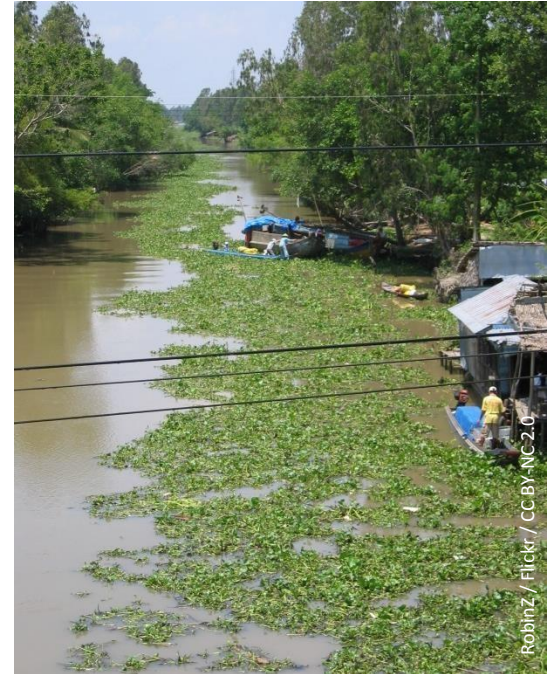




Thematic focus: Ecosystem Management

Water hyacinth: Can its aggressive invasion be controlled?

The spread of invasive alien species is neither easy to manage nor easy to reverse, threatening not only biodiversity but also economic development and human wellbeing (UNEP, 2012). Native to the Amazon Basin in South America water hyacinth has emerged as a major weed in more than 50 countries in the tropical and subtropical regions of the world with profuse and permanent impacts (Patel, 2012; Téllez et al., 2008; Shanab et al., 2010; Villamagna and Murphy, 2010). Worryingly, climate change may allow the spread of water hyacinth to higher latitudes (Patel, 2012). Intensified monitoring, mitigation and management measures are needed to keep water hyacinth at unproblematic levels.



Why is this issue important?

The beautiful, large purple and violet flowers of the South American water hyacinth (*Eichhornia crassipes*) make it a very popular ornamental plant for ponds. However water hyacinth has also been labelled as the world's worst water weed and has garnered increasing international attention as an invasive species (Zhang et al., 2010). Efficient in utilizing aquatic nutrients and solar energy for profuse biomass production, water hyacinth can cause extensive environmental, social and economic problems. It is found in lakes, estuaries, wetlands, marshes, ponds, dambos, slow flowing rivers, streams, and waterways in the lower latitudes where growth is stimulated by the inflow of nutrient rich water from urban and agricultural runoff, deforestation, products of industrial waste and insufficient wastewater treatment (Villamagna and Murphy, 2010; Ndimele et al., 2011). According to recent climate change models,



its distribution may expand into higher latitudes as temperatures rise, posing problems to formerly hyacinth free areas (Rahel and Olden, 2008).

What are the findings?

Invasive alien species are a major global challenge requiring urgent action (Xu *et al.* 2012). They are considered one of the key pressures on world's biodiversity: altering ecosystem services and processes, reducing native species abundance and richness, and decreasing genetic diversity of ecosystems (Rands *et al.*, 2010; Vila *et al.*, 2011; Hejda *et al.*, 2009). They cause substantial economic losses estimated by one study to total US\$120 billion annually in the USA (Pimentel *et al.* 2005; Kettunen *et al.*, 2009). In South Africa, estimated economic costs due to invasive alien species are currently above 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 (Wilgen and Lange, 2011).

Water hyacinth has been identified by the International Union for Conservation of Nature (IUCN) as one of the 100 most aggressive invasive species (Télliez *et al.*, 2008) and recognized as one of the top 10 worst weeds in the world (Shanab *et al.*, 2010; Gichuki *et al.*, 2012; Patel, 2012). It is characterised by rapid growth rates, extensive dispersal capabilities, large and rapid reproductive output and broad environmental tolerance (Zhang *et al.*, 2010). In Africa, for example, where water hyacinth is listed by law as a noxious weed in several countries, it is the most widespread and damaging aquatic plant species. The economic impacts of the weed in seven African countries have been estimated at between US\$20-50 million every year. Across Africa costs may be as much as US\$100 million annually (UNEP, 2006).

The success of this invasive alien species is largely due to its reproductive output. Water hyacinth can flower throughout the year and releases more than 3 000 seeds per year (Gopal, 1987; EEA, 2012). The seeds are long-lived, up to 20 years (Gopal, 1987). While seeds may not be viable at all sites, water hyacinth commonly colonises new areas through vegetative reproduction and propagation of horizontally growing stolons. In the early stages of infestation, the weed takes foothold on the shoreline in the areas where native aquatic plants thrive (Gichuki *et al.*, 2012). However, it is not restricted to shallow water, unlike many submersed and emergent macrophytes, because its roots are free-floating near the surface (Villamagna and Murphy, 2010).



Geographical distribution and pathways of introduction

Water hyacinth is found across the tropical and subtropical regions (Figure 1). Originally from the Amazon Basin, its entry into Africa, Asia, Australia, and North America was facilitated by human activities (Dagno et al., 2012).

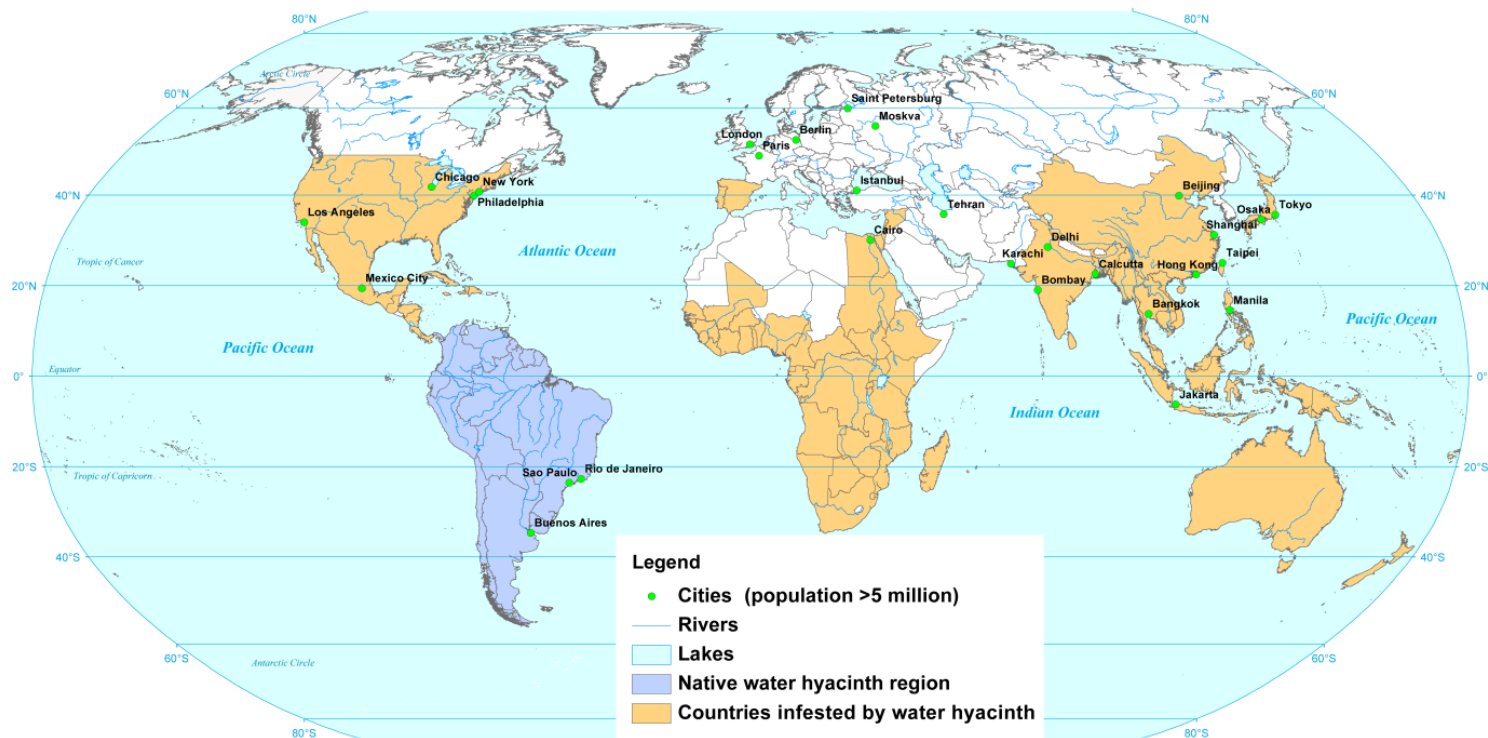
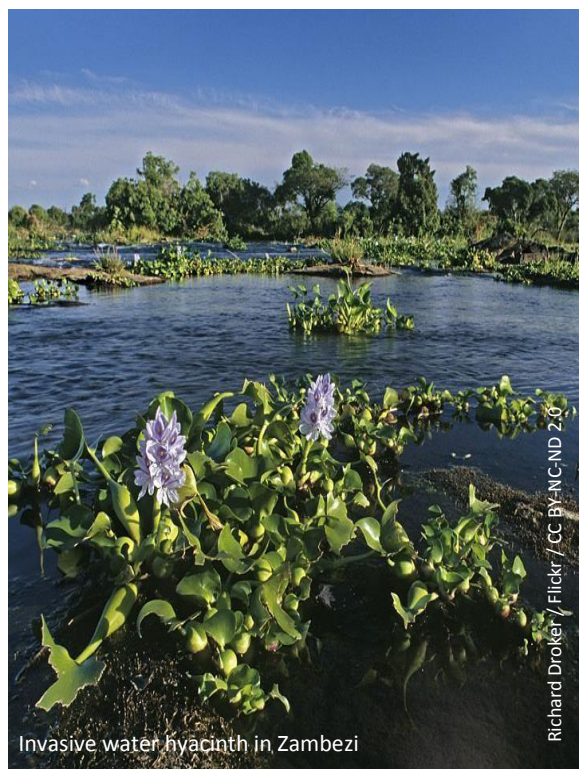


Figure 1. Global distribution of water hyacinth (Map redrawn by UNEP/DEWA from Téllez *et al.* 2008).

Africa has particularly been affected by the introduction and spread of water hyacinth, facilitated in part due to a lack of naturally occurring enemies. In a review of water hyacinth infestation in eastern, southern and central Africa, Mujingni (2012) reports that the weed was first recorded in Zimbabwe in 1937. It colonized important water bodies, such as the Incomati River in Mozambique in 1946, the Zambezi River and some important rivers in Ethiopia in 1956. Rivers in Rwanda and Burundi were colonised in the late 1950s while the rivers Sigi and Pangani in Tanzania were infested in 1955 and 1959. The plant colonised Kafue river in Zambia in the 1960s, the Shire River in Malawi in 1968 and Lake Naivasha in Kenya in 1986 (Mironga et al., 2012). The plant was recorded from Lakes Kyoga in Uganda in 1988-89, Victoria in 1989–1990, Malawi/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 the lake has been a serious nuisance, generating public outcry (World Agro Forestry Centre, 2006; Kateregga and Sterner, 2007; Gichuki et al., 2012). At its peak, it was estimated



that the weed was growing at 3 hectares (12 acres) per day on the lake (Ayodo and Jagero, 2012). The plant also spread fast throughout Uganda's lakes and rivers in just 10 years.

Water hyacinth has also spread to West Africa. It was first reported in Cameroon between 1997 and 2000 and since then the country's wetlands have become "home" for the weed (Forpah, 2009). In Nigeria almost all river bodies have been dominated by water hyacinth (Borokini and Babalola, 2012). The water hyacinth problem is especially severe on the river Niger in Mali where human activities and livelihoods are closely linked to the water systems (Dagno et al., 2012). It occurs throughout the Nile Delta in Egypt and is believed to be spreading southwards, due to the construction of the Aswan Dam which has slowed down the river flow, enabling the weed to invade (Dagno et al., 2007). Infestation of water hyacinth in Ethiopia has also been manifested on a large scale in many water bodies of the Gambella area, Lake Ellen in the Rift Valley and Lake Tana (Fessehaie, 2012).

In Europe, water hyacinth is established locally in the Azores (Portugal) and in Corsica (France), and casual records are known from Belgium, the Czech Republic, Hungary, the Netherlands and Romania (EEA, 2012) In particular, it is a threat in Spain and Portugal (DellaGreca et al., 2009).

In Asia, water hyacinth is widespread on freshwater wetlands of the Mekong Delta, especially in standing water (MWB/RSCP, 2006). It has been detected in the Sundarbans mangrove forest of Bangladesh (Biswas et al., 2007) and has caused heavy siltation in the wetlands of the Kaziranga National Park, India. Deepor Beel, a freshwater lake formed by the Brahmaputra River is heavily infested with this weed (Patel, 2012). The lake is considered one of the large and important riverine wetlands in the Brahmaputra valley of lower Assam, India. As in many other countries, water hyacinth has caused many economic, social and environmental problems in southern China (Choo et al., 2006).

In Mexico, more than 40,000 hectares of reservoirs, lakes, canals and drains are infested with water hyacinth (Jimenez and Balandra, 2007). In California, USA, this weed has caused severe ecological impacts in the Sacramento- San Joaquin River Delta (Khanna et al., 2011).



Water hyacinth covering a waterway in south of India

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Threats posed by water hyacinth

i. Destruction of biodiversity

Today, biological alien invasions are a major driver of biodiversity loss worldwide, (Pyšek and Richardson, 2010; Vila et al., 2011). Water hyacinth is challenging the ecological stability of freshwater water bodies (Khanna et al., 2011; Gichuki et al., 2012), out-competing all other species growing in the vicinity, posing a threat to aquatic biodiversity (Patel, 2012). Besides suppressing the growth of native plants and negatively affecting microbes, water hyacinth prevents the growth and abundance of phytoplankton under large mats, ultimately affecting fisheries (Gichuki et al., 2012; Villamagna and Murphy, 2010).

ii. Oxygen depletion and reduced water quality

Large water hyacinth mats prevent the transfer of oxygen from the air to the water surface, or decrease oxygen production by other plants and algae (Villamagna and Murphy, 2010). When the plant dies and sinks to the bottom the decomposing biomass depletes oxygen content in the water body (EEA, 2012). Dissolved oxygen levels can reach dangerously low concentrations for fish that are sensitive to such changes. Furthermore, low dissolved oxygen conditions catalyse the release of phosphorus from the sediment which in turn accelerates eutrophication and can lead to a subsequent increase in water hyacinth or algal blooms (Bicudo et al., 2007). Death and decay of water hyacinth vegetation in large masses deteriorates water quality and the quantity of potable water, and increases treatment costs for drinking water (Patel, 2012; Mironga et al. 2011; Ndimele et al., 2011).

iii. Breeding ground for pests and vectors

Floating mats of water hyacinth support organisms that are detrimental to human health. The ability of its mass of fibrous, free-floating roots and semi-submerged leaves and stems to decrease water currents increases breeding habitat for the malaria causing anopheles mosquito as evidenced in Lake Victoria (Minakawa et al., 2008). Mansonioides mosquitoes, the vectors of human lymphatic filariasis causing nematode Brugia, breed on this weed (Chandra et al., 2006; Varshney et al., 2008). Snails serving as vector for the parasite of Schistosomiasis (Bilharzia) reside in the tangled weed mat (Borokini and Babalola, 2012). Water hyacinth has also been implicated in harbouring the causative agent for cholera. For example, from 1994 to 2008, Nyanza Province in Kenya, which borders Lake Victoria accounted for a larger proportion of cholera cases than expected given its population size (38.7% of cholera cases versus 15.3% of national population). Yearly water hyacinth coverage on the Kenyan section of the lake was positively associated with the number of cholera cases reported in the Province (Feikin et al., 2010). At the local level increased incidences of crocodile attacks have been attributed to the heavy infestation of the weed which provides cover to the reptiles and poisonous snakes (Patel, 2012; Ndimele et al., 2011).

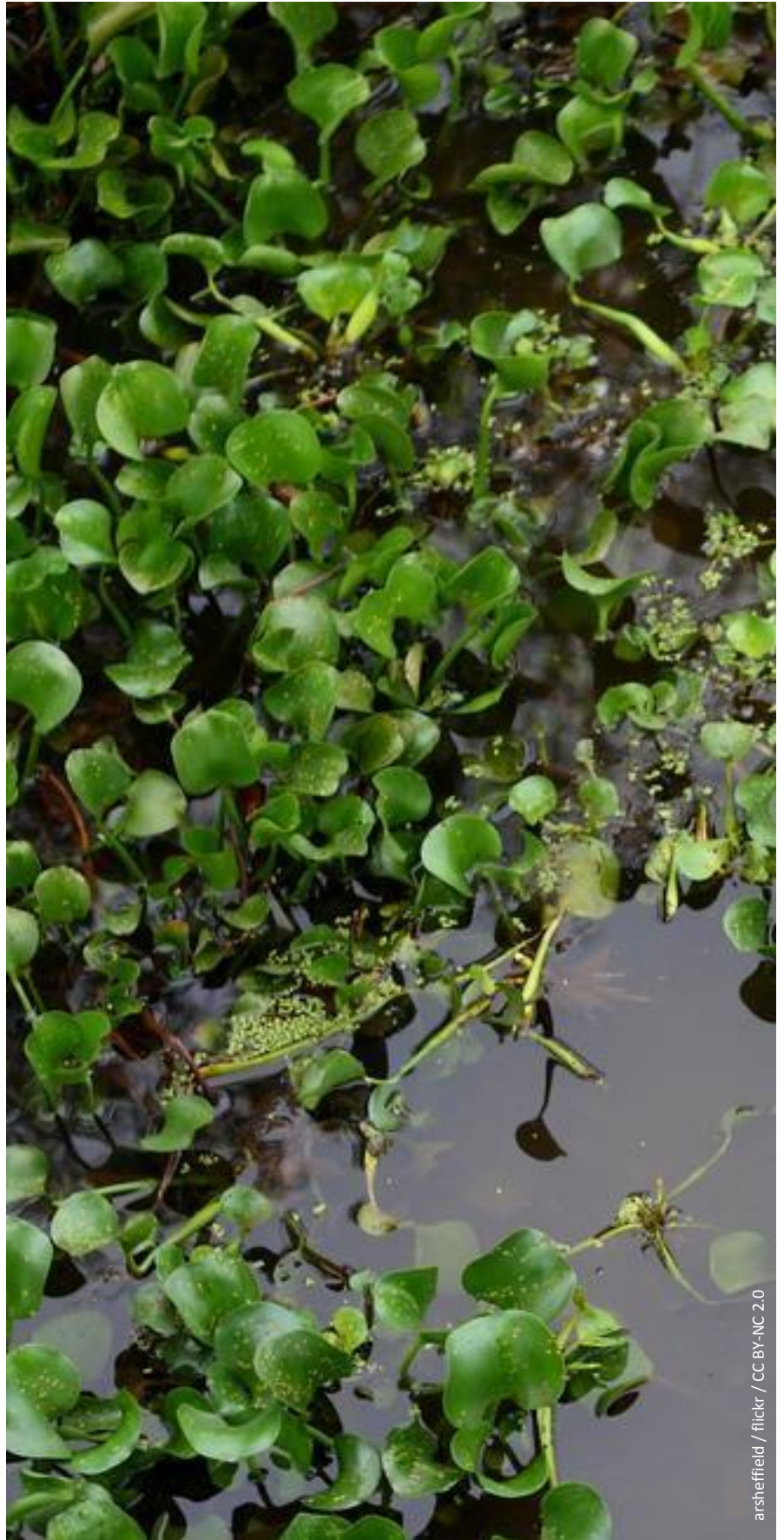
iv. Blockage of waterways hampering agriculture, fisheries, recreation and hydropower

Water hyacinth often clogs waterways due to its rapid reproduction and propagation rate. The dense mats disrupt socioeconomic and subsistence activities (ship and boat navigation, restricted access to water for recreation, fisheries, and tourism) if waterways are blocked or water pipes clogged (Ndimele et al., 2011; Patel, 2012). The floating mats may limit access to breeding, nursery and feeding grounds for some economically important fish species (Villamagna and Murphy, 2010). In Lake Victoria, fish catch rates on the Kenyan section decreased by 45% because water hyacinth mats blocked access to fishing grounds, delayed access to markets and increased costs (effort and materials) of fishing (Kateregga and Sterner, 2009). In the Wouri River Basin in Cameroon the livelihood of close to 900,000 inhabitants has been distorted; the entire Abo and Moundja Moussadi creeks have been rendered impassable by the weed leading to a complete halt in all the

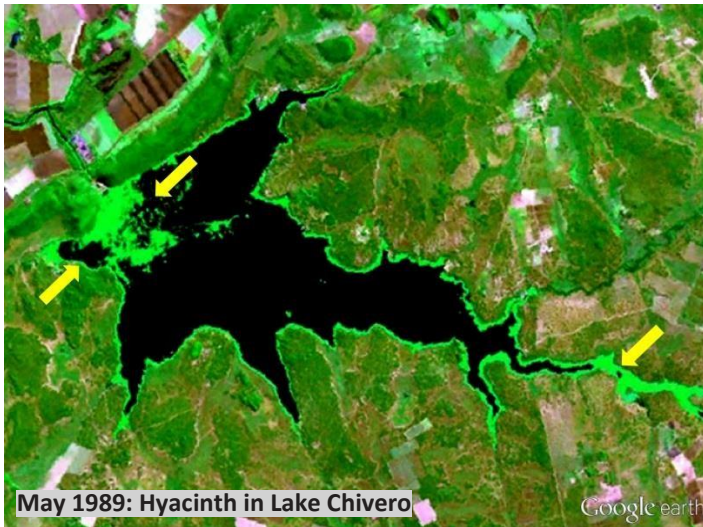
socioeconomic activities with consequent rural exodus (Mujingni, 2012). The weed has made navigation and fishing an almost impossible task in Nigeria (Ndimele et al., 2011).

While navigation in the Brahmaputra River in India has been affected by the weed, it has also blocked irrigation channels and obstructed the flow of water to crop fields (Patel, 2012). For example, in West Bengal, it causes an annual loss of paddy (Patel, 2012) by directly suppressing the crop, inhibiting rice germination and interfering with harvesting (EEA, 2012). The dense growth entangles with boat propellers, hampering fishing (Patel, 2012). Water hyacinth slows water flow by 40 to 95% in irrigation channels (Jones, 2009), which may cause severe flooding. The communities of Bwene and Bonjo in the Wouri River Basin in Cameroon regularly suffer from floods during the rainy season due to blockage of waterways around the villages by the weed (Mujingni, 2012).

It is estimated that the flow of water in the Nile could be reduced by up to one tenth due to increased losses from evapotranspiration by water hyacinth in Lake Victoria (Ndimele et al., 2011). Water loss by the same process and blocking of turbines on Kafue Gorge in Zambia translates into lost water for power generation and eventually into lost revenue of about US\$15 million every year for the power company (ZEO, 2008). Many large hydropower schemes are also suffering the effects of water hyacinth (Shanab et al., 2010). For example, cleaning intake screens at the Owen Falls hydroelectric power plant at Jinja in Uganda were calculated to be US\$1 million per annum (Mailu, 2001).



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Control measures

Water hyacinth control is absolutely essential (Villamagna and Murphy, 2010). Control methods that are often used include mechanical, chemical and biological control. However, existing methods have often been insufficient to contain the aggressive propagation of the weed and viability of its seeds despite substantial monetary investments over the years (Gichuki et al., 2012), mainly due to lack of continued policy and management support by governments. The weed infestation on Lake Chivero which supplies water to Harare, Zimbabwe, was controlled and declined from 42% in 1976 to 22% in 2000. Re-invasion began to emerge in 2005 and included massive amounts of another invasive plant, spaghetti weed (*Hydrocotyle ranunculoide* (UNEP, 2008). The October 2012 image shows the extent of re-invasion (Figure 2).



Figure 2: Satellite images showing progressive invasion, control and re-invasion of water hyacinth on Lake Chivero, Zimbabwe (Image source: Google Earth and Landsat).

i. Manual and mechanical control

Physical methods for control of water hyacinth involve drainage of the water body, manual removal of the weeds or pulling through nets (Patel, 2012). Employing machines like weed harvesters, crusher boats, and destruction boats prove expensive, approximately US\$600-1,200 per hectare (Malik, 2007; Villamagna and Murphy, 2010) as well as unpractical for areas larger than a hectare given the rapid rate of increase of the weed. There may also be additional fees for disposal of plant material. The costs of water hyacinth management in China were estimated to amount around EUR 1 billion annually (EEA, 2012). In Europe, management costs to remove 200,000 tonnes of the plant along 75 km in the Guadiana river basin on the Portuguese-Spanish border amounted to EUR 14,680,000 between 2005 and 2008 (EEA, 2012). Dagno et al. (2007) reported that mechanical management of the weed in Mali cost around US\$ 80,000–100,000 per year. Maintaining a clear passage for ships to dock at Port Bell in Uganda is estimated to cost US\$ 3-5 million per year (Mailu, 2001). 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).



Manual removal of water hyacinth, Kisumu, Kenya

ii. Chemical control

A generally cheaper method has been used worldwide to reduce water hyacinth populations through the use of chemical herbicides (such as Paraquat, Diquat, Glyphosate, Amitrole, 2, 4-D acid) (Villamagna and Murphy, 2010). However, their use directly interferes with the biocontrol agents currently deployed against this weed. Long term use may degrade water quality and put aquatic life at risk (Malik, 2007) with significant socio-economic impacts if beneficial or designated uses of the water body such as drinking and preparing food are affected (Dagno et al., 2012). Considering that hundreds of thousands of hectares have been invaded by the weed, it is unlikely that it will be controlled by chemical means alone (Borokini and Babalola, 2012).

iii. Biological control

In recent years, focus has shifted to natural enemies of water hyacinth including plant pathogens (Dagno et al., 2012; Villamagna and Murphy, 2010). The aim of any biological control is not to eradicate the weed, but to reduce its abundance to a level where it is no longer problematic. While there exists several native enemies of water hyacinth, two South American weevil beetles (*Neochetina eichhorniae* and *Neochetina bruchi*) and two water hyacinth moth species (*Niphograptus albiguttalis* and *Xubida infusella*) have had effective long-term control of water hyacinth in many countries, notably at Lake Chivero (Zimbabwe), Lake Victoria (Kenya), Louisiana (USA), Mexico, Papua New Guinea and Benin (Williams et al., 2007; Venter et al., 2012; Gichuki et al., 2012; Dagno et al., 2012). Researchers have identified another tiny insect, *Megamelus scutellaris*, from South America which is highly host-specific to water hyacinth and does not pose a threat to native or economically important species (Coetzee et al., 2009).

The weevils reduce water hyacinth vigour by decreasing plant size, vegetative reproduction, and flower and seed production. They also facilitate the transfer and ingress of deleterious microorganisms associated with the weevils (both fungi and bacteria) into the plant tissues (Venter et al., 2012).

Control of water hyacinth using fungal pathogens has greatly stimulated interest in the management of the weed. Several fungal species among them *Cercospora rodmanii*, *Alternaria alternata* and *A. eichhorniae* are recognized as potential mycoherbicide agents although no commercial mycoherbicide is available for water hyacinth (Dagno et al., 2012).



Water hyacinth weevils

G. Goergen, IITA Image Library / Flickr / CC BY-NC 2.0



Water hyacinth plants stressed by weevils tend to be of small stature and lose buoyancy

IITA Image Library / Flickr / CC BY-NC 2.0

Box 1. An example of the benefits of biological control

Between 1991 and 1993, a biological control program of water hyacinth was undertaken in Southern Benin. It consisted of the release of three natural enemies, two weevil species (these are the two *Neochetina* spp.) and one moth that feed exclusively on water hyacinth. In 1999, a survey of 365 men and women from 192 households in 24 villages in the target area revealed that water hyacinth, although not eliminated, was perceived by the villagers as having been reduced from a serious pest to one of minor or moderate importance. At the peak of the infestation water hyacinth had reduced the yearly income of this population of about 200 000 by approximately US\$84 million. Lost revenues for men were mostly in fishing, while women experienced lost revenues in trade, primarily food crops and fish. The reduction of water hyacinth cover through biological control was credited with an increase in income of US\$30.5 million per year. The total cost of the control program is estimated at a present value of US\$2.09 million. The benefits therefore appear to outweigh the costs by a ratio of 124:1 (De Groote et al. 2003).



Ganvié, Benin

Carsten ten Brink / Flickr / CC BY-NC-ND 2.0

iv. Reduction by utilization

Research into the utilization and related technologies for the control of water hyacinth have been tested over the last few decades (Ndimele et al., 2011). It is being speculated that the biomass can be used in waste water treatment, heavy metal and dye remediation, as substrate for bioethanol and biogas production, electricity generation, industrial uses, medicines, animal feed, agriculture and sustainable development (Patel, 2012). However, seldom does utilization provide a sustained solution to the spread and impact of water hyacinth, and in fact could provide a perverse incentive to maintain the invasive plant to the detriment of the environment and production systems at high economic and social costs. There is not one example from anywhere in the world where utilization alone has contributed to the management of any invasive plant (EEA, 2012).

Waste water treatment and clean-up of polluted environment

Water hyacinth has the potential to clean up various contaminated waters (Mahamadi and Nharingo, 2010; Rahman and 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 from the water column and grows very well in water polluted with organic contaminants and high concentrations of plant nutrients (Chunkao et al., 2012; Ndimele, 2012). In the Ologe Lagoon, Nigeria, water hyacinth that was not deliberately introduced into the lagoon to absorb heavy metals did so, even when the concentration of the heavy metals in the water column was very small

(Ndimele and Jimoh, 2011). In California, water hyacinth leaf tissue was found to have the same mercury concentration 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 the vast amount of the plant materials which may have to be considered as toxic waste (Zhang, 2012).

As alternative fuel and energy source

Water hyacinth fulfills all the criteria deemed necessary for bioenergy production – it is perennial, abundantly available, non-crop plant, biodegradable and has high cellulose content; however its strong disadvantage is that it has over 90% water content which complicates harvesting and processing. The biomass can be subjected to biogas production to generate energy for household uses in rural areas (Chuang et al., 2011). Experiments in China show that mixing biomass of water hyacinth with pig manure leads to a much higher biogas production than by using pig manure alone (Lu et al., 2010). It can also be used for producing ethanol, but technical and logistical challenges need to be overcome before the commercial scale ethanol production becomes a reality because of the high tissue water content (Ndimele et al., 2011).

Semi-industrial uses and household articles

As a readily available resource, water hyacinth has been used in several small cottage industries in the Philippines, Indonesia and India for paper, rope, basket, mats, shoes, sandals, bags, wallets, vases, etc (Ndimele et al., 2011; Patel, 2012). Yet these are rarely successful to reduce 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.

Animal feedstock and agricultural use

When sun-dried, water hyacinth has been found to be rich in protein, vitamins and minerals and serves as a high quality feedstock for some non-ruminant animals, poultry and fishery in Indonesia, China, the Philippines and Thailand (Lu et al., 2010; Saha and Ray, 2011). But it is not recommended for use if primarily used for removal of heavy metals and toxic substances from wastewater (Chunkao et al., 2012). Decomposed water hyacinth can also be used as green manure or as compost that improves poor quality soils (Ndimele et al., 2011). However, its high alkalinity (pH>9) and potentially toxic heavy metals contents would restrict its use to flowering-plants, with no allowable application to horticulture for edible vegetables (Chunkao et al., 2012; Zhang 2012).

What are the implications for policy?

Water hyacinth infestation is a symptom of broader watershed management and pollution problems. It calls for a concise national and transboundary water hyacinth policy designating the plant as noxious weed to aquatic systems. In October 2010, world leaders adopted the Strategic Plan for Biodiversity (2011–2020) targeting the need for identification of invasive alien species and pathways, the need to control and eradicate priority species, and to manage pathways in order to prevent further invasions (CBD, 2010).

Given the complexity of control options and the potential for climate change to assist the spread of water hyacinth, it is critical to develop comprehensive management strategies and action plans. A multidisciplinary approach should be designed, which ensures that the highest political and administrative levels recognize the

potential seriousness of the weed. Plans should also state clearly the role of each government department, stakeholders, municipal councils and local community involved in the fight against water hyacinth.

Awareness needs to be raised amongst local communities and all stakeholders on the inherent dangers of water hyacinth infestation to mobilize riparian communities towards control measures. One practical approach is to involve communities in manual and biological control activities, for example, in rearing weevils. There are excellent examples of community involvement in the rearing and distribution of the weevils to control the hyacinth around Lake Victoria.

Methods for water hyacinth control should include reduction of nutrient load in the water bodies through treatment of waters flowing from sewage works, urban wastes and factories. Changing land use practices in the riparian communities through watershed management will help reduce agricultural runoff as a mechanism for controlling the proliferation of water hyacinth. This is considered by many as one of the most sustainable long-term management actions.

In order for policy makers to make informed decisions, much more economic information is required on the costs and benefits of environmental programs. For example, it is frequently stated that there are insufficient resources to control hyacinth. However, if the costs of improved water treatment are compared with the costs of decreased fish catches and the costs of increased water-borne diseases, it is likely that resources needed for hyacinth control are modest in comparison to potential losses from its proliferation (see Box 1).

While researchers continue to investigate the perceived potential uses of water hyacinth, the current negative impacts of the weed far outweigh its benefits. The use of water hyacinth as raw material in cottage industry should not encourage propagation of the weed, but rather help control its growth.

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