Chapter 17
Exotic and Invasive Plants: Water Hyacinth

Alie Seid and Banchiamlak Getenet

Abstract This chapter is about biodiversity threats posed by water hyacinth in the pristine Lake Tana, discuss its potential problems and suggest possible solutions. Lake Tana watershed is within the East African Afro-montane Hotspot and the productive agro-ecosystems of Ethiopia. As a hotspot, the watershed is considered as global priority conservation area and Tana is proposed to be designated as a biosphere reserve. The catchment stretched from Lake Tana 1785 m above sea level to mount Guna 4150, and contains three distinct agro ecosystems. The national development strategy is changing the socioeconomic and biophysical landscapes. The expansion of a century old introduced *Eucalyptus* still has unsettled controversies. The lowland plane and the lake shore ecosystem are facing challenges of the worst invasive in 2004. Since then, the alien species is added on the two major environmental challenges namely anthropogenic activities and climate change.

Keywords Biosphere reserve · Invasive plant · Lake Tana · Waterhyacinth

17.1 Introduction

This chapter covers threats to biodiversity posed by exotic invasive plants in the Bahir Dar—Lake Tana region The Lake Tana watershed is one of the 34 Great Biodiversity Hotspots of the world (East African Afro-montane) and a productive agro-ecosystem of Ethiopia. The watershed is home to a number of endemic plants and considered as global priority conservation areas. It stretches from Lake Tana (1785 m above sea level) to mount Guna (4150 m above sea level), and contains

A. Seid (✉)
College of Natural Sciences, Bahir Dar University, Bahir Dar, Ethiopia
e-mail: alinabiot@yahoo.com

B. Getenet
College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia
e-mail: banchugetneta2020@gmail.com

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three distinct ecosystems. However, the watershed's biodiversity is facing challenges of invasive alien species driven both by development activities and climate change.

The recent development and transformation strategy of Ethiopia considered the watershed as a major development corridor likely to change socioeconomic status and biophysical landscapes. Economic development and increasing human population mobility (including tourism) will inevitably lead into intentional and unintentional introduction of non native species. While expansion of *Eucalyptus* in the watershed already has caused controversies for decades, invasive alien species are increasing in number and geographic range. Invasive species threaten agricultural and natural ecosystems requiring concerted efforts and strategic actions to minimize damages. This risk of biological contamination may pose an even greater risk than well-recognized chemical pollution.

Currently, invasive alien weeds are of great concern, for both economic and ecological reasons, posing particular problems in agricultural lands, range lands, national parks, water ways, rivers, power dams, roadsides and urban green spaces. Foremost among these is the Parthenium weed (*Partenium hystrophorus*), although major problems are also being caused by water hyacinth (*Eichhornia crassipes*), mesquites (*Prosopis juliflora), Lantana camara*, and the parasitic weeds of *Striga*, *Orobanche* and *Cuscuta* species.

Water hyacinth, *E. crassipes* Martius (Solms-Laubach) (Pontederiaceae), is a perennial free-floating aquatic plant. In the absence of natural enemies, water hyacinth forms large mats on still and slow-moving water bodies, where it severely degrades aquatic ecosystems and limits their utilization. Water hyacinth has been identified by Holm et al. (1991) as the world's worst weed; the International Union for Conservation of Nature (IUCN) considers it one of the 100 most aggressive invasive species (Téllez et al. 2008) and possibly one of the top 10 worst weeds in the world (Shanab et al. 2010; Gichuki et al. 2012; Patel 2012). Thus, this chapter contains a comprehensive account of the plant's biological features and we identify important research gaps toward improved understanding.

Invasive species have been identified by the Environmental Policy of Ethiopia (EPA 1997) as posing a major threat to biodiversity and economic well being of the population. The water hyacinth has appeared (in the hotter parts of Ethiopia) where it was first reported in 1965 at the Koka Reservoir and in the Awash River. The Ethiopian Electric Light and Power Authority have managed to bring it under moderate control at the location, with a considerable cost in human labor. Other infestations in Ethiopia include many water bodies in the Gambela Region, the Blue Nile just below Lake Tana into Sudan, and Lake Ellen near Alem-Tena (Fessehaie 2005). Even though it is not clear when and how the weed entered Lake Tana, it appeared during the last 3 or 4 years in some pocket grazing and wet farm areas near the mouth of the Megech River and proliferating and covering shoreline habitats in the Rib and Dirma River mouths. According to Amhara National Regional State Bureau of Environmental Protection, Land Administration and Use (BEPLAUA 2015 water hyacinth distribution report, unpublished), the weed has occupied 20,000 hectare (ha) of the lake area and extended up to 1 kilometer (km) into the lake. Similarly, Wondie et al. (2012 water hyacinth infestation at Lake Tana area, unpublished) reported that the infested area have expanded to more than 10% of the shoreline area in the north-eastern part of the lake.

17.2 Nature of Invasive Alien Plants

Human migration and movement of goods around the world have also provided pathways for introducing alien species into regions beyond their place of origin. Most of the world's population depends on food from crops and livestock from other regions of the world. Thus, non-native species are fundamental to most human cultures, and strong economic incentives encourage many sectors of society to continue importing potentially useful new organisms. When the introduction of alien species becomes an invasive, either through intentional or unintentional release and establishment, the impact can be overwhelming for native species, ecosystems and ultimately people. Invasive alien species are a major global challenge requiring urgent action (Xu et al. 2012), for 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).

In general invasive alien species (IAS) are those plants, animals and microbes which are introduced to and spread in new regions, mainly through human activities; the subsequent negative impact on biodiversity, agriculture, water resources, and human health represents a substantial challenge to economic growth and livelihoods.

However, only a few introduced species actually become problematic, with the vast majority of an estimated 480,000 introduced alien species never becoming established or spreading. In fact, beneficial species such as corn, wheat, rice, cattle, and others, provide more than 98% of the world's food supply with a value of more than US$5 trillion annually (USBC 2008). However, many alien species introduced intentionally for horticulture, agro-forestry, landscape restoration, and other purposes—as well as species which have been introduced unintentionally—pose a significant threat to economic development and ecological integrity. It is estimated that the impact and cost of managing IAS globally accounts for US$1.4 trillion annually or 5% of annual global GDP. Put in context, this is double the annual GDP for the whole of the African continent. The threat posed by IAS is increasing at an exponential rate as a result of increased international trade, transport or travel.

17.2.1 Pathways of Invasive Alien Introduction

The same few pathways and vectors are used by a large array of invasive alien species. So, exclusion efforts are best focused on interventions designed to block entire avenues of spread, rather than on intercepting individual species. Common pathways for the introduction of invasive alien species include:

Intentional introductions

- Plants introduced for agricultural purposes
- Exotic plants introduced for forestry use
- Non-native plants introduced for use as soil improvers
- ‘Aid trade’
- Ornamental or hedgerow plants
- Germplasm
- Mammals or birds released for hunting purposes
- Animals released on islands as sources of food
- Biological control agents
- Fishery releases
- Pets released, or escaping, into the wild
- Aquarium trade
- Releases intended to ‘enrich’ the native flora and fauna.

Accidental introductions

- Contaminants of agricultural produce
- Seed or invertebrate contaminants of nursery plants
- Seed or invertebrate contaminants of the cut flower trade
- Organisms in or on timber imports
- Seed contaminants
- Soil inhabiting species
- Contaminated imports of machinery, equipment,
- Vehicles and military hardware
- ‘Hitchhikers’ in, or on, packaging materials
- ‘Hitchhikers’ in, or on, mail or cargo
- ‘Hitchhikers’ on aeroplanes
- Ballast water on ships
- Ballast soils
- Sediments in ballast water tanks
- Hull fouling on ships
- Debris
- Tourists and their clothing, footwear, luggage, or equipment
- Diseases in animals traded for agricultural or other purposes
- Parasites and pathogens of, or ‘hitchhikers’ on, aquaculture and mariculture.

Introductions via captivity

- Escapes from botanical gardens, for example, or zoos
- Feral domestic animals
- Escapes from aquaculture or mariculture
- Escapes from research institutions or facilities.

17.2.2 Invasive Alien Plants Distribution and Trends

Africa is home to hundreds of Invasive Alien Species (IAS) both plant and animal but the magnitude of the problem varies from country to country, and from ecosystem to ecosystem. In many parts, freshwater ecosystems are particularly at risk with IAS surpassing habitat loss as the number one cause of biodiversity loss. Invasive alien species are a problem in diverse ecosystems in northern, western, central, eastern and southern Africa and in the western Indian Ocean islands: they affect both savannahs and tropical forests and they are found on land, in freshwater systems, along the coast, and in the ocean (UNEP 2004).

Virtually all countries in the region are affected by IAS. In 2004, IUCN the World Conservation Union (IUCN) identified 81 IAS in South Africa, 49 in Mauritius, 44 in Swaziland, 37 in Algeria and Madagascar, 35 in Kenya, 28 in Egypt, 26 in Ghana and Zimbabwe, and 22 in Ethiopia (IUCN/SSC/ISSG 2004). In some countries there may be under reporting of the incidence of IAS. Many IAS found in Africa are included on a global list of the 100 worst IAS (IUCN/SSG/ISSG 2004). These include the infamous, *E. crassipes* (water hyacinth); economically important species including the Nile perch, *Oreochromis mossambicus* (Mozambique tilapia) and *Acacia mearnsi* (black wattle); species introduced for biological control, such as *Acridotheres tristis* (Indian myna) and *Bufo marinus* (cane toad); and ornamentals such as *Lantana camara*. There are many others IAS which present serious challenges to regional efforts to conserve the environment and to meet development objectives, the foundation of social, economic and environmental sustainability in Africa. In some countries, IAS has become a major ecological, social and economic problem despite the existence of legal measures and substantial funding to control them.

With increasing globalization, the threat posed by IAS is likely to increase through both intentional and accidental introductions. Human movement and the movement of goods are key drivers in the spread of IAS. With improvements in communications and infrastructure, this is likely to increase. Historically, IAS has been spread through colonization and exploration. Today, mobility through tourism, business travel and migration continues to be an important factor. Many IAS have been introduced to Africa in, for example, soil, plants, luggage, vehicles and aeroplanes (Kirby 2003).

Trade both legal and illegal particularly in, but not limited to, plants and animals, is particularly important. Many species have been introduced through trade in manufactured goods contaminated with seeds or insects. Trade has contributed not only to the introduction of species that colonize and fundamentally alter receiving ecosystems but that are also a factor in the growing incidence of disease. *Aedes albopictus* (Asian tiger mosquito), for example, is associated with the transmission of dengue fever and is believed to have been first introduced through a shipment of tyres from Japan to South Africa in 1989. By 1999 these mosquitoes were found to be present in Douala, Cameroon's main commercial harbor (Fontenille and Toto 2001). Invasive alien species have also been spread through the provision of humanitarian emergency food aid. For example, the weed *P. hysterophorus* is a recent introduction to Africa through grain shipments for famine relief to Ethiopia (McNeeley et al. 2001). The weed was first seen in 1988 near food-aid distribution centres in Ethiopia. Buried seeds of the weed can lie dormant for as long as 20 years before germinating (GISP 2004). Research activities and agricultural extension have also been a factor. Disturbed ecosystems are particularly vulnerable to invasion by alien species.

17.3 Water Hyacinth

The center of origin of Water hyacinth (*E. crassipes)* is from the Amazon basin in Brazil and Peru. It has been spread to most of South America and the Caribbean islands and was first recorded in the United States in New Orleans. According to Hill and Coetzee (2013) the plant has been spread around the world by humans since the late 1800s as an ornamental pond plant. It has established in most tropical and subtropical countries as well as in many warm-temperate regions between 40°N and 40°S (Fig. 17.1). It's beautiful, large purple and violet flowers make it a very popular ornamental plant for ponds. However water hyacinth has also been labeled as the world's worst water weed and has garnered increasing international attention as an invasive species (Zhang et al. 2010).

By the end of the nineteenth century, the plant was recorded in Egypt, India, Australia, and Java. The main mode of spread of water hyacinth throughout the world has been through anthropogenic means, via the horticultural and aquarium trades, due to the appeal of its attractive smooth, green foliage and beautiful purple flowers. It continues to be spread in this fashion.

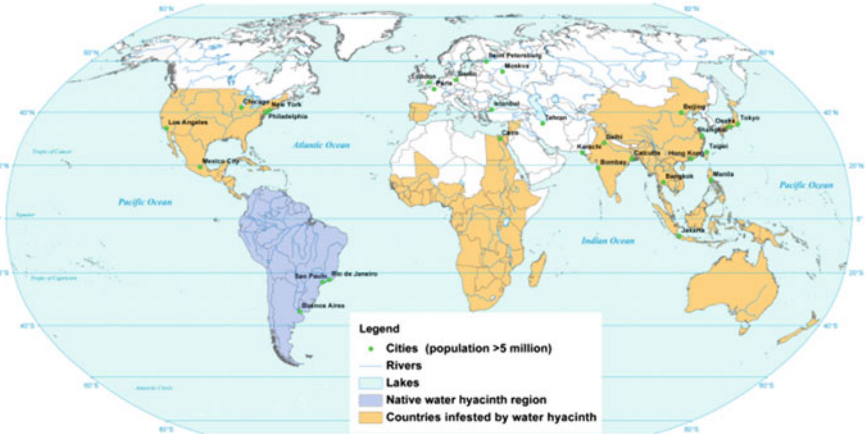

Fig. 17.1 Global distribution of water hyacinth (Map redrawn by Téllez et al. 2008 cited in UNEP 2006)

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 3000 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 colonizes 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).

17.3.1 Distribution in Africa

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 in Comati River in Mozambique in 1946, the Zambezi River and some important rivers in Ethiopia in 1956. Historically, invasive species have been spread into Africa through colonization and exploration. As globalization increased Africa is becoming more exposed to invasive species (Fig. 17.2).

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 (Borokoni 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 the river flow, enabling the weed to invade (Dagno et al. 2012). 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. In Ethiopia, it has been problematic at Koka Dam along the Awash River, and in Gambela along Baro, Gilo, Pibor and Sobate rivers (Hedberg et al. 2006).

17.3.2 Water Hyacinth in Lake Tana

During the preliminary field monitoring end of October, 2012 the maximum cover of stationary mats of water hyacinth in Lake Tana covered about 10–15 ha and was distributed along 60–80% of the shoreline length where it is found. When it was

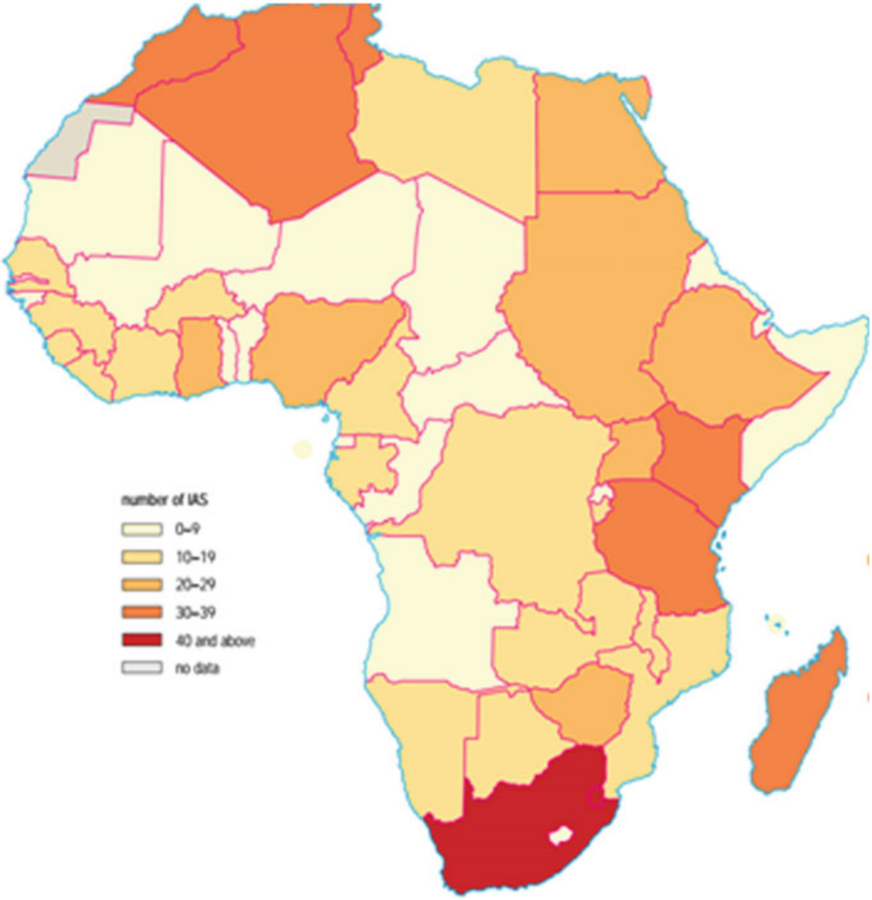

Fig. 17.2 The prevalence of invasive species Africa (IUCN/SSC/ISSG 2004)

first reported the weed remained confined to the northern extremities of the lake, probably because of the turbulence of the lake and the absence of extensive sheltered, shallow banks along other shores, where water hyacinth could anchor itself (Fig. 17.3). Maximum coverage of the mobile components of the weed in this lake is at least 3–4 times the area of stationary mats that cover about 20–30 ha. Surveys demonstrate that large mats of the water hyacinth were floating and moving into the lake especially near cattle grazed or disturbed areas.

However, no influx of the weed has been observed in the vicinity of river mouths, (possibly as a result of fragmentation by wave action). Thus, at present the weed is restricted in the lake shore and rice farm fringes; upstream rivers could be free from the invasive infestation.

Fig. 17.3 Water hyacinth (⊘) infested cites and potential distribution in Lake Tana (📍) free sites (Seid 2014, unpublished)

According to local informants, the stationary mats of the weed observed science 2010 were probably established around the Dirma river mouth, eliciting the local name "Afeshfasho" (Amharic) meaning delicate or weak, and later also named "Enboche" in 2014 with a similar meaning. In the newly invaded area, North-Eastern fringe, the weed has no name and local people perceive the weed as a gift of God "mena" (Amharic) because cattle can used to eat the leaves during times of grass (fodder) shortage. Other informants view the plant as a curse that destroys native grasses and invades rice farms.

17.3.3 Colonization Status in Lake Tana

Other plant species, including hippograss (*Vossia cuspidator*), papyrus (*Cyperus papyrus*) and morning glory (*Ipomea aquatica*), are now observed as the major associated plants promoted by the presence of hyacinths. However, the two popular tall sedges 'Dengle and Filla' (*C. papyrus* and *T. latifolia*) are often followed by hippo-grass or 'yeseytan ruze' (Amharic) (*Vossia cuspidator*) and water ferns (Lily and the like).

Currently in some of the infested places hippo-grass and water hyacinth are found side by side as the dominant weeds. As reported in other East African countries, the hippo-grass might be favored by the nutrients from dying water hyacinth and likely reduced with the removal of water hyacinth. The major associated animals were water fowl (*Alopochen aeguptiaca* L. (Egyptian Goose) and *Balearica Pavonina* L. (Black-crowned Crane) and abundant macroinvertebrates, such as leaches (Huridine species) and insects (Seid 2014) the biology of water hyacinth (*E. crassipes*: Invasive Gust of the Pristine Lake Tana, Ethiopia conference paper, unpublished).

Ecological succession can control stationary hyacinth mats along the shores and banks of rivers. In Lake Victoria, pure mats of water hyacinth are invaded initially by aquatic ferns/sedges (*Cyperus papyrus* and *Ipomea aquatica*) often followed by hippo-grass (*Vossia cuspidata*) which eventually dominates and shades out the remaining stressed and dying/rotting water hyacinth (Seid 2014).

17.4 Impacts of Invasive Alien Species

Invasive alien species may threaten native species as direct predators or competitors, as vectors of disease, or by modifying the habitat or altering native species dynamics (MA 2006). The threat posed to biodiversity by IAS is considered second only to that of habitat loss (CBD 2005). On small islands, it is now comparable with habitat loss as the lead cause of biodiversity loss (Baillie et al. 2004). Invasive species may out-compete native species, repressing or excluding them and therefore, fundamentally changing the ecosystem. They may indirectly transform the structure and species composition of the ecosystem by changing the way in which nutrients are cycled through the ecosystem (McNeeley et al. 2001). Entire ecosystems may be placed at risk through knock-on effects. Given the critical role biodiversity places in the maintenance of essential ecosystem functions, IAS may cause changes in environmental services, such as flood control and water supply, water assimilation, nutrient recycling, conservation and regeneration of soils (GISP 2004; Charles and Dukes 2007). Invasive may also affect native species by introducing pathogens or parasites that cause disease or kill native species. Among other things, both old and newly established IAS contribute to land degradation through soil erosion and the drawing down of water resources, reducing resources available to people and indigenous plants. Others produce leaf litter which poisons the soil, suppressing the growth of other plants, and in particular that of the under storey (UNEP 2004). They may alter the environment in directions that are more favourable for them but less favourable to native species. This could include altering geomorphic processes, biogeochemical cycling, hydrological cycles, or fire or light regimes (MA 2006; Levine et al. 2003).

Wattle trees and mesquite can sink their roots deeper into the soil than indigenous trees, sucking out massive volumes of water and out-competing indigenous plants for nourishment (Preston and Williams 2003). In some environments, invasive trees, like the black wattle, increase rainfall interception and transpiration, which cause a decrease in stream-flow (IUCN/SSC/ISSG 2004). The leaves and branches of the black wattle are believed to have allelopathic properties that are the chemical inhibition of growth and seed germination of other plants. Highly combustible, fire-tolerant alien plants may also alter the fire regime, and combined with competition for light, nutrients, water and space, this is believed to be an important factor in extinctions (Richardson and van Wilgen 2004). Marine IAS is a growing problem in Africa's coastal waters, estuaries and lagoons. Many of these introductions are related to sea vessels and aquaculture. *Hypnea musciformis* (hypnea) is red algae, originally from Trieste in Italy, and is now distributed throughout the world. It occurs in coastland, estuaries and marine habitats where it attaches to coral, stones or shells on sheltered tropical reef flats. Its success is related to its rapid growth rate, ability to epiphytize other algae and easy fragmentation. It is present in the coastal waters of several African countries including Ethiopia. Invasion pathways include aquaculture and dispersal by boats and other vessels (IUCN/SSC/ISSG 2004).

17.4.1 Positive Impacts (Utilization of Water Hyacinth)

Water hyacinth has some beneficial attributes and various bioremediation roles. It can be used in the production of paper, fiber boards, biogas, fertilizer, fish feed and in phytoremediation (the cleanup of polluted water bodies by aquatic plants like water hyacinth) (Khan and Sarwar 2002; Uka et al. 2007). Phytoremediation became popular when physical and chemical measures to remove aquatic pollutants were found to be more harmful than the pollutants themselves (Ndimele et al. 2010). Some of these pollutants are heavy metals and nutrients. Heavy metals are aquatic pollutant of major concern to ecologists because they are non-biodegradable that is, once they enter an aquatic ecosystem, they cannot be eliminated by ordinary biological processes.

There has been considerable research into the utilization of water hyacinth. Uses include in biogas production, animal fodder, as fertilizer, for mulch, the manufacture of paper and furniture, and water quality management (Mahamadi 2011). The main factor for arguing against successful utilization is that water hyacinth has up to 95% water content, which makes most utilization projects commercially not

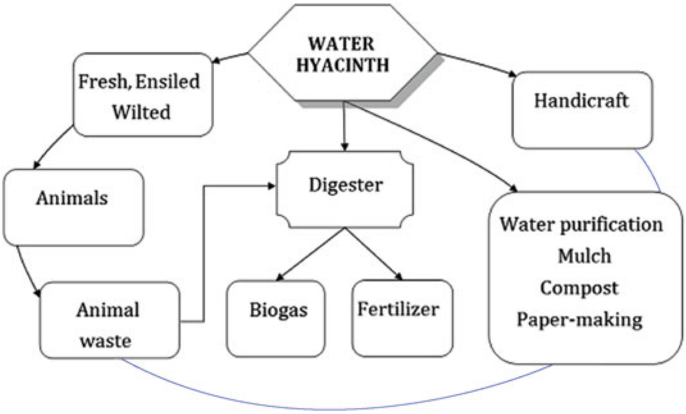

Fig. 17.4 Diagram showing water hyacinth utilization (*Source* Tham 2012)

viable on anything other than a cottage-industry level. Furthermore, no effective utilization program has been shown to control water hyacinth to acceptable levels except in Taiwan. Furthermore, at this moment creating reliance on using the weed as a resource could lead to its increased spread and to possible conflicts of interest between groups utilizing the plant and those wanting it controlled. However, an integrated scheme for water hyacinth control by utilization is also possible (Fig. 17.4).

17.4.2 Negative Impacts of Water Hyacinth

17.4.2.1 Impacts on Biodiversity

Coupled with this is its high rate of reproduction which has made it a serious threat to the continued use of the affected waters as a resource. This poses a great hindrance to the socio-economic potentials of these water bodies if appropriate and effective controls are not introduced. Dense mats of water hyacinth reduce light penetration into the water column, which negatively impacts submerged vegetation, reducing oxygen production in aquatic communities. The lack of phytoplankton production alters the composition of invertebrate communities.

The ‘mat’ of aquatic plants which covers aquatic ecosystem during severe infestation reduces dissolved oxygen by restricting the exchange of oxygen across the water interface. They also affect the chemistry of surface water which could render such water body unfit to support aquatic lives (Chukwuka and Uka 2007). Water hyacinth and other aquatic weeds also generate large amounts of organic matter because of their large biomass. When this macrophyte (water hyacinth) dies, sinks and decomposes, the water becomes more eutrophic due to the large release of nutrients. Water quality deteriorated, clean drinking water can be threatened and human health impacted. As the organic matter decomposes, biological oxygen demand increases due to the activities of decomposing bacteria. These bacteria use dissolved oxygen for their metabolic functions. The result is that the water quality deteriorates. This results in loss of aquatic biodiversity (Muli 1996).

Death of water hyacinth mats may influence changes in the composition, distribution and diversity of aquatic organisms as follows.

- Displacement of hydrophytes and depressed algal biomass (Twongo and Balirwa 1995).
- Increase in diversity and abundance of some macrofauna taxa, especially at the borders of the weed mats (Wanda 1997).
- Increase in the distribution and abundance of schistosome (bilharzias) snail vectors such as *Biomphalaria* spp. and *Bulinus* spp.
- Willoughby et al. (1993) reported that, based on studies on the Ugandan shoreline of Lake Victoria, mats significantly depressed the diversity of fish species and fish biomass. It was subsequently demonstrated that fish diversity, particularly small taxa, increased along the edge of water hyacinth mats (Twongo and Balirwa 1995).

17.4.2.2 Socioeconomic Impacts and Development Challenges

Many alien species, including some that are invasive, have had tremendous economic value for Africa. However, overall their impact on the sustainability of the resources, upon which livelihoods and development are often based, has been adverse, undercutting opportunities, human well-being and contributing to increased human vulnerability.

Invasive alien species are a serious impediment to the sustainable use of global, regional and local biodiversity (CBD 2005); this has implications for freshwater and marine resources, tourism, and forest and woodlands. Invasive alien species may affect livelihood and other economic opportunities in multiple ways. In addition to their impact on the supply of environmental goods, they also affect the integrity of ecosystems, undercutting essential environmental service. Thus IAS, through their impact on the environment, contributes indirectly to poverty, food insecurity, ill health and poor water quality (UNEP 2004; NEPAD 2003). They have multiple level and complex impacts on human wellbeing and the ability to achieve development targets, such as those set out in the Millennium Development Goals (MDGs).

The socio-economic effects of water hyacinth are dependent on the extent of invasion, the uses of the impacted water body, control methods and the response to control efforts (Villamagna and Murphy 2010). As much literature indicates, extensive mats of water hyacinth have a negative impact on aquatic ecosystems and cause problems for all aspects of water resource utilization. It has been found to drastically increase evapo-transpirational losses, as well as cause fish losses (Ndimele et al. 2011). These problems can be particularly severe in water-limited areas and small water bodies when water loss through evapotranspiration from the water hyacinth is 3.7 times that from open water (Timmer and Weldon 1967). 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).

In Ethiopia the weed poses serious problem on reservoirs, drainage structures, and water suppliers. For example since the 1996 flood, Wonji Sugar Factory incurs an additional cost for removing the weed from irrigation and drainage water structures. According to the information obtained from agricultural operation of the factory, the cost incurred to manage this weed increases from year to year. The factory spent more than 130,197 Ethiopia Birr (14,897 USD) over six years due to the water hyacinth (Yirefu et al. 2007).

Just after a year of invasion, the water hyacinth rapidly invades water ways and causes problems to activities dependent of the Lake Tana shore and flood plain complex, which includes the Dembia rice fields. It impedes water transportation preventing people from accessing their sources of livelihood. It also hinders access to fishing grounds especially during the rainy season which, unfortunately, is the period when fishing activities are highest and more profitable.

The socioeconomic impacts of water hyacinth include reduction in the quality and quantity of drinking water caused by bad odors, color, taste, and turbidity; increased incidence of waterborne, water-based, and water-related disease (e.g., malaria, encephalitis, and filariasis); increase in siltation and sedimentation of rivers, lakes, and impoundments; reduction of useful water surface area for fishing, recreation, and water transport; clogging of irrigation canals and pumps; drowning of livestock; interruption of hydroelectric power generation; and enhanced flood damage to road and rail bridges and impoundment walls. Finally, the most direct impact of dense mats of water hyacinth is on boating access, navigability, water supply systems, and drainage canals and on recreation (Villamagna and Murphy 2010).

17.5 Control of Water Hyacinth Invasion

Traditionally the control of water hyacinth has fallen into one of three broad categories: physical control (manual and mechanical removal), herbicidal control, and biological control. More recently, the emphasis has moved to an integration of these three methods.

17.5.1 Physical/Mechanical Control

Manual removal through hand-pulling or through the use of other handheld tools such as pitchforks is employed in a number of developing countries such as Guyana, South Africa, and China. This method is very labor-intensive (Mara 1976), is effective only for small infestations, and essentially is used as employment creation exercises.

Mechanical control using custom-designed machinery has been implemented, for example, on Lake Victoria, with limited success (Villamagna and Murphy 2010). However, the amount of biomass that has to be removed and the growth rate of water hyacinth render this method ineffective, except for very small infestations or to keep specific areas such as the waters around hydro intakes free of the weed. Furthermore, the remoteness of many infestations makes mechanical control impractical. Booms and cables have also been used to prevent water hyacinth from entering water abstraction pumps and hydropower coolant intakes (Wittenberg and Cock 2001). Cables have also been used to concentrate weed infestations behind them, making physical removal and herbicide applications more efficient.

17.5.2 Herbicide/Chemical Application

Herbicide control has been successfully used against infestations of water hyacinth since the early invasion history. Although this control method is relatively expensive, it has the advantage of being quick and temporarily effective. Glyphosate and 2,4-D [(2,4-dichlorophenoxy) acetic acid] have been the most widely used herbicides and considered as effective and relatively safe herbicides (Chen et al. 1989). *E. crassipes* is also susceptible to 2,4-D, Diquat, Paraquat, and Glyphosate herbicides, which have resulted in successful control in small (<1 ha), single-purpose water systems such as irrigation canals and impoundments (Center et al. 2002).

Despite such effectiveness of herbicides, the major disadvantages are that they are non-selective and could cause major environmental problems if incorrectly applied (Wittenberg and Cock 2001). Chemical control needs to be carried out repeatedly as re-infestation of water hyacinth occurs from seeds or clonal multiplication of surviving plants (Chen et al. 1989; Charudattan 1986). Herbicide control provides only short-term results and requires regular follow-up applications. Moreover, it is dangerous for pristine ecosystems like Lake Tana.

17.5.3 Biological Control

Mechanical and chemical controls are viewed as short-term or immediate control options; biological control is perceived as the long-term or sustainable control option for this weed. When chemical control is economically unfeasible or harmful to the environment, biological control is recognized as a cost effective, permanent and environmentally friendly control method (Charudattan 1986). In some areas, they have provided considerable control, but this is not consistent in all areas. The principal drawback with biological control of water hyacinth is the time required to achieve control. In tropical environments, this is usually 2–4 years and is influenced by the extent of the infestation, climate, water nutrient status, and other control options (Wittenberg and Cock 2001).

The first agent for water hyacinth was the weevil, *Neochetina eichhorniae* Warner (Coleoptera: Curculionidae), which was released in Florida in 1972. The most widely used agents are the weevils, *N. eichhorniae* and *N. bruchi* Hustache, and the moth, *Sameodes albiguttalis* (Warren) (Lepidoptera: Pyralidae) (Wittenberg and Cock 2001). Other agents, released as classical biological control agents, are the moth, *Xubida infusella* (Walker) (Lepidoptera: Pyralidae), the water hyacinth bug, *Eccritotarsus catarinensis* (Carvalho) (Hemiptera: Miridae), the galumnid mite, *Orthogalumna terebrantis* Wallwork, and the fungal pathogen, *Cercospora piaropi* Tharp. Most recently, the leafhopper, *Megamelus scutellaris* Berg (Hemiptera: Delphacidae), has been released in the United States. Several other insects could be screened for release in regions of the world, where the other agents have not achieved the acceptable level of control or where the time taken to achieve control (1.5–3 years in the tropics) is perceived to be too long, ultimately affecting fish and other higher-order vertebrate populations (Mara 1976).

17.5.4 Popular Awareness

Public awareness and understanding may also be lacking. Members of the public, made aware of the issue and engaged in the preventive effort, can make an enormous difference. Well-informed travellers are the front-line in any campaign to prevent the dispersal and spread of invasive alien species. A well-informed public is more likely, moreover, to appreciate the need for preventive checks and other regulations, which otherwise might come across as just an inconvenient nuisance. Access to information then, in the form of posters or notices displayed at entry points, or published alerts in travel magazines and other media, is another important aspect of effective exclusion strategy. Inculcation of awareness at all levels of society social, economic and political is of course an essential first step towards mounting a successful campaign to prevent the influx and spread of invasive alien species.

Yet, alien invasions are often the result of entrenched human values, habits and patterns of behaviour. So awareness alone may not be enough to bring about the behavioural changes that are required for such campaigns to be effective. We know, from humanity's response to the impacts of global climate change, how difficult it can be, even against a backdrop of almost universal awareness (of the need to reduce anthropogenic greenhouse gas emissions, say), to usher in behavioural adaptations that might help to mitigate these impacts. Awareness regarding the invasive species' threat is, in the continuing absence of a global treaty (such as that of the Intergovernmental Panel on Climate Change), still far from universal. Yet, even in nations where awareness campaigns have succeeded in raising the profile of the invasive threat through the dissemination of information and educational materials, follow-up actions have not necessarily resulted. The aim of a social marketing campaign is to build motivations and partnerships through which awareness of a pressing social need might be translated into concrete actions which address that need.

17.5.5 Risk Assessment

Another important aspect of control is determining the level of invasive risk associated with the introduction of any species which may be new to a country. For this, a sound regulatory framework is needed, representing and ruling on the wider interests environmental and social, national and regional of alien species' introductions that are proposed by agri-business or by commerce. Under such a framework, the introduction of species deemed to pose an unacceptable invasive threat to ecosystems and societies as a whole can be prohibited under international trade law, irrespective of how useful, or profitable, the species in question might be to a minority of would be importers or investors. A risk assessment is the standard procedure for determining whether or not the proposed introduction of an alien species can be authorised. Invasiveness cannot always be reliably predicted, however. Species that show no invasive tendencies in one region may prove invasive in another, and vice versa. It may also take many years for the invasiveness of an introduced species to become apparent.

The most reliable indicator for invasiveness is to know whether or not a species has become invasive elsewhere in its introduced range, particularly in ecosystems that are comparable and which boast similar climatic and geographic conditions. Certain attributes among plants may create grounds for suspicion. Such attributes typically summarized by Rejmánek and Pitcairn (2002) as:

- Fitness homeostasis or the ability of an individual or population to maintain relatively constant fitness over a range of environments. This is equivalent to Baker (1974, 1995) "general-purpose genotype."
- Small genome size-usually associated with short minimum generation time, short juvenile period, small seed size, high leaf area ratio, and high relative growth rate. Dispersed easily by humans and animals.
- Ability to vegetative propagate. This is an especially important characteristic in aquatic environments (Auld el al. 1983) and at high latitude (Pyšek 1997).
- Alien plants belonging to exotic genera are more invasive than are alien species with native congeners. This may be partly because of an absence or limited

number of resident natural enemies for that species (Darwin 1859; Rejmánek 1999).

- Plant species without dependence on specific mutualisms (root symbiosis, pollinators, seed dispersers, etc.) (Baker 1974; Richardson et al. 2000).
- Tall plants tend to invade mesic plant communities. Persistent seed banks-seeds with different inherent dormancies that provide a random appearance through time and guarantee their survival and persistence.

Thus, plants with production of abundant seeds, capable of utilising highly effective agencies of dispersal Species whose foliage, outside their home environments, is poisonous to animals, or which are allelopathic (meaning they release chemical toxins into the soil that inhibit growth among plants of other species, or prevent the seeds of other plants from germinating), are usually also a high risk.

Plants belonging to certain taxonomic families, such as the Fabaceae (legumes) and the Asteraceae (Composites), which are disproportionately well represented globally among invasive species, are best treated with particular caution. A decision authorising introduction of a useful alien species that may also become invasive should not be taken carelessly, for as such decision, once taken may not reversible. If an invasive species introduced, then future generations as a whole will bear the impacts. Such costs will be very substantial as globally known well from the heavy price we are already paying for invasions control that resulted from ill-informed deliberate and accidental alien species introductions.

17.6 Research Gaps

Observed regional differences in water hyacinth biology exist and more research needs to be done to investigate the reasons for those differences. However, regardless of the slight regional differences the explosive growth rate of water hyacinth makes it a viable candidate for further research and development of water hyacinth benefit and control researches. Thus, the plant biology that relate to the growth, reproduction, ecological interactions, impacts on biodiversity, fishery, management approaches and other issues of water hyacinth are basic research priorities. For future research it would be beneficial to study the placement of water hyacinth in dryer areas for land preservation and waste water abatement.

It is speculated that the biomass can be used for crafting, 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. 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 no example from anywhere in the world where utilization alone has contributed to the management of any invasive plant (EEA 2012). 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.

Bioenergy production through the growth and managed harvesting of water hyacinth can benefit the region along with other coastal regions and give added ecological benefits which offset the higher economic costs of biofuel production while also saving invasive plant species abatement program. For future work it would be beneficial to analyze the wave energy absorption ability of water hyacinth. In future research it would be beneficial to explore several engineering methods of producing bioenergy from water hyacinth.

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.

17.7 Conclusion

Water hyacinth is the most invasive and damaging aquatic plant despite the fact that there are a number of effective ways to control it. Even though good progress has been made in controlling around the world, it still poses a threat to aquatic ecosystems and to human activities. The long-term control of this plant will require an integrated management approach utilizing all appropriate control methods, but with special emphasis on the need to reduce the inflow of nitrate and phosphate pollutants into aquatic environments.

17.8 Recommendations

Water hyacinth infestation in Lake Tana can be a symptom of broader watershed management and pollution problems. It calls for a concise national and transboundary invasive species policy designating noxious weed to aquatic and terrestrial systems. 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 needed.

A multidisciplinary approach should be designed, which includes the highest levels political and administrative to 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 and to mobilize 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 first popular mechanical control champagne to control the hyacinth around Lake Tana.

Methods for water hyacinth control should include reduction of nutrient load in the lake through leaching of fertilizer from highlands, waste waters flowing from sewage works, urban wastes and factories. Changing land use practices in the catchment 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.

References

Auld BA, Hosking J, McFadyen RE (1983) Analysis of the spread of tiger pear and parthenium weed in Australia. Aust Weeds 2:56–60

Baillie JEM, Hilton-Taylor C, Stuart SN (2004) IUCN red list of threatened species. A Global Species Assessment. IUCN—the World Conservation Union, Gland

Baker HG (1974) The evolution of weeds. Annu Rev Ecol Syst 5:1–24

Baker HG (1995) Aspects of the genecology of weeds. In: Kruckeberg AR, Walker RB, Leviton AE (eds) Genecology and ecogeographic races. Pacific Division, American Association for the Advancement of Science, San Francisco, pp 189–224

Borokoni T, Babalola F (2012) Management of invasive plant species in Nigeria through economic exploitation: lessons from other countries. Manag Biol Invasions 3(1):45–55. doi:10.3391/mbi.2012.3.1.05

CBD (2005). Invasive Alien Species. Convention on biological diversity. http://www.biodiv.org/programmes/cross-cutting/alien/. Accessed on 6 Jan 2014

Center TD, Hill MP et al (2002) Water hyacinth. In: van Driesche R, Blossey B et al (eds) Biological control of invasive plants in the Eastern United States. Forest Health and Technology Enterprises Team, West Virginia. http://www.fs.fed.us/foresthealth/technology/pdfs/BiocontrolsOfInvasivePlants02_04.pdf. Accessed 4 June 2015

Charles H, Dukes JS (2007) Impacts of invasive species on ecosystem services. In: Nentwig W (ed) Ecological studies. Biological invasions, vol 193. Springer, Berlin. http://globalecology.stanford.edu/DGE/Dukes/Charles_Dukes_inpress.pdf. Accessed on 6 Feb 2015

Charudattan R (1986) Integrated control of water hyacinth (*Eichhornia crassipes*) with a pathogen, insects, and herbicides. Weed Sci 34:26–30

Chen YL, Chiang HC, Wu LQ et al (1989) Residues of glyphosate in an aquatic environment after control of water hyacinth (*Eichhornia crassipes*). J Weed Sci Technol 34(2):117–122

Chukwuka KS, Uka UN (2007) Effect of Water Hyacinth (*Eichhornia crassipes*) Infestation on Zooplankton Populations in Awba Reservoir, Ibadan South-West Nigeria. J Biol Sci. doi:10.3923/jbs.2007.865.869

Dagno K, Lahlali R, Diourte M et al (2012) Fungi occurring on water hyacinth (*Eichhornia crassipes* (Martius) Solms-Laubach) in Niger River in Mali and their evaluation as Mycoherbicides. J Aquat Plant Manag 50:25–32

Darwin C (1859) The origin of species by means of natural selection. Murray, London
EEA (2012) The impacts of invasive alien species in Europe. EEA technical reports no 16/2012. Publications Office of the European Union, Brussels, Luxembourg. http://www.eea.europa.eu/publications/impacts-of-invasive-alien-species. Accessed 12 Sep 2014
EPA (Environmental Protection Authority) (1997) Environmental Policy of the Federal Democratic Republic of Ethiopia. EPA, Addis Ababa
Fessehaie R (2005) Water hyacinth (Eichhornia crassipes): a review of its weed status in Ethiopia. In: Rezene Fessehaie (ed) Arem, vol 6, pp 105–111
Fontenille D, Tato JC (2001) 'Aedes (Stegomyia) albopictus (Skuse), a Potential new dengue vector in southern Cameroon. Emerg Infect Dis 6(7):1066–1067
Forpah N (2009) Cameroon prepares a national strategy for the control of water hyacinth (exotic species). In: Proceedings on the elaboration of a national strategy for the control of water hyacinth in Cameroon, 15–18 Sept 2009, Douala. http://www.unep.org/pdf/UNEP_GEAS_APRIL_2013.pdf. Accessed 12 June 2014
Gichuki J, Omondi R, Boera P et al (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 J Vol 2012. doi:10.1100/2012/106429
GISP (2004) Africa invaded: the growing danger of invasive alien species. Global invasive Species Programme, Cape Town. http://www.gisp.org/downloadpubs/gisp%20africa%202.pdf. Accessed on 6 Feb 2015
Gopal B (1987) Water hyacinth. Elsevier, Amsterdam
Hedberg I, Kelbessa E, Edwards S et al (eds) (2006) Flora of Ethiopia and Eritrea, vol 5. Addis Ababa, The National Herbarium, Addis Ababa University
Hill M, Coetzee J (2013) Water hyacinth. In: Borgemeister C, Langewald J (eds) Biological control in IPM systems in Africa. Wallingford
Holm LG, Plucknett DL, Pancho JV et al (1991) The world's worst weeds, distribution and biology. Krieger Publishing Co., Malabar, Florida
IUCN/SSC/ISSG (2004) Global invasive species database. IUCN—the World Conservation Union Species Survival Commission, Invasive Species Specialist Group. http://www.issg.org. Accessed on 6 Feb 2014
Khan S, Sarwar KS (2002) Effect of water-hyacinth compost on physical, Physicochemical properties of soil and on rice yield. J Agron 1:64–65
Kirby A (2003) Alien species cost Africa billions. BBC News Science. http://news.bbc.co.uk/2/hi/science/nature/2730693.stm
Levine JM, Vila M, D'Antonio CM et al (2003) Mechanisms underlying the impacts of exotic plant invasions. Proc R Soc Lond B Biol 270:775–781
MA (2006) Ecosystems and human well-being: current state and trends, vol 1. Millennium Ecosystem Assessment. Island Press, Washington. http://www.millenniumassessment.org//en/products. Accessed on 6 Feb 2015
Mahamadi C (2011) Water hyacinth as a biosorbent. Afr J Environ Sci Technol 5(5):1137–1145
Mara MJ (1976) Estimated costs of mechanical control of water hyacinths. J Environ Econ Manag 2(4):273–294
McNeeley JA, Mooney HA, Neville LE et al (2001) Global strategy on invasive Alien Species. IUCN—the World Conservation Union, Gland
Mujingni C (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. Thesis, World Maritime University
Muli JR (1996) Environmental problems in Lake Victoria (East Africa): What the international community can do. Lakes Reservoirs: Res Manag 2:47–53
Ndimele P, Kumolu-Johnson C, Anetekhai M (2011) The invasive aquatic macrophyte, water hyacinth (Eichhornia crassipes (Mart.) Solm-Laubach: Pontedericeae): problems and prospects. Res J Environ Sci 5:509–520

Ndimele PE, Jenyo-Oni A, Ayodele AI et al (2010) The phytoremedation of crude oil-polluted aquatic environment by water hyacinth (*Eichhornia crassipes* (Mart.) Solms) Afr J Livest Extension 8:48–52
NEPAD (2003) Action plan for the environment initiative. New Partnership for Africa's Development, Midrand. http://nepad.org/2005/files/reports/action_plan/action_plan_english2.pdf. Accessed 6 June 2015
Patel S (2012) Threats, management and envisaged utilizations of aquatic weed *Eichhornia crassipes*: an overview. Rev Environ Sci Biotechnol 11:249–259. doi:10.1007/s11157-012-9289-4
Preston G, Williams L (2003) Case study: the working for water programme: threats and successes. Serv Deliv Rev 2(2):66–69. http://www.dpsa.gov.za/documents/service_delivery_review/vol2no2. Accessed on 6 Feb 2015
Pyšek P (1997) Clonality and plant invasions: can a trait make a difference? In: de Kroon H, van Groenendael J (eds) The ecology and evolution of clonal plants. Backhuys, Leiden, pp 405–427
Rands M, Adams W, Bennun L et al (2010) Biodiversity conservation: challenges beyond 2010. Science 329:1298–1303
Rejmánek M (1999) Invasive plant species and invasible ecosystems. In: Sandlund OT, Schei PJ, Vilken A (eds) Invasive species and biodiversity management. Kluwer, Dordrecht, pp 79–102
Rejmánek M, Pitcairn MI (2002) When is eradication of exotic pest plants a realistic goal? In: Veitch CR, Clout MN (eds) Turning the tide: the eradication of invasive species. IUCN/SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland, and Cambridge, pp 249–253
Richardson DM, Allsopp N, D'Antonio C et al (2000) Plant invasions—the role of mutualisms. Biol Rev 75:65–93
Richardson DM, van Wilgen BW (2004). Invasive alien plants in South Africa: how well do we understand the ecological impacts? S Afr J Sci 100:45–52. http://www.dwaf.gov.za/wfw/Docs/Papers/SAJSFeb2004richardson.pdf. Accessed on 6 Feb 2015
Seid A (2014) A review on the biology and control of water hyacinth (Eichhornia crassipes): invasive Gust of the Pristine Lake Tana, Ethiopia. Proceedings of the Second Annual Science Conferance, ASC 2014, pp 161–180
Shanab S, Shalaby E, Lightfoot D et al (2010) Allelopathic effects of water hyacinth (*Eichhornia crassipes*). PLoS ONE 5(10):e13200. doi:10.1371/journal.pone.0013200
Téllez T, López E, Granado G et al (2008) The water hyacinth, *Eichhornia crassipes*: an invasive plant in the Guadiana River Basin (Spain). Aquat Invasions 3:42–53
Tham HT (2012) Water hyacinth (*Eichhornia crassipes*)—biomass production, ensilability and feeding value to growing cattle. Doctoral thesis, Faculty of Veterinary Medicine and Animal Science, Department of Animal Nutrition and Management, Uppsala, Sweden
Timmer CE, Weldon LW (1967) Evapotranspiration and pollution of water by water hyacinth. Hyacinth Control J l6:34–37
Twongo T, Balirwa J (1995) The water hyacinth problem and the biological control option in the highland region of the Upper Nile Basin: Uganda's experience. Paper presented at the 2002 Nile conference, "Comprehensive Water Resources Development of the Nile Basin," Arusha, Tanzania, 13–17 Feb 1995
Uka UN, Chukwuka KS, Daddy F (2007) Water hyacinth infestation and management in Nigeria inland waters: a review. J Plant Sci 2:480–488
UNEP (2004) Invasive aliens threaten biodiversity and increase vulnerability in Africa. Call to Action 1(1). United Nations Environment Programme, Nairobi
UNEP (2006) Africa Environment Outlook 2. Division of Early Warning and Assessment, United Nations Environment Programme, Nairobi
USBC (2008) Statistical Abstract of the United States 2008. U.S. Census Bureau, U.S. Government Printing Office, Washington, DC
Vila M, Espinar J, Hejda M et al (2011) Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecol Lett 14:702–708

Villamagna A, Murphy B (2010) Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes*): a review. Freshw Biol 55:282–298. doi:10.1111/j.1365-2427.2009.02294.x

Wanda FM (1997) The impact of water hyacinth *Eichhornia crassipes* (Mart.) Solms (Pontederiaceae) on the abundance and diversity of aquatic macroinvertebrates in northern Lake Victoria, Uganda. Thesis, International Institute of Infrastructural, Hydraulic and Environmental Engineering

Willoughby NG, Watson IG, Lauer S et al (1993) An investigation into the effects of water hyacinth on the biodiversity and abundance of fish and invertebrates in Lake Victoria, Uganda. NRI Project Number 10066 A0328. Accessed 23 Aug 2013

Wittenberg R, Cock MJW (2001) Invasive Alien species: a toolkit of best prevention and management practices. CAB International, Wallingford, Oxon, UK

Xu H, Qiang S, Genovesi P et al (2012) An inventory of invasive alien species in China. NeoBiota 15:1–26. doi:10.3897/neobiota.15.3575

Yirefu F, Tafesse A, Gebeyehu T et al (2007) Distribution, impact and management of water hyacinth at Wonji-Shewa Sugar Factory. Eth J Weed Manag 1(1):41–52

Zhang Y, Zhang D, Barrett S (2010) Genetic uniformity characterizes the invasive spread of water hyacinth (Eichhornia crassipes), a clonal aquatic plant. Molec Ecol 19:1774–1786