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Ecological and socio-economic utilization of water hyacinth (*Eichhornia crassipes* Mart Solms)

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ABSTRACT: Around the world, there is an increasing trend in areas of land, surface waters and groundwater affected by contamination from industrial, military and agricultural activities due to either ignorance, lack of vision, or carelessness. In the last three decades a special interest in the world is aroused by the potential of using the biological methods in the waste water treatment. Water hyacinth (*Eichhornia crassipes*) constitutes an important part of an aquatic ecosystem. Water hyacinth as a very promising plant with tremendous application in wastewater treatment is already proved. Water hyacinth is used to treat waste water from dairies, tanneries, sugar factories, pulp and paper industries, palm oil mills, distilleries, etc. All the efforts of scientists and technocrats all over the world to eliminate these weeds by chemical and biological means have met with little success. The water hyacinth have been found to have potential for use as phytoremediation, paper, organic fertilizer, biogas production, human food, fiber, animal fodder. @ JASEM

The fast technological and industrial development, and tumultuous demographic growth and rapid urbanization, especially in the last two decades, are confronting the mankind with four large problems: water, food, energy and environment. The water problem is particularly pronounced, because it is implicitly present in other three problems, that is in the food and energy production which depend primarily on the water and the key environmental problems are water quality protection and water damage control.

In the last three decades a special interest in the world is aroused by the potential of using the biological methods in the waste water treatment, whose application as of natural and not artificial procedures of tertiary processing of effluents provides the effluents of required quality in a economically acceptable way in the technically simple structures. The capacity of water hyacinth (*Eichhornia crassipes* (Martius) Solms-Laubach) as a very promising plant with tremendous application in wastewater treatment is already proved (Jafari and Trivedy, 2005; Trivedy, 2001).

Water hyacinth (*Eichhornia crassipes)* is a free floating (but sometimes rooted) freshwater plant of the family *Pontederiaceae* that has proven to be a significant economic and ecological burden to many sub-tropical and tropical regions of the world. Water hyacinth is listed as one of the most productive plants on earth and Water hyacinth shows logisitic growth as does another floating aquatic weeds. Water hyacinth has invaded freshwater systems in over 50 countries on five continents; it is especially pervasive throughout Southeast Asia, the southeastern United States, central and western Africa, and Central America (Bartodziej and Weymouth, 1995; Brendonck *et al*., 2003; Lu *et al*., 2007; Martinez Jimenez and Gomez Balandra, 2007).

Geographic distribution: This tropical plant spread throughout the world in late 19^{th} and early 20^{th} century (Wilson *et al.,* 2005). It is widely reported that water hyacinth is indigenous to Brazil having first been described from wild plants collected from Francisco river in 1824. In Africa it was first reported in Egypt between 1879; in Asia around 1888 and about 1900 in Japan; in Australia it arrived in about 1890 (Cook, 1990). Water hyacinth originated in tropical South America, but has become naturalized in many warm areas of the world: Central America, North America (California and southern states), Africa, India, Asia, Australia, and New Zealand. Water hyacinth (*Eichhornia crassipes*) is the most predominant, persistent and troublesome aquatic weed in India. It was first introduced as an ornamental plant in India in 1896 from Brazil (Rao, 1988). In india, water hyacinth has stretched over 2,00,000 ha of water surface un the country (Murugesan *et al*., 2005) and its exuberance has been highly notived throughout the course of the river Thamirabarani, a prerennial river in south India (Murugesan *et al*., 2002; Murugesan, 2001). Because of its beautiful blooms and foliage, water hyacinth has been carried by tourists, plant collectors and botanists to over 80 countries around the world in the last 100 years.

Chemistry of Water Hyacinth: Fresh plant contains 95.5% moisture, 0.04% N, 1.0% ash, 0.06% P_2O_5, 0.20% K_2O, 3.5% organic matter. On a zero-moisture basis, it is 75.8% organic matter, 1.5% N, and 24.2% ash. The ash contains 28.7% K_2O, 1.8% Na_2O, 12.8% CaO, 21.0% Cl, and 7.0% P_2O_5. The CP contains, per 100 g, 0.72 g methionine, 4.72 g phenylalanine, 4.32 g threonine, 5.34 g lysine, 4.32 g isoleucine, 0.27 g valine, and 7.2 g leucine (Matai and Bagchi, 1980). Water hyacinth roots naturally absorb pollutants, including such toxic chemicals as lead, mercury, and strontium 90 (as well as some organic compounds

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believed to be carcinogenic) in concentrations 10,000 times that in the surrounding water.

Water Hyacinth Habitats and Characteristics: Water hyacinths grow over a wide variety of wetland types from lakes, streams, ponds, waterways, ditches, and backwater areas. The treatment of textile wastewater with water hyacinth has some effects on the growth of the plant, the small size of which may be due to nutrient imbalance mainly of nitrogen in water (Thomas, 1983). The plant height may vary from a few inches to 3 ft (0.9 m). The leaves, growing in rosettes, are glossy green and may be up to 8 in (20 cm) long and 6 in (15 cm) wide. The showy, attractive flowers may be blue, violet, or white and grow in spikes of several flowers. The leaf blades are inflated with air sacs, which enable the plants to float in water. The seeds are very longlived.

High levels of salinity in wastewater can limit the growth of water hyacinth and other aquatic macrophytes (Sooknah and Wilkie, 2004). The plant has very prominent black, stringy roots, and when it occasionally becomes stranded in mud, it may appear rooted. Its growth rate is among the highest of any plant known, and populations can double in as little as 12 days (Aquatic Ecosystem Restoration Foundation, 2005). Habitats for the water hyacinth have ranged from shallow temporary ponds, marshes and sluggish flowing waters to large lakes, rivers and reservoirs. A broad spectrum of physico-chemical environments characterizes these habitats. In temporary water bodies, the plants often have to survive on moist mud for prolonged periods, or perennate in the form of seeds Gopal (1987). The nutrient bases provided by the various habitats differ widely. They range from clean waters that are poor in major nutrients such as rivers and reservoirs to highly polluted waters with large amounts of nutrients and organic matter, as is the case in sewage lagoons. In addition such waters may receive a variety of organic and inorganic industrial effluents containing heavy metals. The water hyacinth plants can stand both highly acidic and highly alkalinic conditions, but more vibrant growth is supported by neutral water bodies (Gopal, 1987). Wilson *et al.,* (2001) assumed a logistic growth model in their analysis of water hyacinth population dynamics in temperate and tropical zones. Their results revealed that growth rates in temperate regions vary with seasons. In tropical zones the intrinsic rate of growth for the weed was estimated to be in the range 0.04 to 0.08 per day. In waters with high nutrient contents, the plants have shorter roots, which are extensive laterally, longer shoots and relatively bigger leaves. In nutrient poor waters, the plants have longer roots, set deeper in search for food, relatively shorter shoots and smaller leaves. High multiplicative rates may seem to suggest that such an unhealthy competition will impose negative externalities for the community members and retard growth.

Ecological Factors: Water hyacinth is heliophyte plant growing best in warm waters rich in macronutrients (Center *et al.*, 2002). Optimal water pH for growth of this aquatic plant is neutral but it can tolerate pH values from 4 to 10 (Center *et al.*, 2002). This is very important fact because it points that *Eichhornia crassipes* can be used for treatment of different types of wastewater. Optimal water temperature for growth is 28-30 ^{o}C (Center *et al.*, 2002). Temperatures above 33^{o}C inhibit further growth (Center *et al.*, 2002). Optimal air temperature is 21-30 ^{o}C (U.S. EPA, 1988). If lasting for 12 hours temperature of -3 ^{o}C will destroy all leaves and temperature of -5 ^{o}C during the period of 48 hours will destroy whole plant (U.S. EPA, 1988). Work of other authors also presents similar data about water hyacinth sensibility to low temperatures. *Eichhornia crassipes* can survive 24 hours at temperatures between 0.5 and -5 ^{o}C, but it will die at - 6 to -7 ^{o}C and can not be grown in open where average winter temperature drops under 1 ^{o}C (Stephenson *et al.*, 1980). So if aquatic systems with water hyacinth are constructed in colder climates it would be necessary to build greenhouses for maintaining optimal temperature for plant growth and development (Reed and Bastian, 1980). Low air humidity from 15% to 40% can also be limiting factor for undisturbed growth of water hyacinth (Allen, 1997). *Eichhornia crassipes* tolerates drought well because it can survive in moist sediments up to several months (Center *et al.*, 2002). Salinity is the main obstacle for growth of water hyacinth in costal areas (Olivares and Colonnello, 2000). De Casabianca and Laugier (1995) have studied the production of this aquatic macrophyte in relation to different effluent salinity value. They were also tracking plant reactions to high levels of salinity by observing symptoms of a different intensity (De Casabianca and Laugier, 1995). They have concluded that production of water hyacinth was reducing and necroses on leaves and bulbous petioles were occurring earlier with increase of salinity.

Possible Applications of Water Hyacinth: Through water hyacinth's engulfing presence, large amounts of sunlight are blocked, thorough oxygen exchange is prevented and dissolved oxygen levels drop, the food web is altered, habitat for water fowl and other organisms is either destroyed or changed, and the biological diversity of the invaded area is greatly reduced (Denny *et al.*, 2001, Brendonck, 2003). Water hyacinth can be a problem economically as it negatively affects fisheries, slows or even prevents water traffic, impedes irrigation, reduces the water supply, obstructs water ways, and slows hydropower generation (Denny *et al.*, 2001, Brendonck, 2003). The positive aspects of the weed thus seem to outweigh its negative attributes.

Prior research on water hyacinth's effects on water quality has focused mainly on the consequences of the dense mats formed by the interlocking of individual plants. The most commonly documented effects are lower phytoplankton productivity and dissolved oxygen concentrations beneath mats (Rommens *et al.*, 2003; Mangas-Ramirez and Elias-Gutierrez, 2004; Perna and Burrows, 2005). Water hyacinth also has been found to stabilize pH levels and temperature in experimental lagoons, thereby preventing stratification and increasing mixing within the water column (Giraldo and Garzon, 2002). Photosynthesis is limited beneath water hyacinth mats, and the plant itself does not release oxygen into the water as do phytoplankton and submerged vegetation (Meerhoff *et al.*, 2003), resulting in decreased dissolved oxygen concentration. The extent of dissolved oxygen reduction is dependent on the capacity of the water hyacinth mat to prevent light infiltration into the water column.

Water hyacinth is just beginning to be used for phytoremediation. This use came about for a few reasons, the first being that water hyacinth is so plentiful. People have been trying to remove the plant from many water ways, spending billions of dollars in doing so. In many cases this removal is nigh unto impossible. It has been discovered that water hyacinth's quest for nutrients can be turned in a more useful direction. Water hyacinth is already being used to clean up waster water in small scale sewage treatment plants. Phytoremediation used for removing heavy metals and other pollutants is a newly developed environmental protection technique. Extensive studies on freshwater resources decontamination revealed that some freshwater plants, among which is the water hyacinth growing prolific in wastewater, can efficiently accumulate heavy metals (Yahya, 1990; Vesk *et al.*, 1999; Ali and Soltan, 1999; Soltan and Rashed, 2003; Tiwari *et al.*, 2007). Water hyacinth also absorbs organic contaminants (Zimmels *et al.*, 2007), and nutrients from the water column (Aoi and Hayashi, 1996). 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 if disposed of properly (Greenfield *et al.*, 2007). On a similar note, water hyacinth's capacity to absorb nutrients makes it a potential biological alternative to secondary and tertiary treatment for wastewater (Ho, 1994; Cossu *et al.*, 2001).Water hyacinth has long been used commercially for cleaning wastewater. The luxuriant plant's tremendous capacity for absorbing nutrients and other pollutants from wastewater has long been overlooked by many wastewater engineers. Water hyacinth is also known for its ability to grow in severe polluted waters (So *et al.*, 2003). *Eichhornia crassipes* is well studied as an aquatic plant that can improve effluent quality from oxidation ponds and as a main component of one integrated advanced system for treatment of municipal, agricultural and industrial wastewaters (U.S. EPA, 1988; Sim, 2003; Wilson *et al.*, 2005; Mangabeira *et al.*, 2004; De Casabianca and Laugier, 1995; Maine *et al.*, 2001). To regret water hyacinth is often described in literature as serious invasive weed (Wilson *et al.*, 2005; U.S. EPA, 1988; Maine *et al.*, 1999; So *et al.*, 2003; Singhal and Rai, 2003). In last few years a great interest has been shown for research of aquatic macrophytes as good candidates for pollutant removal or even as bioindicators for heavy metals in aquatic ecosystems (Aoi and Hayashi, 1996; Maine *et al.*, 1999). Water hyacinth just one of the great number of aquatic plant species successfully used for wastewater treatment in decades, was of particular importance. It is important to emphasize that *Eichhornia crassipes* has a huge potential for removal of the vast range of pollutants from wastewater (De Casabianca and Laugier, 1995; Maine *et al.*, 2001; Mangabeira *et al.*, 2004; Sim, 2003) and that a great number of aquatic systems with water hyacinth as basic component were construct (U.S. EPA, 1988; Aoi and Hayashi, 1996).

Water hyacinth harvests have been put into valuable uses in several countries. Methods of converting the plant material into valuable products have emerged. Apart from its ornamental value, the plant has been found useful as a source of animal feed (Gopal, 1987), as a source of fertilizers for use in agriculture (Oyakawa *et al.*, 1970; Majid, 1986), a source of bio-mass energy, a source of raw materials for building, handcraft making, paper and boards. In addition the plant has been found to be useful as a filter worth of solving man created problems of pollution in water bodies. However all the potential uses of the water hyacinth do not promote utilization of the weed to the level that qualifies it as a viable control option (Ogutu-Ohwayo *et al.*, 1996). Below I will consider a number of possible uses for the plant, some which have been developed and others which are still in their infancy or remain as ideas only.

Paper: Similar small-scale cottage industry papermaking projects have been successful in a number of countries, including the Philippines, Indonesia, and India.

Fibre Board: Another application of water hyacinth is the production of fibreboards for general-purpose use and also a bituminised board for use as a low cost roofing material.

Yarn and Rope: The fiber from the stems of the water hyacinth plant can be used to make rope. The stalk from the plant is shredded lengthways to expose the fibers and then left to dry for several days. The rope making process is similar to that of jute rope. The finished rope is treated with sodium metabisulphite to prevent it from rotting. In Bangladesh, the rope is used by a local furniture manufacturer who winds the rope around a cane frame to produce an elegant finished product.

Basket Work: In the Philippines water hyacinth is dried and used to make baskets and matting for domestic use. The key to a good product is to ensure that the stalks are properly dried before being used. In India, water hyacinth is also used to produce similar goods for the tourist industry. Traditional basket making and weaving skills are used.

Charcoal Briquetting: This is an idea which has been proposed in Kenya to deal with the rapidly expanding carpets of water hyacinth which are evident on many parts of Lake Victoria. The proposal is to develop a suitable technology for the briquetting of charcoal dust from the pyrolysis of water hyacinth.

Biogas Production: The possibility of converting water hyacinth to biogas has been an area of major interest for many years. Conversion of other organic matter, usually animal or human waste, is a well established small and medium scale technology in a number of developing countries, notably in China and India. The process is one of anaerobic digestion which takes place in a reactor or digester and the usable product is methane gas which can be used as a fuel for cooking, lighting or for powering an engine to provide shaft power. Other studies have been carried out, primarily in India with quantities of up to 4000 liters of gas per tonne of semi dried water hyacinth being produced with a methane content of up to 64% (Gopal, 1987). Most of the experiments have used a mixture of animal waste and water hyacinth. There is still no firm consensus on the design of an appropriate water hyacinth biogas digester.

Animal Fodder: Studies have shown that the nutrients in water hyacinth are available to ruminants. In Southeast Asia some non ruminant animals are fed rations containing water hyacinth. In China pig farmers boil chopped water hyacinth with vegetable waste, rice bran, copra cake and salt to make a suitable feed. In Malaysia fresh water hyacinth is cooked with rice bran and fishmeal and mixed with copra meal as feed for pigs, ducks and pond fish. Similar practices are much used in Indonesia, the Philippines and Thailand. The use of water hyacinth for animal feed in developing countries could help solve some of the nutritional problems that exist in these countries.

Fertilizers: Water hyacinth can be used on the land either as a green manure or as compost. As a green manure it can be either ploughed into the ground or used as mulch. The plant is ideal for composting. After removing the plant from the water it can be left to dry for a few days before being mixed with ash, soil and some animal manure. Microbial decomposition breaks down the fats, lipids, proteins, sugars 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. The compost increases soil fertility and crop yield and generally improves the quality of the soil. In developing countries where mineral fertilizer is expensive, it is an elegant solution to the problem of water hyacinth proliferation and also poor soil quality. In Sri Lanka water hyacinth is mixed with organic municipal waste, ash and soil, composted and sold to local farmers and market gardeners.

Fish Feed: The Chinese grass carp is a fast growing fish which eats aquatic plants. Other fish such as the tilapia, silver carp and the silver dollar fish are all aquatic and can be used to control aquatic weeds. The manatee or sea cow has also been suggested as another herbivore which could be used for aquatic weed control. Water hyacinth has also been used indirectly to feed fish. Dehydrated water hyacinth has been added to the diet of channel catfish fingerlings to increase their growth. It has also been noted that decay of water hyacinth after chemical control releases nutrients which promote the growth of phytoplankton with subsequent increases in fish yield (Gopal, 1987). The response of the fish communities to water hyacinth is highly dependent on the pre-existing fish community, preferred and available fish habitat, food requirements and availability, physiochemical conditions and, likely although not proven, water hyacinth density. The combination of these factors makes it very difficult to predict specific effects. However, given that dissolved oxygen concentrations decrease with increasing water hyacinth density, and given that macroinvertebrates and zooplankton are found at higher densities and in great diversity along the edges of water hyacinth mats, it is logical to suggest that fish could benefit from highly fragmented mats of water hyacinth. Such mats will have a higher edge-tocore ratio, providing some of the benefits of water hyacinth and minimizing the negative effects of dense non-fragmented mats.

Conclusion: In conclusion, water hyacinth can be brought to make compost, mulching and to clean the sewage. It is a good way to change waste products into useful things. More research is needed in order to define the optimum water hyacinth density in the reservoirs to determine its influence on the water quality of the effluent. Although all efforts must be made to control these plants where they are nuisance from natural ecosystems, research efforts must be stepped up to tap these recourses for human welfare. At a broader scale, we suggest research that focuses on the potential spread of water hyacinth into northern latitudes as a response to global climate change (Hellmann *et al.*, 2008; Rahel and Olden, 2008). Finally, more research is needed on alternatives for the sustainable management of this worldwide invader; this includes economic incentives for private removal, spread prevention, or utilization projects that create goods from water hyacinth. In conclusion, our understanding of water hyacinth is still relatively weak, and hinders our ability to manage systems appropriately where this invader occurs. With the likely spread of aquatic invaders due to climate change, it is imperative that we continue and refine our water hyacinth research efforts to reflect better the needs of managers. The socio-economic effects of water hyacinth are dependent on the extent of the invasion, the uses of the impacted water body, control methods, and the response to control efforts. Ecosystem-level research programmes that simultaneously monitor the effects of water hyacinth on multiple trophic levels are needed to further our understanding of invasive species.

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