, USA, as PB80 – 194228).

Neuenschwander P., Borgemeister C. & Langewald J. (2003). *Biological Control in IPM Systems in Africa*. CABI Publishing, U.K.

Nguelo C. (2007). Gestion integrée de la jacinthe d'eau (*Eichhornia crassipes* Mart. Solms-Laub.) dans l'estuaire du Wouri. Mémoire présenté pour le Diplôme d'Ingénieur de Génie Rural, Université de Dschang.

Nguendo Y. H. B. (2008). Pathogenic microorganisms associated with childhood diarrhea in low-and-middle income countries: Case Study of Yaoundé–Cameroon. *International Journal of Environmental Research and Public Health*, **5(4):** 213–229; doi:10.3390/ijerph5040213

Njiokou L. J. M. (2004). Distribution spatial de *Pistia stratiotes* L. (Araceae) dans quelques ecosystems aquatiques de la ville de Douala. Mémoire présenté en vue de l'obtention dela Maitrise en Biologie des Organismes Vegetaux. Université de Douala. 68 pp.

Ntamak-Nida M. J., Bourquin S., Makong J., Baudin F., Mpesse J. E., Ngouem C. I., Komguem P. B. & Abolo G. M (2010). Sedimentology and sequence stratigraphy from outcrops of the Kribi-Campo sub-basin: Lower Mundeck Formation (Lower Cretaceous,, Southern Cameroon). *Journal of African Earth Sciences,* **58**: 1–18.

Ntiba M. J., Kudoja W. M. & Mukasa C. T. (2001). Management issues in the Lake Victoria watershed. *Lakes and Reservoir: Research and Management,* **6**: 211–6.

Nutter Jr. F. W., Teng P. S. & Shokes F. M. (1991). Disease assessment terms and concepts. *Plant Disease*, **75:**1187–1188.

Nye P. H. & Tinker P. B. (1977). *Solute movement in the soil-root system*. Berkeley: University of California Press. 342 pp.

O'Brien L. B. & Wilson S. W. (1985). "Planthopper systematics and external morphologyZ". In: L. R. Nault and J. G. Rodrigues (eds.), *the leafhoppers and planthopper*. Willer, New York. pp. 61–101.

Obed M. & Taggel M. (1976). Factors affecting dormancy and germination of seeds of *Eichhornia crassipes* (Mart.) Solms, from the Nile. *Weed Research*, **16**: 71–80.

Ochiel G. R. S., Mailu A. M., Gitonga W. & Njoka S. W. (1999). Biological control of water hyacinth on Lake Victoria. In: "*Proceedings of the 1st Meeting of the IOBC Global Working Group for the Biological and Integrated Control of water hyacinth"*, Eds. Hill, M.P., Julien, M.H. and Center, T.D. Biological and Integrated control of water hyacinth, *Eichhornia crassipes*. Harare, Zimbabwe, 16–19 November 1998. Plant Protection Research Institute, Pretoria, South Africa. pp: 115–118.

Ochiel G. S., Njoka S., Mailu A. M. & Gitonga W. (2001). Establishment, spread and impact of Neachetina sp. On water hyacinth in Lake Victoria, Kenya. In: "*Proceedings of the Second Global Working Group Meeting for the Biological and Integrated Control of Water Hyacinth*". Julien M. H., Hill M. P., Center T. D. and Ding J. (eds). Biological and integrated control of water hyacinth, *Eichhornia crassipes. Beijing, China*, 9–12 October 2000. *ACIAR proceedings* No. **102**: 89–95.

Ogwang J. A & Molo R. (1999) Impact studies on *Neochetina bruchi* and *Neochetina eichhorniae* in Lake Kyoga, Uganda. In: *Proceedings of the First IOBC Global Working Group Meeting for the Biological and Integrated Control of Water Hyacinth*

(Ed. Hill MP, Julien MH & Center TD), pp. 10–13. 16–19 November 1998, Zimbabwe. Plant Protection Research Institute, Pretoria (ZA).

Onana J. M. (2008). Les Nouvelles découvertes de l'Herbier National, Recherche Florifique.

Onana V. P., Rudant J. P., Etouna J. & Wade S., (2005). Dynamique urbaine à l'aide d'images RSO de ERS et HRV de spot, et son impact dans les facteurs d'aggravation des risques d'inondation en milieu urbain: Cas de la ville de Douala (Cameroun). *Comtemporary publishing international. Editions scientifiques. G.B.*, **5 (1.2.3)**: 19–32.

Opande G. O. (2002). Distribution of the water hyacinth [*Eichhornia crassipes* (mart.) Solms.], its carpet characteristics, some of its diseases and pests in the Winam Gulf ofLake Victoria. PhD. Thesis. Maseno University.

Opande G. O., Onyango J. C. & Wagai S. O. (2004). Lake Victoria: The water hyacinth (*Eichhornia crassipes* [Mart.] Solms), its Socio-economic effects, control measures and resurgence in the Winam gulf. *Limnologica - Ecology and Management of Inland Waters*, **34(1–2):** 105–109.

Ouedraogo L. R., Mailu A. W., Gitonga W. & Mtsekwa S. (1999). Integrated management of water hyacinth in Burkeno Faso. In: Hill, M.P., Julien, M.H. and Center, T.D. (Eds.) Biological and Integrated control of water hyacinth, *Eichhornia crassipes*. *Proceedings of the 1st Meeting of the Global Working Group for the Biological and Integrated Control of water hyacinth,* Harare, Zimbabwe, 16-19 November 1998. *Plant Protection Research Institute*, Pretoria, South Africa. pp: 153–159.

Owens C. S. & Madsen J. D. (1995). Low temperatures limits of water hyacinth. *Journal of Aquatic Plant Management,* **33**: 63–68.

Pantone D. J., William W. A. & Maggenti A. R. (1989). An alternative approach for evaluating the efficacy of potential biocontrol agents of weeds. 1. Inverse linear model. *Weed Science*, **37**: 771–777.

Parija P. (1934a). Physiological investigations on water hyacinth, *Eicchornia crassipes*, in Orissa with notes on some other aquatic weeds. *Indian Journal of Agricultural Science,* **4**: 399–429.

Parija P. (1934b). A note on the reappearance of water hyacinth seedlings in cleared tanks. *Indian Journal of Agricultural Science* **4**: 1049.

Parker M., Simberloff D., Lonsdale W. M., Goodell K., Wonham M., Kareiva P. M., Williamson M. H., Holle B. V., Moyle P. B., Byers J. E. & Goldwasser L. (1999). Impact: Toward a framework for understanding the ecological effects of invaders. *Biological Invasions*, **1**: 3–19.

Parsons M., McLoughlin C. A., Kotschy K. A., Rogers K. H. & Rountree M. W. (2005). The effects of extreme floods on the biophysical heterogeneity of river landscapes. *Frontiers in Ecology and the Environment,* **3:**487–494.

Patel S. (2012). Threats, management and envisaged utilizations of aquatic weed Eichhornia crassipes: an overview. *Reviews in Environmental Science and Biotechnology*, **11**:249–259.

Paterson I. D., Mangan R., Downie D. A., Coetzee J. A., Hill M. P., Burke A. M., Downey P. O., Henri T. J. & Compton S. G. (2016). Two in one: Cryptic species discovered in biological control agent populations using molecular data and crossbreeding experiments. *Ecology and Evolution*, **6(17):** 6139–6150. DOI: 10.1002/ece3.2297

Penfound W. T. & Earle T. T. (1948). The Biology of the Water Hyacinth. *Ecological Monographs*, **18 (4):** 447–472.

Perez A. E., Téllez T. R. & Sánchez Guzmán J. M. (2010). Influence of physic-chemical paramters of the aquatic medium on germination of *Eichhornia crassipes* seeds. *Plant Biology*, **13:** 643–648.

Perkins B. D. (1973). Arthropods that stress waterhyacinth. *Proceedings 3rd International Symposium on Biological Control of Weeds*, Montpellier, France, 1973. 49–60.

Perkins B. D. (1972). Potential of waterhyacinth management with biological agents. In: *Proceedings of the Annual Tall Timbers Conference on Ecological Animal Control by Habitat Management*, February 24–25, 1972, pp. 53–64.

Perkins B. D. (1973). Release in the United Sates of *Neochetina eicchorniae* Warner, an enemy of water-hyacinth. *Proceedings of the Annual Meeting of the Southern Weed Science Society* (USA) v. 26, p. 368.

Perkins B. D. (1974). Arthropods that stress water hyacinth. *Pest Articles and News Summaries,* **20**: 304–314.

Perrings C. (2005). The Socioeconomic Links between Invasive Alien Species and Poverty. Rapport non publié du Programme mondial sur les espèces envahissantes. 35 pp.

Perrings C., Dehnen-Schmutz K., Touza J. & Williamson M. (2005) How to manage biological invasions under globalization. *Trends in Ecology & Evolution*, **20:**212–215.

Petr T. (2000). *Interactions between fish and aquatic macrophytes in Inland waters*. Food and Agriculture Organization of the United Nations: Rome, 396, 185pp.

Phiri P. M., Day R. K., Chimatiro S., Hill M. P., Cock M. J. W., Hill M. G. & Nyando E. (2000). Progress with biological control of water hyacinth in Malawi. In: Julien, M.H., Hill, M.P. and Jianqing, D. (eds) *Proceedings of the Second Meeting of Global Working Group for the Biological and Integrated Control of Water Hyacinth*, 9–12 October 2000, Beijing, China. ACIAR, Canberra, Australia, Proceedings 102, 47–52.

Phiri P. M., Day R. K., Chimatiro S., Hill M. P., Cock M. J. W. & Hill G. (2001) Progress with biological control of water hyacinth in Malawi. In: *Biological and Integrated Control of Waterhyacinth, Eichhornia crassipes. Proceedings of the 2nd Meeting of the Global Working Group for the Biological and Integrated Control of Waterhyacinth, Beijing, China* (Ed. Julien M. H., Hill M. P., Center T. D. & Jianqing D.), pp. 47–52. 9–12 October 2000. Australian Centre for International Agricultural Research, Canberra (AU).

Pielou E. C. (1975). Ecological Diversity. Wiley, New York.

Pieterse A. H. (n.d.). The water Hyacinth (*Eichhornia crassipes*) – a review. Pp. 9–36.

Pieterse A. H., Aris J. J. A. M. & Butter M. E. (1976). Inhibition of float formation in water hyacinth by gibberellic acid. *Nature*, **260:**423–424.

Pimentel D., McNair S., Janecka J., Wightman J., Sommonds C., O'Conell C., Wong E., Russel L., Zern J., Aquino T. & Tsomondo T. (2001). Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environement*, **84**: 1–20.

Pimentel D., Zuniga R. & Morrison D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, **52(3):** 273–288.

Poff N. L. & Ward J. V. (1990). Physical habitat template of lotic systems: recovery in the context of historical pattern of spatiotemporal heterogeneity. *Environmental Management,* **14:**629–645.

Polis G. A. & Strong D. R. (1996). Food web complexity and community dynamics. *The American Naturalist*, **147:** 813–846.

Ponnappa K. M. (1970) - On the pathogenicity of *Myrothecium roridum Eichhonia crassipes* isolate. *Hyacinth Control J.,* **8:** 18–20.

Ponnappa K. M. (1971) - A hyghly virulent strain of *Myrothecium roridum* on *Trapa bispinosa. Indian Journal of Mycology and Plant Pathology,* **1:** 90–94.

Poorter H. & Nagel O. (1999). The role of biomass allocation in the growth response of plants to different level of light, CO2, nutrients and water: a quantitative review. *Australian Journal of Plant Physiology (*2000), **27**: 595–607.

Praveena R. & Naseema A. (2004). Fungi occurring on water hyacinth [*Eichhornia crassipes* (Mart.) Solms] in Kerala. *Journal of Tropical Agriculture,* **42:** 21–23.

Priso R. J., 1994. Contribution à l'identification des indicateurs écologiques de pollution dans les régions de Yaoundé et Douala. Thèse de Doct. 3ème Cycle, Université de Yaoundé I, Cameroun. P. 180.

Priso R. J., Din N., Njiokou L. J., Dina E. N., Essome K. G. & Amougou A. (2010a). *Pistia stratiotes* (Araceae) morphological variation in non-polluted and polluted ecosystems in Douala (Cameroon). In: X. Van der Burgt, J. van der Maesen & J-M. Onana (eds), *Systematics and conservation of African plants*, 273–280 p. Royal Botanic Gardens, Kew.

Priso R. J., Dibong S. D., Tchinda M. C., Taffouo V. D., Ndongo D. & Amougou A. (2010b). Impacts des eaux polluées sur la croissance, les teneurs en chlorophylles et substances organiques dans les feuilles de deux poaceae. *International journal of biological and chemical sciences*, **4 (4)**: 1122–1129.

Priso R. J., Ndongo D., Njiokou L. J., Dina E. N., Essome K. G. & Amougou A. (2009). *Pistia stratiotes* (Araceae) morphological variation in non-polluted and polluted ecosystems in Douala (Cameroon). In: X. Van der Burgt, J. van der Maesen & J.-M. Onana (eds).

Systematics and conservation of African plants, pp. 271–278. Royal Botanic Gardens, Kew.

Quackenbush J. (2001). Computational analysis of microarray data. *Nature Reviews Genetics*, **2:** 418–427. 10.1038/35076576.

Quinlan C. & Mulamoottil G. (1987). The effects of water level fluctuations on three Lake Ontario shoreline marshes. *Canadian Water Resources Journal / Revue canadienne des ressources hydriques,* **12 (1)**: 64–77. DOI: 10.4296/cwrj1201064

Ramette A. (2007). Multivariate analyses in microbial ecology. *FEMS Microbial Ecology*, **62(2):** 141–160. DOI:10.1111/j.1574-6941.2007

Ray P. & Hill M. P. (2012). Fungi associated with *Eichhornia crassipes* in South Africa and their pathogenicity under controlled conditions. *African Journal of Aquatic Science*, **37 (3):** 323–331.

Ray P., Sushilkumar & Pandey A. K. (2008). Survey and selection of potential pathogens for biological control of waterhyacinth. *Indian Journal of Weed Science*, **40 (1&2)**: 75–78.

Reaser J. K., Meyerson L. A., Cronk Q., De Poorter M., Eldrege L. G., Green E., Kairo M., Latasi P., Mack R. N., Mauremootoo J., O'Dowd D., Orapa W., Sastroutomo S., Saunders A., Shine C., Thrainsson S. & Vaiutu L. (2007). Ecological and socio economic impacts of invasive alien species in island ecosystems. *Environmental Conservation*, **34 (2)**: 98–111.

Reddy K. R. & Tucker J. C. (1983). Productivity and nutrient uptake of water hyacinth, *Eichhornia crassipes* I. Effect of nitrogen source. *Economic Botany*, **37 (2):** 237–247. Stable URL: http://www.jstor.org/stable/4254487 Accessed: 13/02/2010 19:32

Reddy K. R., Agami M. & Tucker J. C. (1989). Influence of nitrogen supply rates on growth and nutrient storage by *E. crassipes (Eichhornia crassipes*) plants. *Aquatic Botany*, **36**: 33–43.

Reddy K. R., Agami M. & Tucker J. C. (1990). Influence of phosphorous on growth and nutrient storage by water hyacinth (*Eichhorniae crassipes* (Mart.) Solms) plants. *Aquatic Botany,* **37**: 355–365.

Remes Lenicov A. M. D. & Hernandez M. C. (2010). A new species of *Taoxa* (Hemiptera: Dictyopharidae) from South America associated with water hyacinth. *Annals of the Entomological Society of America,* **103**: 332–340.

Rhaman M. & Hasegawa H. (2011). Aquatic arsenic: phytoremediation using floating macrophytes. *Chemosphere,* **83**: 633–646.

Richardson D. M. & van Wilgen B. W. (2004). Invasive alien plants in South Africa: How well do we understand the ecological impacts? *South African Journal of Science,* **100:** 45–52.

Richarson D. M., Pysek P., Rejmanek M., Barbour M. G., Panetta F. D. & West C. J. (2000). Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions,* **6**: 93–107.

Rintz R. E. (1973). A zonal leaf spot of waterhyacinth caused by *Cephalosporium zonatum. Hyacinth Control Journal,* **11:** 41–44.

Robach F., Hajnsek I., Eglin I. & Trémolières M. (1995). Phosphorus sources for aquatic macrophytes in running waters: water or sediment? *Acta Botanica Gallica,* **142 (1995):** 719–731.

Roy H. E. & Pell J. K. (2000). Interactions between entomopathogenic fungi and other natural enemies: Implications for biological control. *Biocontrol Science and Technology*, **106(6):** 737–752. DOI: 10.1080/09583150020011708

Sala O., Chapin S., Armesto J., Berlow E., Bloomfield J., Dirzo R., Huber-Sanwald E., Huenneke L., Jackson R., Kinzig A., Leemans R., Lodge D., Mooney H., Oesterheld M., Leroy Poff N., Sykes M., Walker B., Walker M. & Wall D. (2000). Global biodiversity scenarios for the year 2100. *Science,* **287:** 1770–1774.

Salmah M. R., Mansor M. & Ahmad A. B. (1991). A preliminary study of the distribution of *Neochetina eichhorniae*; a possible biological agent for water hyacinth in Kerian District, Perak. In: "*Proceeding Asas dan Gunaan dalam Biologi*". Ed. Bidin A. A. UKM.

Sannigrahi A. K., Chakrabortty S., & Borah B. C. (2002). Large scale utilization of water hyacinth (*Eichhornia crassipes*) as raw material for vermin composting and surface mulching in vegetable cultivation. *Ecology, Environment and Conservation*, **8**: 269–271.

Sculthorpe C. D. (1967). *The biology of aquatic vascular plants*. Arnold, London, 610 pp.

Seebold Jr. K. W., Langston Jr. D. B., Kemerait Jr. R. C. & Hudgins J. E. (2005). "First Report of a Leaf Spot and Stem Canker Caused by *Myrothecium roridum* on Watermelon in the United States". *Plant Disease*, **89(3):** p. 342. doi:10.1094/PD-89-0342A

Shabana Y. M. (1997). Formulation of *Alternaria eichhorniae*, a mycoherbidide for water hyacinth, in invert emulsions averts dew dependence. *Journal of Plant Disease and Protection*, **104 (3):** 231-238.

Shabana Y. M., Elwakil M. A. & Charudattan R. (2001). Biological control of waterhyacinth by a mycoherbicide in Egypt. In Biological and Integrated Control of Waterhyacinth, *Eichhornia crassipes*: "*Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth*" held in Beijing, China, 9–12 October 2000, ed. M. P. Hill, T. D. Center and J. Ding. Canberra, Australian Centre for International Agricultural Research, pp. 53–56.

Shabana Y. M., Elwakil M. A. & Charudattan R. (2000). Effect of media, light and pH on growth and spore production by *Alternaria eichhorniae*, a mycoherbicide agent for waterhyacinth. *Journal of Plant Disease and Protection,* **107:** 617–626.

Shabana Y. M., Charudattan R., & Elwakil M. A. (1995a). Identification, pathogenicity and safety of *Alternaria eichhorniae* from Egypt as a bioherbicide agent for waterhyacinth. *Biological Control*, **5**: 123–135.

Shabana Y. M., Charudattan R. & Elwakil M. A. (1995b). Evaluation of *Alternaria eichhorniae* as a bioherbicide for waterhyacinth (*Eichhornia crassipes*) in greenhouse trials. *Biological Control,* **5:** 136–144.

Shabana Y. M., Charudattan R. & Elwakil M. A. (1995c). First record of *Alternaria eichhorniae* and *Alternaria alternata* on waterhyacinth in Egypt. *Plant Disease,* pp 279–319.

Shabana Y. M., Charudattan R., DeValerio J. T. & Elwakil M. A. (1997). An evaluation of hydrophilic polymers for formulating the bioherbicide agents *Alternaria cassia* and *Alternaria eichhorniae*. *Weed Technology*, **11**: 212–220.

Shabana Y. M. (2005). The use of oil emulsions for improvising the efficacy of *Alternaria eichhorniae* as a mycoherbicide for waterhyacinth (*Eichhornia crassipes*). *Biological Control,* **32 (1):** 78–89.

Shanab S., Shalaby E., Lightfoot D. & El-Shemy H. (2010). Allelopathic effects of water hyacinth (*Eichhornia crassipes*). *PLoS One*, **5(10):** e13200. doi:10.1371/journal.pone.0013200

Shannon C. E. & Weaver W. (1963). *The mathematical theory of communication*. University Illinois Press, Urbana.

Sheppard A. W. (2003). Prioritizing agents based on predicted efficacy. In: Jacobs H. S., Briese D. T. (Eds.), *Improving the Selection. Testing and Evaluation of Weed Biological Control Agents*. CRC for Australian Weed Management, Glen Osmond, pp. 11–21.

Simpson E. H. (1949). Measurement of Diversity. *Nature*, **163(4148):** 688–688. doi:10.1038/163688a0;

Smith B. & Wilson J. B. (1996). A consumer's guide to Evenness indices. *Oikos,* **76(1):** 70–82. Published by: Wiley on behalf of Nordic Society Oikos. DOI: 10.2307/3545749. Stable URL: http://www.jstor.org/stable/3545749

Smith V. H. (1982). The nitrogen and phosphorus dependence of algal biomass in lakes: an empirical and theoretical analaysis. *Limnology and Oceanogaphy***, 27:** 1101–112.

Smolyakov B. (2012). Uptake of Zn, Cu, Pb, and Cd by water hyacinth in the initial stage of water system remediation. *Applied Geochemistry*, **27(2012)**:1214–1219 doi:10.1016/j.apgeochem.2012.02.027.

Somero G. N. (2002). Thermal physiology and vertical zonation of intertidal animals: Optima, limits and costs of living. *Integration of Computational Biology*, **42**: 780–789.

Sorensen T. (1948). A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. *Biologiske Skrifter* (K. Danske Vidensk. Selsk. NS), **5:** 1–34.

Sosa A. J., De Remes Lenicov A. M. M., Mariani R. & Cordo H. A. (2005). Life history of *Megamelus scutellaris* with description of immature stages (Hemiptera: Delphacidae). *Annals of the Entomological Society of America,* **98**: 66–72.

Sosa A. J., Cordo H. A. & Sacco J. (2007a). Preliminary evaluation of *Megamelus scutellaris* Berg (Hemiptera: Delphacidae), a candidate for biological control of waterhyacinth. *Biological Control,* **42**: 129–138.

Sosa A. J., De Remes Lenicov A. M. M. & Mariani R. (2007b). Species of Megamelus (Hemiptera: Delpha- cidae) associated with Pontederiaceae in South America. *Annals of the Entomological Society of America*, **100:** 798–809.

Soti P. G. & Volin J. C. (2010). Does water hyacinth (*Eichhornia crassipes*) compensate for simulated defoliation? Implications for effective biocontrol. *Biological Control*, **54(1):** 35–40.

Space J. C. & Flynn T. (2000). *Observations on invasive plant species in American Samoa*. USDA Forest Service, Honolulu. 51 pp.

Space J. C. & Flynn T. (2002). *Report to the Government of Samoa on invasive plant species of environmental concern.* USDA Forest Service, Honolulu. 83 pp.

Space J. C., Waterhouse B., Denslow J. S., Nelson D. & Mazawa T. (2000). Invasive plants species in Chuuk, Federated States of Micronesia. USDA Forest Service, Honolulu. 41 pp.

Stent S. M. (1913). Water hyacinth (*Eichhornia crassipes*). Publication No. 68. Department of Agriculture, Union of South Africa.

Strange A., Rudall P. J. & Prychid C. J. (2004). Comparative floral anatomy of Pontederiaceae. *Botanical Journal of the Linnean Society*, **144(4):** 395–408.

Strayer D. L. (2010). Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future. *Freshwater Biology*, **55 (1):** 152–174.

Sutton G. F., Compton S. G. & Coetzee J. A. (2016). Naturally occurring phytopathogens enhance biological control of water hyacinth (*Eichhornia crassipes*) by *Megamelus scutellaris* (Hemiptera: Delphacidae), even in eutrophic water. *Biological Control*, **103 (2016):** 261–268.

Taheruzzaman Q. & Kushari D. P. (1989). Evaluation of some common aquatic macrophytes cultivated in enriched water as possible source of protein and biogas. *Hydrobiological Bulletin,* **23 (2):** 207–212 (1989).

Takem G. E., Chandrasekharam D., Ayonghe S. N. & Thambidurai P. (2010). Pollution characteristics of alluvial groundwater from springs and bore wells in semi-urban informal settlements of Douala, Cameroon, Western Africa. *Environmental Earth Sciences,* **61**: 287–298. DOI: 10.1007/s12665-009-0342-8.

Takhtajan A. (1997). *Diversity and Classification of Flowering Plants*. Columbia University Press, New York.

Téllez T. R., López E. M., Granado G., Pérez E. A., López R. M. & Sánchez Guzmán J. M. (2008). The Water Hyacinth, *Eichhornia crassipes*: an invasive plant in the Guadiana River Basin (Spain). *Aquatic Invasions*, **3(1)**: 42–53.

Tening A. S., Chuyong G. B., Asongwe G. A., Fonge B. A., Lifongo L. L. & Tandia B.K. (2013). Nitrate and ammonium levels of some water bodies and their interaction with some selected properties of soil in Douala Metropolis, Cameroon. *African Journal of Environmental Science and Technology*, **7 (7):** 648–656. DOI: 10.5897/AJEST12.082.

Terry P. J. (1991). Water hyacinth in the Lower Shire, Malawi and recommendations for its control. Unpublished report, University of Bristol, Bristol. 64 pp.

Tessmann D. J., Charudattan R., Kistler H. C. & Rosskopf E. N. (2001). A molecular characterization of *Cercospora* species pathogenic to water hyacinth and emendation of *C. piaropi*. *Mycologia*, **93(2):** 323–334. DOI: 10.2307/3761654

Tharp B. C. (1917). Texas parasitic fungi. *Mycologia,* **9(2):** 105–124.

Thompson D. G., Stuckey R. L. & Thompson E. B. (1987). Spread, impact, and control of purple loosestrife (Lythrum salicaria) in North American wetland. U.S. Fish and Wildlife Service, Fish and Wildlife, Washington, DC, p.2.

Thorne R. F. (1992). Classification and geography of flowering plants. *Botanical Review*, **58**: 225–348.

Tipping P. W., Sosa A., Pokorny E. N., Foley J., Schmitz D. C., LAne J. S., Rodgers L., Mccloud L., Livingston-Way P., Cole M. S. & Nichols G. (2014). Release and establishement of *Megamelus scutellaris* (Hemiptera : Delphacidae) on waterhyacinth in Florida. *Florida Entomologist Society*, **97(2) :** 804–806.

Toft J. D. (2000). Community effects of the non-indigenous aquatic plant water hyacinth (*Eichhornia crassipes*) in the Sacramento/San Joaquin Delta, California. Master Degree Thesis in Fisheries, University of Washington, 2000. Pp. 97.

Tryfos P. (1997). Cluster Analysis. http://www. yorku.ca/ptryfos/f1500.pdf. Chapter 15. 23 p.

Tsague H. R. (2013). Croissance et écologie d'*Eichhornia crassipes* (Martius) Solms-Laubach dans quelques plans d'eau de Douala-Ouest. Mémoire de Master II. 78p.

Twongo T. (1996). Growing impact of water hyacinth on nearshore environments on Lakes Victoria and Kyoga (East Africa). In: *The Limnology, Climatology, and Paleoclimatology of the East African Lakes*. JOHNSON T.C. et E.O. ODADA (éditeurs). *Gordon and Breach Publishers*, Amsterdam, The Netherlands, 633–642.

Ueki K., Ito M. & Oki Y. (1975). *Water and its habitats in Japan*. Paper presented at 5th Asian-Pacific Weed Science Society Conference, Tokyo.

Uka U. N. & Chukwuka K. S. (2007). Effect of water hyacinth infestation on the physico-chemical characteristics of AWBA reservoir, Ibadan, South-West, Nigeria. *Journal of Biological Sciences,* **7:** 282 – 287.

UNEP (United Nations Environmental Programme). (2012). *Fifth Global Environment Outlook (GEOS). Environment for the future we want*. United Nations Environment Programme.Nairobi.

UNEP/MINEF **(**1997). First National Report on Biodiversity Cameroon 19pp.

Van Donk E. & Otte A. (1996). Effects of grazing fish and waterfowl on the biomass and species composition of submerged macrophytes. *Hydrbiologia*, **340 (1/3)**: 285–290.

Van Driesche R. G., Carruthers R. I., Center T. D., Hoddle M.S., Hough-Goldstein J., Morin L., Smith L., Wagner D. L., Blossey B., Brancatini V., Casagrande R., Causton C. E., Coetzee J. A., Cuda J., Ding J., Fowler S. V., Frank J. H., Fuester R., Goolsby J., Grodowitz M., Heard T. A., Hill M. P., Hoffmann J. H., Huber J., Julien M., Kairo M. T. K., Kenis M., Mason P., Medal J., Messing R., Miller R., Moore A., Neuenschwander P., Newman R., Norambuena H., Palmer W. A., Pemberton R., Perez Panduro A., Prat P.D., Rayamajhi M., Salom S., Sands D., Schooler S., Sheppard A., Shaw R., Schwarzländer M., Tipping P.W. & van Klinken R. D. (2010) Classical biological control for the protection of natural ecosystems: past achievements and current efforts. *Biological Control,* **54:**2–33

Van T. K. & Center T. D. (1994). Effect of paclobutrazol and water hyacinth weevil (*Neochetina eichhornia*) on plant growth and leaf dynamics of water hyacinth, (*Eicchornia crassipes*). *Weed Science*, **42:** 665–672.

Van T. K., Wheeler G. S. & Center T. D. (1998). Competitive interactions between Hydrilla (*Hydrilla verticillata*) and Vallisneria (*Vallinesria Americana*) as influenced by insect herbivory. *Biological Control*, **11**: 185–192.

Van Wilgen B. W. & De Lange W. J. (2011). The costs and benefits of biological control of invasive alien plants in South Africa. *African Entomology*, **19(2):** 504–514.

Van Wyk E. & Van Wilgen B. W. (2002). The cost ofwater hyacinth controlin South Africa: a case study of three options. *African Journal of Aquatic Science* **27:** 141–149.

Van der Meer M. B. & Verdegem M. C. J. (1996). Comparison of amino acid profiles of feeds and fish as a quick method for selection of feed ingredients: a case study of *Colossoma macropomum* (Cuvier). *Aquaculture Research*, **27**: 487–495.

Venter N., Hill M. P., Hutchinson S. L. & Ripley B. S. (2013). Weevil borne microbes contribute as much to the reduction of photosynthesis in water hyacinth as does herbivory. *Biological Control,* **64:** 138–142. DOI: 10.1016/j.biocontrol.2012.10.011.

Villamagna A. M. & Murphy B. R. (2006). Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes*): a review. *Freshwater Biology*, **55**: 282–298.

Villamagna A. M., Murphy B. R. & Trauger D. L. (2010). Behavioral Response of American Coots (*Fulica americana)* to Water Hyacinth (*Eichhomia crassipes*) in Lake Chapala, Mexico. *The International Journal of Waterbird Biology*, Vol. **33 (4):** 550–555. Stable URL: http://www.jstor.org/stable/40985876 Accessed: 01-08-2016 12:38 UTC.

Villamagna A. M. & Murphy B. (2010). Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes*): a review. *Freshwater Biology*, **55**: 282–298.

Vincent A. C. (2001). Evaluation of two plant pathogens, *Cercospora piaropi* and *Myrothecium roridum* as potential bioherbicides to control water hyacinth, *Eichhornia crassipes.* M.Sc. Thesis, University of Florida, USA.

Visalakshy P. N. G. & Jayanth K. P. (1996). Effect of Silt Coverage of Water Hyacinth Roots on Pupation of *Neochetina eichhorniae* Warner and *N. bruchi* Hustache (Coleoptera: Curculionidae). *Biocontrol Science and Technology,* **6:** 11–13.

Vyas S. & Kumaranayake L. (2006). Constructing socio-economic status indices: how to use principal components analysis. *Health Policy and Planning*, **21 (6):** 459–468.

Wang Y., Tang M., Hao P., Yang Z., Zhu L. & He G. (2008). Penetration into rice tissues by brown plant-hopper and fine structure of the salivary sheaths. *Entomologia Experimentalis et Applicata*, **129:** 295–307.

Ward J. V. & Tockner K. (2001). Biodiversity: towards a unifying theme for river ecology. *Freshwater Biology,* **46:** 807–819.

WCMC (1994). World Conservation Monitoring Centre Cameroon, Conservation Status Listing of Plants. Report compiled from WCMC Plant, Data Base, Cambridge U.K. WCMC.

Weber H. J. (1950). Morphologische und anatomische studien über *Eichhornia crassipes* (Mart.) Solms. *Adhandllungen der Mathematisch – Naturwissenschattlicher Klasse, Akademie der Wissenhaften und der Litterature Mainz*, **6**: 135–161.

Weyl P. S. R. (2011). "Is more, less?" Insect-insect interactions in a biological control context using water hyacinth as a model. Msc dissertation. Rhodes University, Grahamstown, South Africa. pp. 150.

White P. S. & Jentsch A. (2001). The search for generality in studies of disturbance and ecosystem dynamics. *Progress in Botany,* **62:**399–450.

White G. (1997). Population ecology and biological control of weeds. In: Julien, M., and Graham, W. 1997. Biological Control of Weeds: Theory and Practical Application. ACIAR Monograph N° **49**. pp 39-45.

WHO (World Health Organizatio) (1983). Cholera surveillance. *Wkly Epidemiol Rec.* 1983 Jan 21; **58 (3):** 19.

WHO (1985). The control of schistosomiasis. Report of a WHO Expert Committee. Geneva, World Health Organization, 1985. WHO Technical Report Series 728.

WHO (2008). Guideline for Drinking-water Quality. WHO, Geneva, p. 668.

William A. E., Duthie H. C. & Hecky R. E. (2005). Water hyacinth in Lake Victoria: Why did it vanish so quickly and will it return? *Aquatic Botany*, **81**: 300–314.

Williams A. E. & Hecky R. E. (2005). Invasive aquatic weed and eutrophication: the case of water hyacinth in Lake Victoria. Pp.187–225. In: Reddy M. V. (ed.). *Restoration and Management of Tropical Eutrophic Lakes*. Enfield Science Publishers, Inc.

Williamson M. H. (1996). *Biological invasion*. Chapman and Hall, London. 244p.

Wilson J. B. (1988). A review of evidence on the control of shoot: root ratio, in relation to models. *Annales of Botany*, **61:** 433–449.

Wilson J. R. U., Gairifo C. & Gibson M. R. (2011) Risk assessment, eradication, and biological control: global efforts to limit Australian acacia invasions. *Diversity and Distributions*, **17:** 1030–1046.

Wilson J. R., Holst N. & Rees M. **(**2005). Determinants and patterns of population's growth in water hyacinth. *Aquatic Botony,* **81***: 51–67.*

Wilson J. R., Rees M. & Ajuonu O. (2005). Population regulation of a classical biological control agent: larval density dependence in *Neochetina eichhorniae* (Coleoptera: Curculionidae), a biological control agent of water hyacinth *Eichhornia crassipes. Bulletinof Entomological Research*, **96**: 145–152.

Wilson J. R. U., Ajuonu O., Center T. D., Hill M. P., Julien M. H., Katagira F. F., Neuenschwander P., Njoka S. W., Ogwang J., Reeder R. & Van T. (2007). Short communication: The decline of water hyacinth on Lake Victoria was due to biological control by *Neochetina* spp. *Aquatic Botany*, **87**: 90–93.

Winston R. L., Schwarzländer M., Hinz H. L., Day M. D., Cock M. J. W., Julien M. H., & Lewis M. (2014). B*iological control of weeds: A world catalogue of agents and their target weeds*. Fift edition. United States Department of Agriculture. 838 p.

Wise R. M., Van Wilgen B. W., Hill M. P., Schulthess F., Tweddle D., Chabi-Olay A. & Zimmermann H. G (2007). The Economic impact and appropriate management of selected invasive species on the African continent. Report prepared by CSIR for GISP, South Africa.

Woomer P. L., Muzira R., Bwamiki D., Mutetikka D., Amoding A. & Bekunda M. A. (2000). Biological management of water hyacinth waste in Uganda. *Biological Agriculture and Horticulture*, **17**: 181–196.

Wright A. D. & Purcell M. F. (1981). *Eicchornia crassipes* (Mart.) Solms – Laubach. In: Groves R. H., Shepherd R. C. H., Richardson R. G. (Eds.), t*he Biology of Australian Weeds*. R. G. & F. G. Richardson, Melbourne, pp. 111–121.

Wright A. D. (1979). Preliminary report on damage to *Eichhornia crassipes* by an introduced weevil at a central Queensland liberation site, pp. 227–229. In Medd, R. W. and B. A. Auld (eds). *Proceedings of the 7th Asian-Pacific Weed Science Society Conference*, November 26–30, 1979, Sydney, Australia. Council of Australian Weed Science Societies for the Asian-Pacific Weed Science Society.

Wright A. D. (1980). Biological control of waterhyacinth in Australia. Pages 529–535 in E. S. Del Fosse ed. *Proc. V Int. Symp. On Biol. Control of weeds. Commonw. Sci. Ind. Res. Organ.,* Canberra, Australia.

Wright A. D. & Bourne A. S. (1990). Effect of the 2, 4-D on the quality of water hyacinth as food for insects. *Plant Protection Quaterly*, **5:** 139–141.

Wright A. D. & Center T. D. (1984). Predicting population intensity of adult *Neochetina eichhorniae* (Coleoptera: Curculionidae) from incidence of feeding leaves of water hyacinth, *Eichhornia crassipes*. *Environmental Entomology*, **13:** 1478–1482.

Wright A. D. & Purcell M. F. (1995). *Eichhornia crassipes* (Mart.) Solms-Laubach. In: *the Biology of Australian Weeds*. Groves, R. H., Shepherd, R.C.H. and Richardson, R.G. (Eds), R. G. and F. J. Richardson, Melbourne, Australia, **Vol. 1**: 111–121.

Wright A. D. & Skilling L. (1987). Herbicide toxicity and biological control agents. *Proceedings of the 8th Australian Weeds Conference*, Sydney, September 21–25, 1987. Pp. 93–96.

WTG (Watershed Task Group) (2011). Water hyacinth mapping report of the Wouri-Basin Douala, Littoral Region. Feasibility study for WTG project: contract No: 00103/M/MINEP/SG/DAG/SDBMM/SM/2010.

WTG (Watershed Task Group) (2012). Etude de faisabilité sur la collecte, la valorisation et la gestion des déchets de la jacinthe d'eau dans le Bassin hydrographique du Wouri. Pp. 28.

Xie Y. & Yu D. (2003). The significance of lateral roots in phosphorus (P) acquisition of water hyacinth (*Eichhornia crassipes*). *Aquatic Botany*, **75**: 311–321.

Xu Y., Kang D., Shi Z., Shen H. & Wehner T. (2004). Inheritance of resistance to zucchini yellow mosaic virus and watermelon mosaic virus in watermelon. *Journal of Heredity*, **95:** 498–502.

Yamoah E., Jones E. E., Suckling D. M., Bourdôt G. W., Walter M. & Stewart A. (2011). Using insects as potential vectors of *Fusarium tumidum* to control gorse. *New Zealand Entomologist*, **34(1):** 5–11. DOI: 10.1080/00779962.2011.9722202

Yang F. & Nakagoshi N. (2004). Alien plant invasion in water systems in Sghanghai, China. *Journal of International Development and Cooperation*, **10(2):** 1–11.

Zavaleta E. S., Hobbs R. J. & Mooney H. A. (2001). Viewing invasive species removal in whole-ecosystem context. *Trends in Ecology and Evolution*, **16:** 454–459.

ZESCO (2008). Zambia Environment Outlook Report 3. Environmental Council of Zambia, 201pp.

Zhang H. (2012). Can Water Hyacinth Clean Highly Polluted Waters? —A Short Paper for Discussion. *Journal of Environmental Protection*, **3**: 340–341.

Zhu Y. L., Zayed A. M., Qian J. H., Souza M. & Terry N. (1999). Phytoaccumulation of trace elements by wetland plants. II. Water hyacinth. *Journal of Environmental Quality*, **28**: 339–344.

APPENDIXES

ANNEXURE 1: SURVEY QUESTIONNAIRE

Influence of presence of *Eichhornia crassipes* on riparian communities life's

Dear Respondents,
I am conducting a survey of the impact that might have water hyacinth in different areas infested. In the following questionnaire, I would like to know the different problems to which you are facing related to the infestation of the waterway by this plant. This survey is part of my PhD thesis and your help is crucial for my successful completion of this research project. Your responses will be anonymous; data will be combined and analysed as a whole. Please attempt to answer all the questions and tick one appropriate box that best suits your perspective for each statement.
Your response in the study will be greatly appreciated. Thank you very much for your time and assistance.

N°_________

Date: /_______/________/__________

I - GENERAL

1- Name of investigator /--/
2- Name of area investigate /……………………………………………………… /

II- DETAILS OF THE RESPONDENT

3- Name of the respondent (facultative) /--/

4- Gender: ☐ Female ☐ Male

5. a - Marital Status ☐ Yes ☐ No ; if married, continues with 5 b and 5 c

5 b - How many wives do you have (facultative)? …………………………………

5 c – How many childrens do you have (facultative)? ☐ 1 ☐ 2 ☐ 3 ☐ More than 3

6-Age/ : ☐ >25 years ☐ < 25 years

7- Occupation: ☐ Employee ☐ Self-employed ☐ Casual work ☐ Apprentice ☐ Contributing family work ☐ Domestic ☐ Others /…………………./

9.b- What are your main / second activities? ☐ Fishing ☐ Sand Extraction ☐ Transport

There is any health care centre in this area? ☐ Yes ☐ No

8- Status of the respondent: ☐ Owner ☐ Lease

☐ Live with a parent ☐ 4- Other /---------------------------------/

9- How many years have you lived in the district?

☐ 0- 2 years ☐ 2-5 Years ☐ 6-10 Years

☐ 10-15 Years ☐ >15 Years

III- PRESENCE OF *E. crassipes* AND ITS INFLUENCE ON RIPARIAN COMMUNITIES

10- Are you aware of the existence of any plants/invasive alien species (IAS)?

Yes ☐ No ☐

11- If yes, could you please describe them? ☐ Beautiful plant/flower

☐ Invasive grass/plant ☐ Large and green leaves ☐ Dense mat

☐ Floating/ Aquatic plant ☐ Reed ☐ Long Petiole

☐ Water hyacinth ☐ Water lettuce

12- Where are they found? ☐ Rivers/streams ☐ Ponds

☐ Wetlands ☐ Lagoons ☐ Others (specify)

13- Do you know the plant called water hyacinth? ☐ Yes ☐ No

If yes, where do we find this plant? (Give the name where there are mostly found)

Street: /…………………………………………………………………/

Village:/…………………………………………………………………../

Stream: /…………………………………………………………………/

Lake: /………………………………………………………………………../

14- When was (were) this/ these / IAS first noticed in this area?

☐ 1 year ago ☐ Less than 5 years ago

☐ Less than 10 years ago ☐ More than 10 years ago

15- Do you know where this plant / IAS originate from?

☐ Yes ☐ No

16- If yes, where did it come from? ☐ Neighbouring country (specify): /………………/

☐ Boat ☐ Men ☐ Other (specify)

17- How does water hyacinth spread out these different sites?

☐ At the edge of the lake ☐ Invade the entire watercourse ☐ Heap/ Tuft

18- What kinds of activities were being carried out in the river before the appearance of water hyacinth?

☐ Fishing ☐ Extraction of sand
☐ Transport ☐ Agriculture
☐ Mangrove exploitation ☐ Looking for shells ☐ Other (Specify)

19- Which activities can no longer be carried out in the river due to the presence of water hyacinth?

☐ Fishing ☐ Extraction of sand
☐ Transport ☐ Agriculture
☐ Mangrove exploitation ☐ Looking for shells ☐ Other (Specify)

20- How does this plant affected the use of this river? ☐ 1- Reduce fish species
☐ Harbours pest (Snakes, etc) ☐ Clogs fishing gear ☐ Blocks water ways
☐ Causes siltation and water loss ☐ Blocks navigation ☐ Sand reduction
☐ Invasion of water ways ☐ Other (Specify)

IV- IMPACTS OF THE PRESENCE OF WATER HYACINTH ON DIFFERENT ACTIVITIES RELATED TO THE RIPARIN COMMUNITIES LIVES

A – FISHING

21- How many fishermen were there in this village before the appearance of the water hyacinth? ☐ 0-20 ☐ 20-40 ☐ 40-60 ☐ 60-80 ☐ 80-100 ☐ >100

And how many are there now?

☐ 0-10 ☐ 10-20 ☐ 20-30 ☐ 30-40 ☐ 40-50 ☐ 50-60 ☐ > 60

22- Do you fishing for commercial purposes or for home consumption?

☐ Commercial Purpose ☐ Home consumption

22- How many kilogramme (Kg) of fish did you make daily before the presence of water hyacinth? ☐ 0-20 ☐ 20-40 ☐ 40-60 ☐ 60-80 ☐ 80-100 ☐ >100

22-b- And now, with the invasion of water hyacinth, how many Kg can you make?
☐ 0-10 ☐ 10-20 ☐ 20-30 ☐ 30-40
☐ 40-50 ☐ 50-60 ☐ > 60

23- Before the presence of water hyacinth, how much per Kg was it sold then (Fcfa)? …….
☐ 0-500 ☐ 500-1000 ☐ 1000-1500 ☐ 1500-2000
☐ 2000-2500 ☐ > 2500

23.b- And now, with the presence of water hyacinth, how much does it cost (Fcfa)?
☐ 0-500 ☐ 500-1000 ☐ 1000-1500 ☐ 1500-2000
☐ 2000-2500 ☐ > 2500

24- Which kind of fishes did you usually catch before the appearance of water hyacinth?
☐ Lamentin ☐ Crabs ☐ Carps
☐ Prawns ☐ Tilapia ☐ Cat-fish
☐ Machoiron ☐ Other (Specify)

25- Which kinds of fish have disappeared with the presence of water hyacinth? …………….
☐ Lamentin ☐ Crabs ☐ Carps
☐ Prawns ☐ Tilapia ☐ Catfish
☐ Machoiron ☐ Other (Specify)

26- What was the size of fish that you catch before the appearance of water hyacinth?
☐ Big and long ☐ Medium ☐ Small

26-b- And now? ☐ Big and long ☐ Medium ☐ Small

27- What technic of fishing do you usually use before the appearance of water hyacinth?
☐ Net ☐ Trap ☐ Chemical Products
☐ Other technique (specify)

28- Do you know any kind of fish which appeared with the presence of water hyacinth?
☐ Yes ☐ No

29- Do you know if prawns are still abundant in this area? ☐ Yes ☐ No
If no, what could be the reason?
☐ Decrease because of presence of WH ☐ Never had prawn here
☐ Decrease during rainy season

30- With the presence of water hyacinth, did you develop any technics of fishing to increase your fish efficiency? ☐ Yes ☐ No
If Yes, which one? ☐ Net ☐ Trap ☐ Chemical Product
☐ Arrow ☐ Fishing rod

31- Which age group were mostly involved in fishing activity? ☐ 15 to 25 years
☐ 25 to 35 years ☐ 35 to 45 years ☐ More than 45 years

32- Apart from fishing, are there other economic activities being carried out by the people of this community? ☐ Yes ☐ No
If yes, what are they? ☐ Trade ☐ Agriculture ☐ Sand extraction
☐ Sand Extraction ☐ Wood exploitation ☐ Mangrove exploitation
☐ Sale of land ☐ Transport

33- About which percentage of the population was involved in other economic activities before water hyacinth appeared?
☐ 0-20 ☐ 20-40 ☐ 40-60 ☐ 60-80
☐ 80-100 ☐ >100

And after water hyacinth appeared? ☐ 0-10 ☐ 10-20 ☐ 20-30
☐ 30-40 ☐ 40-50 ☐ 50-60 ☐ > 60
32- How does water hyacinth affect your fishing activity? ☐ Reduces fish species
☐ Clogs fishing gear ☐ Blocks water ways ☐ Block navigation
☐ Invade ☐ Block creek ☐ Appearance of snake
33- How many fishing gears did you buy a year when water hyacinth was absent? …
☐ 0-2 ☐ 3-5 ☐ 6-8 ☐ 9-12
How many do you buy a year now? ☐ 0-4 ☐ 4-8 ☐ 8-12
☐ 12-16
34- How many times in a week (day) do you go for fishing before water hyacinth appeared?
☐ 0-2 ☐ 2-4 ☐ 4-6 ☐ Whole week

And now? ☐ 0-2 ☐ 2-4 ☐ 4-6 ☐ Whole week

35- How do you preserve your fish?
☐ Sell directly ☐ In the cooler bag with ice before sell
☐ Cook directly ☐ In the fridge

36- Do you have a period along the year, where you do not fish? ☐ Yes ☐ No
If yes, when? ☐ Rainy season ☐ Dry season

37- Could you estimate your benefice per week or months for fishing activity you are involved?
Before (Fcfa): ☐ 0-10.000 ☐ 10.000-20.000 ☐ 20.000-30.000
☐ 30.000-40.000 ☐ >40.000
After (Fcfa): ☐ 0-5000 ☐ 5.000-10.000 ☐ 10.000-15.000
☐ 15.000-20.000 ☐ 20.000-25.000 ☐ >25.000

38- Are you still doing fishing now? ☐ Yes ☐ No
If no, what economic activity do you do now? ☐ Trade ☐ Drive
☐ Carpenter ☐ Employee ☐ Technician

39- In this area, do you fight against water hyacinth? ☐ Yes ☐ No

If yes, how do you do? ☐ Remove and burn ☐ Remove and use
☐ Apply chemical ☐ Nothing ☐ Remove and leave to the edge

B- SAND EXTRACTION

40- Do you extract sand in this area? ☐ Yes ☐ No

41- If yes, how many sand extractors are there in the community? …………………………
☐ 0-20 ☐ 20-40 ☐ 40-60 ☐ 60-80
☐ 80-100 ☐ >100

42- What is the average or interval (class) age group involved in sand extraction and why?
☐ 15 to 25 years ☐ 25 to 35 years ☐ 35 to 45 years ☐ More than 45 years

43- What do you do with the sand? ☐ Sell ☐ Personal use
44- What are the good conditions to extract sand? ☐ Dry season ☐ Tide down
☐ Free surface of watercourse ☐ Low depth of water

45-a- How many days in week, did you use to go for sand extraction before water hyacinth appeared? ☐ Every days ☐ 1 to 2 times per week
☐ 2 to 4 times per week ☐ 4 to 6 times per week

45-b- And Now, with the presence of water hyacinth? ☐ Every day
☐ 1 to 2 times per week ☐ 2 to 4 times per week ☐ 4 to 6 times per week

46- Which quantity of sand did you usually extracted when there was no water hyacinth? (Number of boat per day) ☐ 0-2 ☐ 2-4 ☐ 4-6 ☐ 6-8 ☐ 8-10

47.a- And now, with the appearance of water hyacinth, which quantity do you extract? (Number of boat per day) 0-2 ☐ 2-4 ☐ 4-6 ☐ 6-8 ☐ 8-10 ☐

48- How do you sell the sand that you have removed or extracted?
☐ Wheelbarrow ☐ Truck

48 a- How much do you sell a wheelbarrow of sand or a truck of sand before the appearance of water hyacinth?

1- Wheelbarrow (fcfa): ☐ 0-500 ☐ 500-1000

2- Truck (fcfa): ☐ 0-15.000 ☐ 15000-25.000 ☐ 25.000-35.000

49.a- And now, how much do you sell?

1- Wheelbarrow (fcfa): ☐ 0-500 ☐ 500-1000 ☐ 1000-1500

2- Truck (Fcfa): ☐ 0-15.000 ☐ 15.000-25.000 ☐ 25.000-35.000 ☐ 35.000-45.000

50- How much was a trip of sand before water hyacinth appeared (fcfa)?

☐ 0-5000 ☐ 5.000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000 ☐ 20.000-25.000 ☐ >25.000

51.a- And now, how much is the price (fcfa)?

☐ 0-5000 ☐ 5.000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000 ☐ 20.000-25.000 ☐ >25.000

And why?

☐ Increase of fuel price ☐ Need more persons ☐ Too much time

52- Do you have a period along the year, where you do not fish? ☐ Yes ☐ No

If yes, when? ☐ Rainy season ☐ Dry season ☐ Too cold ☐ Tide

53- What are the kinds of problems sand extraction face with the presence of water hyacinth when carrying out their activities? ☐ Snakes ☐ Dirty ☐ Block water way and motor ☐ Tide up ☐ Heavy rain ☐ Drowning

54- In this area, do you fight against water hyacinth? ☐ Yes ☐ No

If yes, how do you do? ☐ Remove and burn ☐ Remove and use ☐ Apply chemical ☐ Nothing ☐ Remove and leave to the edge

55- Do you use water hyacinth? ☐ Yes ☐ No

If yes, how? ☐ Medicine ☐ Compost ☐ Animal fodder

C- TRANSPORT

56- Since how many years are you involved in the transport? ☐ Less than 5 years ☐ 5 to 10 years ☐ 10 to 20 years ☐ More than 20 years

57- How many times do you use a river for transportation? ☐ Every days ☐ 1 to 2 times per week ☐ 2 to 4 times per week ☐ 4 to 6 times per week

58- What are the common areas where you usually go? /…………………………../

59- How many owner used boats for transportation for commercial purpose? …

☐ 0-2 ☐ 3-6 ☐ 6-9 ☐ >9

60- Has this number increased/ decreased since water hyacinth appeared in this area?

☐ Increased ☐ Decreased

, and why? ☐ Increasing of price of fuel ☐ Not enough clients ☐ Lack of material

61- What is being transported across the river? ☐ People ☐ Goods

☐ Sand ☐ Fish ☐ others

62- Do you use paddling or engine boats? ☐ Paddling ☐ Engine boats

63- If engine boats, how much fuel did you use a day for transportation when water hyacinth was absent? ☐ 0-30 ☐ 30-60 ☐ 60-90

64.a- And Now, how much do you spend and why?

☐ 0-30 ☐ 30-60 ☐ 60-90

65- How much money do you make for one trip when you transport?

Before the appearance of water hyacinth

1- People ☐ 0-5000 ☐ 5000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000
☐ 20.000-25.000 ☐ >25.000

2- Sand ☐ 0-5000 ☐ 5000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000
☐ 20.000-25.000 ☐ >25.000

3- Poisson ☐ 0-5000 ☐ 5000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000
☐ 20.00-25.0 ☐ >25.000

3- Goods ☐ 0-5000 ☐ 5000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000
☐ 20.000-25.000 ☐ >25.000

5- Other ☐ 0-5000 ☐ 5000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000
☐ 20.000-25.000 ☐ >25.000

After water hyacinth

1- People ☐ 0-5000 ☐ 5000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000
☐ 20.000-25.000 >25.000

2- Sand ☐ 0-5000 ☐ 5000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000
☐ 20.000-25.000 ☐ >25.000

3- Poisson ☐ 0-5000 ☐ 5000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000
☐ 20.00-26.0 ☐ >25.000

3- Goods ☐ 0-5000 ☐ 5000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000
☐ 20.000-25.000 ☐ >25.000

5- Other ☐ 0-5000 ☐ 5000-10.000 ☐ 10.000-15.000 ☐ 15.000-20.000
☐ 20.000-25.000 ☐ >25.000

66- What are the difficulties faced by people displacing themselves in this river since the invasion by water hyacinth? ☐ Some roads are blocked ☐ Lack of clients
☐ Change of direction ☐ Invasion of waterway

67- How many days a week did you transport in this river when water hyacinth was not present?
Every day ☐ 1 to 2 times ☐ week
☐ 2 to 4 times per week ☐ 4 to 6 times

68.a- And now? ☐ Every day ☐ 1 to 2 times per week
☐ 2 to 4 times per week ☐ 4 to 6 times

69- What is the loss of income per month in this activity due to the presence of water hyacinth (fcfa)? ☐ 0-25.000 ☐ 25.000 to 50.000
☐ 50.000 to 75.000 ☐ More than 100.000

70- In this area, do you fight against water hyacinth? ☐ Yes ☐ No

If yes, how do you do? ☐ Remove and burn ☐ Remove and use
☐ Apply chemical ☐ Nothing ☐ Remove and leave at the edge

71- Do you use water hyacinth? ☐ Yes ☐ No

If yes, how? ☐ Medicine ☐ Compost ☐ Animal fodder

D- BIODIVERSITY

72- Which kind of fishes, prawn, animal, plants useful were present in the river in this area? (Give the name and specify)
1-Plants: ☐ Water lettuce ☐ *A. conyzoides* ☐ Boussa ehba ☐ Masebe
☐ Plant with two face ☐ Reed ☐ *E. pyramidalis*

2- Fish
☐ Lamentin ☐ Crabs ☐ Carps
☐ Prawns ☐ Tilapia ☐ Catfish
☐ Machoiron ☐ Other (Specify)

3- Animal
☐ Prawns

73- Which kind disappeared when water hyacinth appeared? (Give the name and specify)

1-Plants: ☐ Water lettuce ☐ *A. conyzoides* ☐ Boussa ehba ☐ Masebe

☐ Plant with two face ☐ Reed ☐ *E. pyramidalis*

2- Fish

☐ Lamentin ☐ Crabs ☐ Carps

☐ Prawns ☐ Tilapia ☐ Catfish

☐ Machoiron ☐ Other (Specify)

3- Animal

☐ Prawns

74- Are there any plant species which have medicinal value? ☐ Yes ☐ No

Which? ☐ Water lettuce ☐ *A. conyzoides* ☐ Boussa ehba ☐ Masebe

☐ Plant with two face ☐ Reed ☐ *E. pyramidalis*

75- Are they present in water hyacinth infested area? ☐ Yes ☐ No

76- Does the presence of *E. crassipes* eradicate other plants which were present in the site?

☐ Yes ☐ No

If yes, which (Give vernacular names if possible)?

☐ Water lettuce ☐ *A. conyzoides* ☐ Boussa ehba ☐ Masebe

☐ Plant with two face ☐ Reed *E. pyramidalis*

77- Have you discovered any new plant that appeared in water hyacinth mats?

☐ Yes ☐ No

If yes, which plant? …………………………………………………………….

78- About water hyacinth, are there any economic uses for the plant/IAS in your community?

☐ Yes ☐ No

79.a - If yes, what do you use it/ them for?

☐ Medicine ☐ Compost

☐ Fodder crop ☐ Handicraft

80- What are the animals which live with water hyacinth? ☐ Insects

☐ Birds ☐ Snakes ☐ Crocodile ☐ Other (Specify)

81- What are those who feed on water hyacinth? ☐ Birds ☐ Snakes

☐ Crocodile ☐ Insects ☐ Other (Specify)

82- Has the plant/IAS caused any problems since it was detected?

☐ Yes ☐ No

83- If yes, what are some of the problems?

☐ Reduces fish species ☐ Harbours pests (snakes, etc)

☐ Clogs fishing gear ☐ Blocks water ways

☐ Causes siltation and water loss ☐ Other (specify)………

84- Do you know how the plant/IAS is propagated? ☐ Yes ☐ No

62.a- If yes, how?

☐ Seed ☐ Stems

☐ Roots ☐ Leaves ☐ Other (specify)

E- WATER SUPPLY

85- Before the appearance of water hyacinth, what did you use this water for?

☐ Drinking ☐ Laundry ☐ Bathing

☐ Cook ☐ Other

86.a- And now, what do you use it for? ☐ Drinking ☐ Laundry

☐ Bathing ☐ Cook ☐ Other

87.b. If is for drinking or cooking, do you treat the water before these uses? (Yes or No)

☐ Yes ☐ No

If yes, how do you treat it? ☐ Boiling ☐ Filtering

☐ Others methods

88- How has the appearance of water hyacinth affected the water quality?

☐ Bad odour ☐ Highly polluted ☐ Doesn't change ☐ colour is dark

☐ Can no longer ☐ Never used ☐ Doesn't know ☐ water itches

89- How has the presence of water hyacinth affected the laundry and bathing in this area?

☐ Bad odour and dark ☐ Highly polluted ☐ Doesn't change ☐ dark

☐ Can no longer use ☐ Never used ☐ Doesn't know ☐ water itches

☐ Invasion of the surface of watercourse ☐ Remove and do what they want to do

☐ Look for a new place

90- How do you cope with the presence of water hyacinth when you want to bath or to laundry? ☐ Use water from well ☐ Look for a new place

☐ Can no longer use ☐ Never used ☐ Doesn't know ☐ water itches

☐ Invasion of the surface of watercourse ☐ Remove and do what they want to do

91- Have there been cases of floods in this area? ☐ Yes ☐ No

92- How often do you have flood in this area per year?

☐ 0-10 ☐ 10-20 ☐ 20-30 ☐ 30-40 ☐ 40-50 ☐ >50

93.a- When was the last flood? (Day, month and year)………………………………

94- What do you think is the cause? ☐ Heavy rain ☐ movement of tide

☐ Bad drainage system ☐ invasion of waterway by WH ☐ wastes

95- How many households were affected?

☐ 0-10 ☐ 10-20 ☐ 20-30 ☐ 30-40 ☐ 40-50 ☐ >50

96- Can you estimate the loss in monetary term (Fcfa)? ☐ 0-10.000 ☐ 10-20.000
☐ 20-30.000 ☐ 30-40.000 ☐ 40-50.000 ☐ 50-60.000 ☐ >60.000

97- Where do you reject your waste water? ☐ On the road ☐ In the stream (Lake)
☐ Canalisation systems ☐ other

98- Where are located your toilets? ☐ Riverside ☐ Outside on stilts
☐ Modern toilets inside ☐ Other (Specify)

99- Do you have farm? ☐ Yes ☐ No
99 a- Where are located your farm? ☐ Riverside ☐ Near to the houses
☐ Not around
100- Do you use fertilizer in your farm? ☐ Yes ☐ No
If yes, what kinds? ☐ Chemical ☐ Organic (compost, chicken dung)

F- HEALTH

101- What kinds of health problems are common with people in this area?
☐ Cholera ………. ☐ Malaria …………….. ☐ Filarial …
☐ Typhoid ……….. ☐ Schistosomiasis ☐ Others (Specify)……

102- Do you have mosquitoes in this area? ☐ Yes ☐ No
If yes, this number has it increased with the appearance of water hyacinth? ☐ Yes ☐ No

103- How has the appearance of water hyacinth affected the prevalence of these diseases?
☐ Increased ……….. ☐ Decreased ……….
☐ Constant ……….. ☐ Deaths ……. ☐ Other effects ……

104- Are snakes and crocodiles common in the water in this area since water hyacinth appeared? (Yes or No) ☐ Yes ☐ No
105- Were they common when there was no water hyacinth? ☐ Yes ☐ No

106- How frequent do you have cases attacks from these snakes and crocodiles?
☐ Never ☐ 1-5 ☐ 5-10 ☐ 10-15 ☐ 15-20

108- How much (fcfa) in average does a complete treatment of these diseases cost?
A . Cholera ☐ 0-5000 ☐ 5-10.000 ☐ 10-20.000 ☐ 20-30.000
☐ 30-40.000 ☐ 40-50.000 ☐ 50-60.000 ☐ > 60.000
B. Typhoid ☐ 0-5000 ☐ 5-10.000 ☐ 10-20.000 ☐ 20-30.000
☐ 30-40.000 ☐ 40-50.000 ☐ 50-60.000 ☐ > 60.000
C. Malaria ☐ 0-5000 5-10.000 ☐ 10-20.000 ☐ 20-30.000
☐ 30-40.000 ☐ 40-50.000 ☐ 50-60.000 ☐ > 60.000
D. Filarial ☐ 0-5000 ☐ 5-10.000 ☐ 10-20.000 ☐ 20-30.000
☐ 30-40.000 ☐ 40-50.000 ☐ 50-60.000 ☐ > 60.000

E. Schistosomiasis ☐ 0-5000 ☐ 5-10.000 ☐ 10-20.000 ☐ 20-30.000 ☐ 30-40.000 ☐ 40-50.000 ☐ 50-60.000 ☐ > 60.000

F. Diarrhea ☐ 0-5000 ☐ 5-10.000 ☐ 10-20.000 ☐ 20-30.000 ☐ 30-40.000 ☐ 40-50.000 ☐ 50-60.000 ☐ > 60.000

109- How many time a year in average does one member of the family can suffer of these diseases?

A . Cholera ☐ 0-4 ☐ 4-7 ☐ 7-10 ☐ 10-13 ☐ 13-16 ☐ 16-20

B. Malaria ☐ 0-4 ☐ 4-7 ☐ 7-10 ☐ 10-13 ☐ 13-16 ☐ 16-20

C. Filarial ☐ 0-4 ☐ 4-7 ☐ 7-10 ☐ 10-13 ☐ 13-16 ☐ 16-20

D. Typhoid ☐ 0-4 ☐ 4-7 ☐ 7-10 ☐ 10-13 ☐ 13-16 ☐ 16-20

E. Shistosomiasis ☐ 0-4 ☐ 4-7 ☐ 7-10 ☐ 10-13 ☐ 13-16 ☐ 16-20

F. Diarrhea ☐ 0-4 ☐ 4-7 ☐ 7-10 ☐ 10-13 ☐ 13-16 ☐ 16-20

G- BIOCONTROL

109- Have you ever attempted to control the plant/IAS in any way? ☐ Yes ☐ No

110- If yes, what did you do or what do you normally do?

☐ Remove and burn ☐ Remove and use

☐ Apply herbicides ☐ Don't do anything

☐ Remove and leave at the edge ☐ other (specify)

111- Are the practices adopted successful? ☐ Yes ☐ No

112- If no, why do you think the practices were not successful?

☐ The plant rejuvenates too fast ☐ Seeds germinate and grow very fast

☐ The weed is resistant to herbicides ☐ The plant sprouts from cuttings of all parts

☐ Other (specify)

113- From your experience, how else do you intend to deal with the problems of the plant/IAS?

Seek advice ☐ Seek assistance from NGOs ☐

☐ Seek communal involvement in its management

☐ Apply more herbicides at higher doses

☐ Other (specify)

114- Would you like to see the plant/IAS exterminated or controlled? ☐ Yes ☐ No

If yes, what, in your view, is the most appropriate option to manage the plant/IAS?

☐ Chemical treatment with herbicides

☐ Physically remove all plant and burn regularly

☐ Introduce natural enemies to suppress the IAS ☐ Other (specify)

115- Do you see yourself as a partner in the control of the plant/IAS? ☐ Yes ☐ No

116- If yes, how do you intend to contribute to the control of the plant/IAS?

☐ Financial contributions ☐ Reporting the occurrence of the weed

☐ Cooperation with and support for researchers and extension staff

☐ Propagation of the methodology of control ☐ Other (specify)

117- Would you agree to the introduction of any new plants in your area?

☐ Yes ☐ No

118- If no, why not?

☐ They may pose several health problems

☐ They may take over the environment and damage biodiversity

☐ They may reduce water quality ☐ They may impede water utilisation

☐ They could increase cost of water treatment

☐ They may introduce pests and diseases

☐ They may reduce fish population and diversity ☐ Other (specify)

119- If yes, why?

☐ They may enhance fishing ☐ They provide herbs for medicines

☐ They are food for domestic animals and wild life

☐ They can be used as botanical pesticide ☐ They may possess aesthetic value

☐ Other (specify)

120- What will you do to prevent the recurrence of the plant/IAS in your community?

☐ Report strange plants to extension officers, NGOs, district assemblies, etc.

☐ Physically remove and destroy strange plants before they spread

☐ Other (specify)

121- In relation to environmental measures, where do you dispose of your household water?

☐ In the river ☐ Canalisation drainage ☐ Behind house ☐ In the nature

☐ In the road ☐ Everywhere

Thank you for your participation

Comment of the investigator

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………………………………………………

QUESTIONNAIRES FOR HEALTH CARE

1- Name of the health care centre ……………………………………………………………..

2- Do you know water hyacinth? ☐ Yes ☐ No

3- What are the main diseases recorded in this healthcare centre ?

☐ Cholera ☐ Malaria ☐ Filarsiose
☐ Typhoid ☐ Shistosomiasis ☐ Diarrhea ☐ other

4- In which frequency (%) do you receive this group of person in consultation per month?

Man : ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

Women : ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

Young : ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

Childrens: ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

5- What are the rate (%) of patients suffering from these diseases?

A . Cholera: ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

B. Malaria ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

C. Filarsiose ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

D. Typhoid ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

E. Schistosomiasis ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

F. Diarrhea ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

G. Other ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

6- What is the percentage of patients recorded for the diseases related to water quality?

1-Diarrhea ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

2- Cholera ☐ 0-10 ☐ 15-30 ☐ 30-45 ☐ 45-60 ☐ 60-75 ☐ 75-90 ☐ >90

7a- What is the age group (year) most affected by these diseases ?

A. Cholera ☐ < than 5 years ☐ 5-9 years ☐ 10-24 years ☐ > than 25 Years

B. Malaria ☐ < than 5 years ☐ 5-9 years ☐ 10-24 years ☐ > than 25 Years

C. Filarsiose ☐ < than 5 years ☐ 5-9 years ☐ 10-24 years ☐ > than 25 Years

D. Typhoid ☐ < than 5 years ☐ 5-9 years ☐ 10-24 years ☐ > than 25 Years

E. Schistosomiasis ☐ < than 5 years ☐ 5-9 years ☐ 10-24 years ☐ > than 25 Years

F. Diarrhea ☐ < than 5 years ☐ 5-9 years ☐ 10-24 years ☐ > than 25 Years

8- Does the data from years before infestation of the waterway by water hyacinth showed there had been any change (decrease or increase)? ☐ Decrease ☐ increase
If increase, explain? ……………………………………………………………………………

9- Whether the fluctuation of these diseases could be related to the presence of water hyacinth in the area? ☐ Yes ☐ No

If yes, please could you explain ?..

10- What is your own perception of water hyacinth on their lifestyle and justification of the presence of water hyacinth and increase of diseases? ……………………………

ANNEXURE 2: Meteorological data

REPUBLIQUE DU CAMEROUN
Paix – Travail – Patrie
MINISTERE DES TRANSPORTS
REGION DU LITTORAL
DELEGATION REGIONALE DU LITTORAL
SERVICE DE LA METEOROLOGIE

N° 404 /MDT/MINT/C/DRLT/SM

REPUBLIC OF CAMEROON
Peace – Work -Fatherland
MINISTRY OF TRANSPORT
LITTORAL REGION
REGIONALDELEGATION OF LITORAL
SERVICE OF METEOROLOGY

Douala, le 30 MARS 2016

The littoral Regional Delegate of Transport

TO

Kenfack Voukeng Sonia N. (PHD Student University of Rhodes)

Subject: Meteorological data for Douala 2014-2016.

Madam KENGFACK,

Following your request dated 17th March 2016 on the above subject,

I have the honor to present to you on Meteorological data table below , the Rainfall, Temperature and Relative Humidity for Douala data solicited;

METEOROLOGICAL DATA TABLE

Met. Station: ***Douala P30*** Latitude: ***04° 00'N*** Longitude: ***09° 44'E*** Altitude: ***05m***

Monthly Rainfall in mm and 1/10

YEARS	JAN	FEB	MAR	APRI	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
2016	2.2	22.2	/	/		/	/	/	/	/	/	/
2015	13.4	67.7	151.0	139.6	292.3	590.3	299.9	507.8	455.6	X	217.3	0.9
2014	15.6	1.4	184.8	362.7	254.5	393.3	387.5	716.4	680.6	344.1	156.9	44.5

Mean monthly Temperatures in °C and 1/10

YEARS	JAN	FEB	MAR	APRI	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
2016	28.6	29.2	/	/		/	/	/	/	/	/	/
2015	28.1	28.6	28.0	27.1	27.9	23.3	25.0	25.3	25.8	X	27.2	28.1
2014	28.1	28.3	27.5	30.9	27.4	26.2	24.8	24.3	25.6	26.1	30.3	27.0

Relative Humidity in %

YEARS	JAN	FEB	MAR	APRI	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
2016	73	74	/	/		/	/	/	/	/	/	/
2015	74	76	79	79	78	85	84	83	84	X	80	72
2014	77	76	79	76	80	81	83	87	83	81	81	77

NB: X = Unavailable data

COPY

MINT/YNE

GOV/LT

Le Délégué Régional des Transports du Littoral

Mm. Ayuketah

MONTHLY MEAN TEMPERATURE IN °C AND 1/10

PERIOD: 1978 – 2014 STATION: DOUALA

Years	JAN	FEV	MAR	APR	MAY	JUNE	JUL	AUG	SEP	OCT	NOV	DEC
1978	27,8	28,5	27,4	27,1	26,8	26,2	25,1	25,0	25,3	26,1	27,0	27,6
1979	28,2	28,2	27,9	27,5		26,3	25,5	25,0	26,0	26,2	26,8	27,3
1980	27,9	28,1	27,9	27,4	27,3	26,3	25,1	25,1	25,8	26,1	26,8	27,7
1981	27,4	28,5	27,9	27,8	27,0	26,2	24,8	24,9	25,4	26,4	27,3	27,5
1982	27,8	28,3	27,9	27,6	26,9	25,8	25,0	24,8	25,5	26,0	27,3	27,8
1983	27,8	29,2	29,5	28,2	27,8	26,2	25,1	24,6	25,6	25,6	26,7	26,8
1984	27,5	28,5	27,7	27,5	27,0	26,6	26,3	26,1	26,2	26,2	27,2	27,2
1985	27,5	28,2	27,8	27,4	27,0	26,2	25,7	25,6	25,9	25,9	27,3	27,5
1986	28,1	28,3	27,5	28,2	27,7	26,2	24,9	25,3	25,8	26,0	26,4	27,4
1987	28,1	28,5	28,4	28,4	27,8	27,3	26,8	26,0	26,5	26,6	27,8	28,1
1988	28,5	29,2	28,6	28,1	27,6	26,6	25,5	25,6	26,1	26,3	27,3	27,0
1989	27,4	28,3	28,1	27,6	27,0	26,3	25,4	25,2	26,0	26,2	27,3	27,8
1990	27,8	28,5	29,3	28,7	27,5	26,7	24,9	25,3	25,9	26,7	27,2	27,5
1991	28,0	29,3	28,8	27,8	27,6	27,1	25,5	24,9	25,7	26,1	26,7	27,6
1992	27,4	29,2	28,2	28,0	27,6	26,2	25,0	24,8	25,5	26,1	27,1	28,0
1993	28,0	28,6	27,9	27,9	27,8	26,8	25,8	25,3	26,4	26,6	26,5	28,0
1994	28,0	28,5	28,5	27,8	27,3	26,6	25,4	25,1	26,2	26,3	26,8	28,2
1995	28,0	28,4	28,1	27,9	27,5	26,5	25,5	25,7	26,2	26,0	27,1	27,5
1996	27,8	28,1	27,7	28,0	27,5	26,5	25,2	25,3	26,1	26,7	28,3	28,3
1997	28,5	29,1	28,9	27,4	27,6	26,9	25,7	25,7	26,7	27,2	27,9	28,3
1998	28,9	30,5	30,7	29,5	29,0	27,8	26,8	26,2	26,7	27,4	28,0	28,2
1999	28,3	28,8	28,7	28,1	27,8	27,6	26,3	26,3	25,6	24,9	25,5	27,0
2000	28,8	29,3	29,2	27,6	26,4	26,2	26,3	25,6	26,3	26,4	27,4	27,8
2001	27,8	29,1	28,3	28,2	27,7	26,7	25,4	25,1	25,9	27,1	27,6	28,2
2002	28,5	29,0	28,6	28,2	28,4	27,2	25,7	26,1	26,4	26,7	27,5	28,6
2003	28,6	29,0	28,9	28,3	28,4	26,9	26,7	26,0	26,2	27,2	27,8	28,8
2004	28,7	29,4	28,2	27,0	27,3	26,8	26,5	25,8	26,8	27,1	27,5	28,4
2005	28,5	29,4	28,6	29,1	27,8	26,8	28,5	28,1	29,9	30,3	28,2	28,0
2006	28,7	29,1	28,8	28,5	27,6	27,6	26,3	25,8	26,4	27,4	28,0	28,6
2007	28,6	29,7	29,8	28,3	28,3	26,2	26,1	25,9	26,5	26,5	26,8	28,1
2008	27,3	29,0	28,0	27,8	27,9	26,7	26,2	26,2	26,8	27,2	28,0	28,0
2009	28,5	28,4	28,8	28,2	27,7	26,8	26,2	25,6	26,0	26,9	27,5	28,8
2010	29,0	29,0	29,0	29,0	28,3	27,1	26,2	26,0	26,7	26,8	27,7	28,5
2011	28.5	28.5	29.1	28.4	28.4	27.05	25.95	28.0				
2012							28.4	26.4	26.4	27.1	27.8	28.5
2013	29	28.9	28.65	28.2	28.2	26.6	25.4	25.3	26.2	2615	26.9	27.1
2014	28.13	28.51	27.79	27.49	27.44	26.76						

MONTHLY MEAN PRECIPITATION (mm and 1/10)

PERIOD: 1983 – 2014 STATION: DOUALA

Years	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1983	0.0	3.7	131.4	156.2	157.9	245.0	534.2	490.5		385.1	102.2	73.2
1984	31.6	32.5	129.0	294.2	298.5	174.5	280.2	534.1	313.0	452.1	53.8	2.4
1985	117.8	19.7	312.9	341.9	246.7	267.2	403.4	755.0	535.8	282.1	215.6	1.7
1986	6.5	67.9	179.2	194.7	323.8	451.2	936.2	537.1	597.9	519.7	305.2	0.7
1987	40.4	19.2	109.3	168.3	258.3	176.8	416.8	851.4	569.1	452.6	82.7	14.6
1988	27.7	35.5	174.9	265.8	214.1	392.5	865.3	588.4	408.3	443.7	97.7	124.0
1989	0.0	2.3	89.0	233.3	186.9	296.2	332.4	861.3	621.3	371.5	115.1	5.2
1990	43.5	90.2	53.0	212.6	229.9	442.0	656.3	828.9	539.6	435.8	208.8	96.4
1991	1.3	64.4	116.6	348.1	166.2	203.3	1091.3	733.4	398.3	321.2	34.1	3.4
1992	8.2	4.8	242.4	197.7	267.8	404.4	665.1	369.5	557.8	438.5	161.3	0.0
1993	1.6	60.7	149.3	260.1	433.1	303.7	592.6	897.2	288.6	348.4	232.1	49.9
1994	106.8	17.8	170.3	534.6	373.0	263.6	519.6	843.7	802.6	257.3	232.1	0.0
1995	7.0	8.7	165.3	186.3	380.1	387.8	609.9	635.0	715.0	483.6	156.0	24.9
1996	33.2	153.5	246.9	307.3	405.8	355.8	318.3	451.6	477.5	323.4	6.6	11.5
1997	13.0	4.4	232.6	249.7	290.7	377.9	962.1	632.5	267.6	407.7	109.3	16.9
1998	28.0	7.9	21.1	206.0	216.2	327.9	498.6	558.1	700.5	226.7	0.0	22.9
1999	86.5	79.3	76.1	231.3	274.8	436.7	811.5	465.6	470.0	631.8	133.2	7.4
2000	28.2	4.2	228.8	215.7	133.0	435.9	789.1	871.3	386.0	322.4	117.1	47.6
2001	8.4	71.0	155.0	254.5	406.0	753.3	751.7	524.4	602.2	303.6	205.1	0.0
2002	2.9	103.8	214.2	284.9	315.7	709.4	647.7	961.3	591.2	427.4	125.4	8.5
2003	158.4	84.9	106.7	182.4	265.5	336.2	166.4	947.9	339.5	307.3	140.7	14.5
2004	43.1	25.1	-	250	-	365.3	483	816.8	520.4	398	229.7	80.1
2005	19.8	61.6	228	171.7	394.8	393	302.6	668.8	803.7	321.3	87.5	13.7
2006	24.1	89.4	236.1	194.7	324	220.4	973.6	854	1027.2	385.5	117.1	38.6
2007	0.0	63.6	64.4	236.3	143.1	894.4	792.5	882.5	443.7	359.0	253.2	64.8
2008	33.8	28.2	129.0	250.0	177.6	263.4	339.1	718.0	649.4	215.0	196.0	68.0
2009	115.0	53.9	124.4	224.0	232.2	397.0	266.0	872.0	617.9	368.0	91.2	7.0
2010	38,2	198,7	186,9	176,3	376,5	488,3	727,3	727,3	444,7	457,4	198,9	29,5
2011	14.1	107.2	183.9	109.4	171.7	370.2	839.5	872.8				
2012			166.3	234.8	275.6	414.5	665.1	750.5	600.2	387.7	133.4	31.0
2013	42.7	117.9	235.8	464.5	130.9	618.1	740.9	317.8	746.3	415.4	348.5	82.6
2014	15.6	1.4	159.6	362.7	254.5	341.8						