PROJECT PROPOSAL

FOR THE COMMERCIAL PRODUCTION OF

POLY-FIBRILLATED CELLULOSE RESIN

FROM OUT OF WATER HYACINTH AND
USING THE RESIN FOR THE PRODUCTION OF
PARTICLE BOARDS AND FLOOR TILES

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THE PROJECT OFFERS SCOPE FOR MANUFACTURE OF
FORMALDEHYDE-FREE RESIN FOR PARTICLE BOARDS
AND AN ENVIRONMENT FRIENDLY PERMANENT SOLUTION
FOR THE GLOBEL WATER HYACINTH WEED MENACE

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SCHEME

Water hyacinth (*Eichhornia crassipes*) has become the most noxious menace, pausing threat to Aquatic life, Water Transport, Fishing, Human health (through bacteria and / or viruses, with the help of mosquitoes and other vectors established in Water hyacinth carpet), Drinking water availability, Healthy Environment, etc., jeopardizing lives of millions of people worldwide, mainly in the tropical and subtropical regions of the globe.

The project's objective is to develop and apply the Patented technology [**India Patent 413150**] for manufacturing ***FIBRILLATED CELLULOSE***, in the form of pulp, which contains ***Nanocellulose fiber*** also, making use of the invasive weed **Water Hyacinth** as the raw material**,** and the pulp as such can be polymerized alongwith drying, in suitable molds to generate ***POLY-FIBRILLATED CELLULOSE*** **RESIN.**

The **Poly-Fibrillated cellulose resin** can be employed as the **binding resin** for manufacturing **Particle boards**, both **laminated** as well as without, as **MDF**, and other boards, and as **Tiles** for **Flooring, Wall covering, or Ceiling**, making use of **different fillers** to form the composites. The particle boards or tiles have the additional important advantage of NOT having Formaldehyde which is present in most of the Particle boards now being manufactured.

INTRODUCTION

The world is now turning to **nanotechnology** for every new development, and this is more important in the case of organic materials due to energy and environmental conservation factors. The world's greatest concern is Global Warming which has expressed its impact through rising ocean levels due to melting of glaciers, increase in temperature of ocean water, thereby affecting the marine lives negatively, much increase in catastrophic weather conditions, and more diseases as well as health-related problems for mankind. The scientific community is looking for or trying to develop newer and simpler technologies that would consume less energy, and for non-polluting products to prevent further damage to the environment. Everywhere, people are trying to replace petroleum products with more natural and biodegradable materials. The advantages of such materials and products are many. In this project we have embarked upon a new patented technology and process for the manufacture of FIBRILLATED CELLULOSE CONTAINING CELLULOSE NANOFIBRE as a PULP IN WATER and then, producing **Particle Board laminated**, or **MDF** (without lamination) and further, **Floor / Wall / Ceiling Tiles**, making use of various waste materials, giving preference in this proposal, for the noxious weed **Water hyacinth** (*Eichhornia crassipes*) as the basic raw material.

Water hyacinth is now found to fill water bodies to such an extent that aquatic life itself is threatened to a great extent. In addition, use of water resources for transportation is highly hindered due to the presence of this weed. It grows to about 25-30 cm height, or even much more in certain regions, and it is observed that one hectare of surface water contains 250 to 500 tons of the plant. Now-a-days millions of dollars are being spent for the removal of this menace, by governments as well as interested parties, who are to make use of the water resources as well as farm lands. In addition to the pollution created, this has affected the livelihood of thousands of families who were depending on fishing, water transport and tourism; the best example is the fate of the villages and towns on the Shore of Victoria Lake in African continent. The menace is mostly in the tropical and subtropical regions, affecting the developing countries [References]. Most of these countries have large number of poor people who are jobless. As far as the process and project are concerned, it produces a new material that has very many applications.

The **raw material,** Water hyacinth plant, is originally generated from atmospheric carbon dioxide through photosynthesis, thereby reducing atmospheric carbon dioxide, a major cause of global warming, and the nutrients from the water, which are polluting organic matter and minerals. At the same time, removal of the invading menace and discarding it in open space can liberate more **methane**, a greenhouse gas (Global Warming Index of methane is 20.5 while that of Carbon dioxide is 1). By making use of the cellulose plant material for developing new useful products, the production of methane from the decomposition of discarded plants can be reduced. Additionally, many of the **products made of fibrillated cellulose or cellulose nanofiber** as the resin, can substitute wood including plywood, fiber glass reinforced plastic, particle board, fiber board, chip board, or other similar products, mainly manufactured from wood, with or containing petroleum-based derivatives / polymers.

ENVIRONMENTAL PRODUCT DECLARATION [EPD] LABELING

In the case of Particle boards and similar building materials, the EPD labeling is done on the basis of the Environmental Indicators calculated depending on the materials used, taking sample of $1m^2$ board of 6 to 40 mm thickness; the Indicators are: (1) Global Warming Potential; (2) Ozone Layer Depletion Potential; (3) Acidification Potential; (4) Eutrophication Potential; (5) Photochemical Oxidation Potential; (6) Primary Energy, Non-renewable; (7) Primary Energy, Renewable; and (8) Electricity Consumption.

For the MDF being manufactured, **the content is only cellulose, and hence the values of EPD environmental indicators will be equivalent to that of wood**, or soft wood, while for melamine laminated particle board, environmental indicators will be slightly different, but very close to that of wood.

Thus, the new patented technology will be capable of bringing in a gigantic shift in the impact on environment through the manufacture of Particle Boards, MDF, and Tiles, using Fibrillated Cellulose Resin made out of water hyacinth.

Regarding the **Employment Opportunities** in the industry, employment is created in the collection and transportation (with or without preliminary processing) sectors, and in the processing units. At the same time, considering the immense quantity of Water hyacinth available and its growth rate, a large number of processing units would have to be established throughout the world, providing **job opportunities for thousands of unskilled and semiskilled job seekers**. This can alleviate poverty to a great extent.

EXECUTIVE SUMMARY

The main objective of the project is to develop and apply the technology for manufacturing ***Fibrillated cellulose***, in the form of pulp, which also contains ***Nanocellulose fiber***, making use of **Water Hyacinth** as the raw material**,** and the pulp being polymerized along-with drying in suitable molds to generate ***Poly-Fibrillated cellulose*** **Resin.**

The **Poly-Fibrillated cellulose Resin** can be employed as the **binding Gum** for manufacturing Particle boards, both laminated (mostly with melamine-formaldehyde resin) as well as without, i.e., MDF, and other boards as Tiles for floor, walls or ceiling, using various other fillers to form these composites. The particle boards or tiles have the **additional important advantage of NOT having Formaldehyde**, as found in majority of the Particle boards now being manufactured.

A **secondary objective** is to characterize the structure and properties of the end-products and develop more applications for its use. Initial studies show that the material, i.e., processed cellulose, is a composite that contains a mix of macro-, micro- and nano- Cellulose fiber with interesting properties and with potential for a wide range of applications. Additional detailed studies are required to fully develop processing technologies to manufacture different types of products for diverse applications. With increasing awareness and emphasis on green operations and technology, the breadth and depth of potential use of this organic material can marginally increase. In this regard, even particle board manufacturers are awaiting new **non- formaldehyde resins** for producing particle boards, due to concerns over indoor air quality, since carcinogenic Formaldehyde (gas) evolves from commonly used Urea-Formaldehyde (UF) or Phenol Formaldehyde (PF) resin containing boards.

The promoters of the project have already invested in a Prototype processing unit with limited manufacturing capability, and **Patent has been awarded for the process as well as the products [India Patent 314150]**. Additional work is required to extend the scale to pilot-plant level, perform material/product characterization, develop further applications, and establish technical and marketing strategies.

This proposal provides detailed estimates of the technological and marketing resources required and also the funding required for making this transition possible.

OBJECTIVES

A) Manufacture **Fibrillated Cellulose pulp containing Cellulose nanofiber** using the weed Water hyacinth and make **Poly-fibrillated cellulose resin**.
B) Using the **Fibrillated Cellulose pulp**, manufacture **Particle boards, with and without lamination, Tiles, etc.,** by making **composites of the resin** with the addition of **fillers like, saw dust, waste-wood powder, wood chips, clay, etc.,** derived from wastes.

VISION:

Re-establish the life-supporting, beautiful Environment, especially the Water bodies / resources, and provide healthy, formaldehyde-free, construction Boards and Tiles to the human generations of 21st Century, through "Waste (Menace) to Wealth" principle.

MISSION:

To remove and clear off wastes and weeds, especially Water hyacinth to maximum extent, so that water resources become utilizable for human needs, worldwide;

To manufacture and provide "Whole-Cellulose" Particle Boards that are **free** of carcinogenic 'Formaldehyde';

To provide employment for thousands of skilled, semiskilled and unskilled youth, especially in the developing countries, as jobs in manufacturing plants and getting employed in Fishing, Water Transport, Tourism, etc.;

To attain healthier environment by the elimination of disease-causing mosquitoes, rats, worms, and other vectors that are surviving in the water hyacinth carpets;

To recoup the Clean Drinking Water sources which are, otherwise, disappearing from the face of the earth after getting covered with the 'Weed Carpet'; and

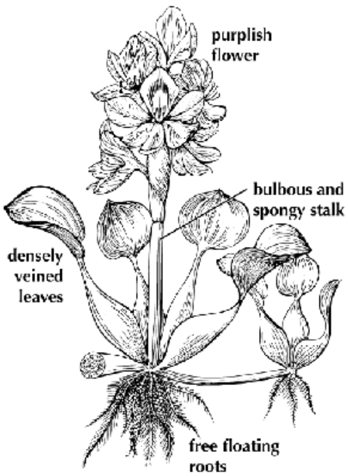
To reduce the environmental impacts that enhance Global Warming, by the **Fixation of Carbon as cellulose**, which otherwise would have resulted in the liberation of the greenhouse gases, Carbon dioxide and Methane.

KEYS TO SUCCESS

The First advantage is getting the water resources cleared (partially, in the initial phase) from the menace, allowing the people to return to the sources for working and earning their daily bread. The next advantage is that, the project can avail the credit for eliminating, to a good extent, the noxious weed, making the world cleaner and at the same time producing Formaldehyde-free particle board which can provide much healthier indoors compared to the existing formaldehyde resin boards.

SUMMARY

THE WEED



The invasive noxious weed is scientifically named as ***Eichhornia crassipes (*****Mart.) Solms**, which has its origin in Brazil. But it is commonly known worldwide as **Water Hyacinth**, having other names in different regions or countries. In India the plant is known by different names in Indian languages: ***akasa thamarai; German pana; jalkhumbi; kachuripana; kajor pati; kolavazha; kulavali; neithamarai; pisachi thanana; sokhsamundar; tagoi; and vilayati pana.*** In English itself it has different names, like **Floating water hyacinth, Lilac devil, Nile lily, Pickerel weed, Water orchid, Water violet or Water raft (USA)**.

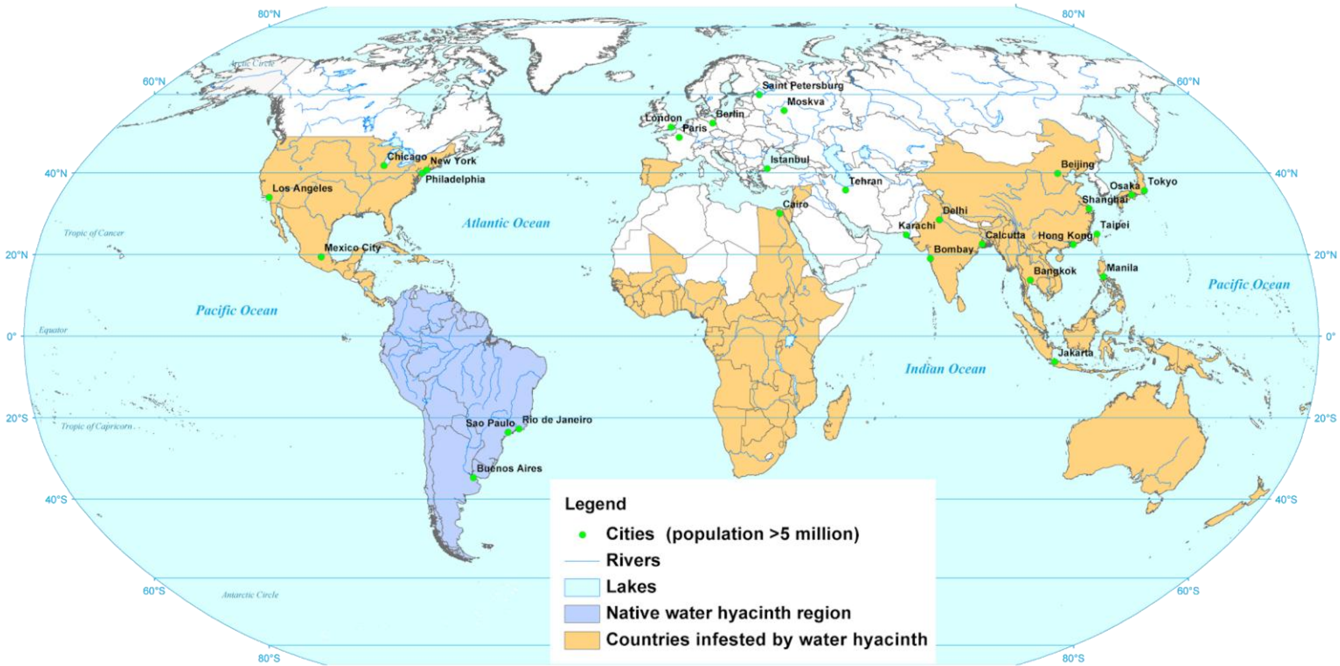
SUMMARY OF INVASIVENESS

Eichhornia crassipes, is a major freshwater weed found in most of the frost-free regions of the world and is generally regarded as the most troublesome aquatic plant. It has been widely planted as a water ornamental around the world because of its striking flowers. Wherever it has encountered suitable environmental conditions it has spread with phenomenal rapidity to form vast monotypic stands in lakes, rivers and rice paddy fields. Then it adversely affects human activities (fishing, water transport) and biodiversity. It was found to be almost impossible to eradicate, and often an integrated management strategy, can only provide a long-term solution to this pest.

This project proposal is a revolutionary one in this regard, that **a new technology is being put forward** which is expected to be capable of drastically reducing the weed from the water sources to a very comfortable extent bringing relief to millions of common people, and at the same time generating very useful, environment friendly construction materials.

DISTRIBUTION

Though *E. crassipes* is native of Amazon basin, Brazil, it is now naturalized in Africa, China, Australia, India, South America and many other countries.



In Asia the distribution is as follows:

Widespread in Bangladesh, Cambodia, China, **India (except Jammu & Kashmir and Rajasthan states)**, Indonesia, Japan, Korea (Republic of), Laos, Malaysia, Philippines, Singapore, Sri Lanka, Thailand, and Vietnam, while,

Present (to some extent) in Brunei- Darussalam, Jordan, Korea, DPR, Lebanon, Maldives, Myanmar, Syria, Taiwan and Turkey.

Africa

Widespread: Congo, Congo Democratic Republic (CDR), Egypt, Kenya, Madagascar, Malawi, Rwanda, South Africa, Sudan, Tanzania, Uganda, Zambia, Zimbabwe; and **Present (to some extent)**: Botswana, Burkina Faso, Burundi, Cameroon, Equatorial Guinea, Gabon, Ghana, Guinea-Bissau, Liberia, Mauritius, Morocco, Niger, Nigeria, Reunion, Rodriguez Island, Seychelles, Sierra Leon, Swaziland, and Togo.

North America, Central America and Caribbean

Widespread: Bermuda, Mexico, USA (Florida), Cuba, Dominican Republic, Jamaica, Panama, Porto Rico; and

Present (to some extent): Canada, USA - Arizona, Arkansas, California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Kentucky, Maryland, Missouri, New Jersey, New York, Oregon, Tennessee, Virginia, Washington; Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Costa Rica, Dominica, El Salvador, Guadeloupe, Guatemala, Haiti, Honduras, Martinique, Nicaragua, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago and United States Virgin Islands.

South America

Widespread: Brazil (all 25 states), Colombia, and Guyana;

Present (to some extent): Argentina, Bolivia, Chile, Ecuador, Paraguay, Peru, Uruguay, and Venezuela.

Europe

Present (to some extent): Italy, Portugal, Romania and Spain;

Present (in small quantities): Czech Republic, France, Corsica, Hungary, Sardinia and Sicily.

Oceania

Widespread: Fiji and Papua New Guinea;

Present (to some extent): American Samoa, Australia, Cook Islands, French Polynesia, Guam, Marshall Islands, Micronesia and Federated States, New Zealand, Northern Mariana Islands, Palau, Solomon Islands, US Minor Outlying Islands and Vanuatu.

MEANS OF MOVEMENT AND DISPERSAL

Natural Dispersal (Non-Biotic)

Wind will readily move the plant and the upright leaves act as sails in lakes and canals. Along rivers, water flow is the prime mover of vegetative material but strong winds may sometimes blow the plant upstream.

Vector Transmission (Biotic)

Seeds are thought to be transported over long distances by birds (e.g. waterfowl and shore birds) and if coated in mud they may cling to both mammals and birds (Holm et al., 1969; Batcher, 2000).

Accidental Introduction

New infestations may arise via unintentional human transportation such as canoes, boats and probably even charcoal transport as sacks used in the process are, in some parts of Africa, plugged with the plant.

Intentional Introduction

The high ornamental value of the plant still makes it liable to intentional introductions, especially as the species is up for sale on the internet.

Impact Summary

Category	**Impact**
Animal/plant collections	None
Animal/plant products	None
Biodiversity (generally)	**Negative**
Crop production	**Negative**
Environment (generally)	**Negative**
Fisheries / aquaculture	**Negative**
Forestry production	None
Human health	**Negative**
Livestock production	Positive
Native fauna	**Negative**
Native flora	**Negative**
Rare/protected species	**Negative**
Tourism	**Negative**
Trade/international relations	None
Transport/travel	**Negative**

ECONOMIC IMPACT OF THE WEED MATS

As a result of its rapid growth and large biomass, *E. crassipes* has a range of detrimental effects, which include**:**

Physical Interference with Water Transport, Communication and Access.

Gopal (1987) refers to serious interference with navigation in Southern USA, South Africa, Southeast Asia, Australia, Congo and Sudan. Annual costs of control or removal have, in the past, amounted to millions of dollars on the Panama Canal, on the Nile in Sudan, on the Congo and have been as much as $35 million in southern USA. Costs of controlling water hyacinth in Malaysia have been estimated at M$ 10 million per year (Mahomed et al., 1992), while Harley et al. (1996) quoting this figure, state that present actual costs are believed to be much higher. In recent years, the operation of Port Bell, Uganda, on Lake Victoria has been seriously threatened and costs have involved $1 million for a mechanical harvester, as well as the loss of trade at times when the port was completely blocked (Hill, 1999). Infestations are also increasing in Ethiopia, creating a range of problems including restricted access (Aweke, 1994). Harley et al. (1996) refer to 'devastating effects' on socio-economic structure and on the environment in the lower flood plain of the Sepik river in Papua New Guinea resulting from problems of access to subsistence gardens, hunting and fishing areas, and markets. The same authors refer to the recent increase in water hyacinth infestations in West Africa which are resulting in serious disruption of the socio-economic structure, food supply and health of several million people. In Nigeria, Alimi and Akinyemiju (1991) showed that costs of fuel and repairs to boats on infested waterways was approximately three times that on un-infested waterways. The problem has also been increasing recently in Mali (Dembele et al., 2000). Economic losses also result from interference with recreational uses of water bodies (for example, Gopal, 1987; Aweke, 1994; Cilliers et al., 1996).

Interference with Fishing

This effect is most acute for small-scale inland fishing communities. Apart from the problems of access to fishing grounds and interference with the spreading or retrieval of nets or with landing their catch, there are serious effects on fish stocks and fish breeding. Although a sparse cover of water hyacinth may not reduce fish and may even be used to advantage in some fishing techniques (Gopal, 1987), a dense infestation can lead to de-oxygenation and kill-off fish or reduce fish stocks. Gopal (1987) refers to heavy losses of fish production in the Congo, Nile and other rivers and in Pakistan and to losses amounting to 45 million kg in West Bengal, India in the 1950s, and reductions of 70% in fish production in the USA as a result of a cover of only 25%, presumably due to reduction of phosphorus levels and phytoplankton. The shallow water of lake edges can be especially important spawning areas for fish and a dense cover of water hyacinth can interfere severely with fish breeding. Hill (1999) refers to this phenomenon on Lake Victoria where the estimated 10,000 ha of the weed includes an almost continuous fringe along the shoreline extending to at least 10 m. Labrada (1996) quotes fuel costs increased by a factor of 2-3 and fish catches down 50-75% on parts of Lake Victoria. Fishermen affected by another relatively new infestation, in the Shire river in Malawi, report reduced catches which are not confirmed by the locally available statistics but there is no doubt fishermen are being troubled by a reduced range of fish species, loss of nets and impeded access (Terry, 1996).

***Risks of Mechanical Damage to Hydro-electric Installations and Other Structures such as Bridges*.**

Expensive barriers or mechanical harvesters may be needed to minimize these risks, for example, to the Owen Falls Dam on Lake Victoria (Hill, 1999). Elsewhere, there are similar concerns in South Africa (Harley et al., 1996), Brazil (Pitelli, 2000), New Zealand (Clayton, 2000) and Ethiopia (Aweke, 1994).

***Reduced Irrigation Flow can indirectly cause Crop Loss but there can also be Direct Interference and Competition from Water hyacinth where it occurs in Flooded Rice*.**

Such losses have been estimated at many million dollars in West Bengal, India and as significant in many other countries including Sri Lanka, Bangladesh, Myanmar, Malaysia, Indonesia, Thailand, Philippines, Japan and Portugal (Gopal, 1987).
Nang'alelwa (2008) summarizes the socioeconomic effects in the Victoria Falls World Heritage site in Zambia. Major impacts include effects on the generation of hydro electric power, tourism development, native biodiversity, fish catches and human health. Other recorded impacts are reduced quality and quantity of water for domestic use, restricted navigation of waterways and the threat posed to vital infrastructure.

ENVIRONMENTAL IMPACT

Once it proliferates in a water body, *E. crassipes* dramatically alters the ecosystem and often results in environmental degradation and a reduction in bio-diversity. A number of researchers note that in many water bodies and wetland areas, the encroachment of water hyacinth has reduced or eliminated natural vegetation (Terry, 1996; Kumar and Rohatgi, 1999).
The plant may negatively impact some native species of invertebrates, fish, birds and plants. For example, in Madagascar, many parts of the Alaotra Lake, a site of biological importance, have been reported as covered with carpets of *E. crassipes* that are detrimental to a number of species, such as the duck *Thalassornis leuconotus* (Binggeli, 2003).

OTHER ENVIRONMENTAL IMPACTS INCLUDE:

***Restricting Water Flow in Rivers, Irrigation and Drainage Channels, thus Reducing Irrigation Water and/or Leading to Greater Risk of Flooding*.**
Gopal (1987) refers to water flow being reduced by 40-95% in irrigation channels, sometimes leading to flooding in Malaysia and Guyana.

Excess Evapotranspiration, causing Wastage of Water that would otherwise be used for Irrigation, Drinking, Fisheries, etc.

Rates of loss have been reported **up to 13 times that from a free water surface**, with an average of 2.5 times the loss (Gopal, 1987). In India, the loss of water of the mats of *E. crassipes* was 7.8 times greater that of open water thus resulting in massive wastage of water especially in dry regions (Vasudevan and Jain, 1991). However, it has recently been claimed that these figures have been grossly exaggerated by inadequate experimental technique (Allen et al., 1997). But it is observed that the level of water in the Victoria Lake has got reduced by One meter compared to that of 1995.

When Water hyacinth Mats Decompose Dissolved Oxygen Levels are Reduced and Sedimentation increases.

The effects of *E. crassipes* on physicochemical characteristics of water in Lake Naivasha, Kenya, are described by Mironga et al. (2012). Impacts include greater levels of free carbon dioxide, lower pH and lower levels of dissolved oxygen in infested areas than in open water. A similar study in Badagry Creek and Ologe Lagoon, Lagos, Nigeria (Ndimele, 2012) found effects on salinity, conductivity, total hardness and total dissolved solids.

It is suggested that while there are negative impacts on water quality, the ability of *E. crassipes* to passively **absorb heavy metals and nutrients** can be put into good use.

SOCIAL IMPACT

E. crassipes may reduce Water Quality in various ways and encourage Mosquitoes, Snails and Other Organisms associated with Human Illnesses, including Malaria, Schistosomiasis, Encephalitis, Filariasis and Cholera (Gopal, 1987).

Harley et al. (1996) comment that people in Papua New Guinea have died through a combination of reduced nutrition, degraded water, increased disease vectors and generally reduced health, **directly related to the degrading effect of water hyacinth** on the environment. Dense mats greatly hinder boating by fishermen and may prevent fishing altogether, thus denying the locals their main source of protein and sometimes forcing people to relocate. In extreme cases of competition between *E. crassipes* and rice crops, fields have been abandoned. In the Lake Victoria Basin, the main negative social impact were identified by interviewees as an increase in certain diseases, difficulties associated with clean water availability and migration of communities (Mailu, 2001).

RISK AND IMPACT FACTORS

Invasiveness

- Invasive in its native range
- Proved invasive outside its native range
- Highly adaptable to different environments
- Tolerates, or benefits from, cultivation, browsing pressure, mutilation, fire, etc
- Highly mobile locally
- Has high reproductive potential
- Has propagules that can remain viable for more than one year

Impact outcomes

- Damaged ecosystem services
- Ecosystem change/ habitat alteration
- Negatively impacts agriculture
- Negatively impacts tourism
- Reduced amenity values
- Reduced native biodiversity

Impact mechanisms

- Competition - monopolizing resources

Likelihood of entry/control

- Highly likely to be transported internationally deliberately
- Difficult to identify/detect as a commodity contaminant
- Difficult/costly to control

USES

The weed ***E. crassipes*** can be utilized in various ways. Although **not generally suitable as an animal feed**, small amounts can be fed to pigs and buffaloes, but in China during the 1950s - 1970s, when fodder was scarce, it was widely used as an animal feed (Ding Jianqing et al., 2001). It can be used as a mulch, for making compost, fuel bricks, paper or board, for generating methane biogas, and for removing nutrients and toxic chemicals from water. Recent work on composting includes Montoya et al. (2013) who found that a large-scale composting system using water hyacinth as a primary feedstock reached high enough temperatures to inactivate seeds and other propagules, and thus that the plant can be composted without the potential danger of spread.

It's very high growth rate and ability to withstand various types of pollution are proving of interest for the treatment of polluted water but there remains the problem of disposal of the harvested (polluted) material (Aoyama et al., 1986; Ayade, 1998). Yan et al. (2012) tested *E. crassipes* for removal of pollutants in Lake Caohai, China, and found that the plant could not only remove phosphorus in the water, but also remove the soluble phosphorus in the sediment of Lake Caohai, Ndimele and Ndimele (2013) suggest that the species absorbs petroleum hydrocarbon and can be used for *phytoremediation* of crude oil-polluted aquatic ecosystems.

Potentially, Water hyacinth could be very important in **sewage and waste water treatment**. Its fast growth rate and high absorption of nutrients and heavy metals could make it a cheap and largely environmentally benign form of decontamination (Hill et al., 1999; Zhu et al., 1999). However, the biggest use made of water hyacinth is probably as an ornamental plant in temperate regions (Cohen, 1993).

Work on utilization includes use as an organic manure in Bangladesh (Nasima et al., 1997); as a compost to suppress nematodes in India (Verma et al., 1997); for water purification (Ayade, 1998); for biogas production (Rodriguez et al., 1997; Sarkar and Banergee, 2013)); for feeding buffaloes in India (Mitra et al., 1997); and as a mulch to suppress weeds in Indonesia (Lamid and Wahab, 1996). Masto et al. (2013) explored the conversion of *E. crassipes* to biochar for improvement of soil quality. There are many recent studies on utilizing *E. crassipes* for bioenergy. Hussain et al. (2013) converted *E. crassipes* biomass into liquid hydrocarbon fuel using catalytic pyrolysis. Bergier et al. (2012) suggest that biomass from water hyacinth in the Panatanal of South America could be managed for production of biofuels. Sudhakar et al. (2013) assess bioelectricity production using water hyacinth biomass. Anaerobic co-digestion with poultry litter for biogas production is considered by Patil et al. (2013), while Zhang et al. (2013) report on hydrothermal liquefaction. Biogas production from water hyacinth polluting water bodies in Nigeria is studied by Adeleye et al. (2013).

THE URGENCY FOR THE REMOVAL OF WATER HYACINTH FROM FRESH WATER SOURCES

Water hyacinth has become a very dangerous menace in most of the tropical countries. In this regard, even the United Nations Environmental Program [UNEP] has published a special **Global Environmental Alert Service [GEAS]** notification titled **“Water hyacinth – Can its Aggressive Invasion be Controlled?”** in April 2013 [Appendix 1].

According to the publication, which is meant as warning as well as a request, for the control of Water hyacinth in the affected countries, and very badly **affecting above 50% of the world population**.

According to the paper, “the spread of invasive alien species (like Water hyacinth) is neither easy to manage nor easy to reverse, **threatening not only biodiversity but also economic development and human well-being**. 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**. Worryingly, climate change may allow the spread of Water hyacinth to higher latitudes. **Intensified monitoring, mitigation and management measures are needed to keep water hyacinth at unproblematic levels**”.

“The millions of people who depend on the water bodies for their daily bread are in great distress”.

URGENT NEED OF THE HOUR - THE BEST METHOD:

“*CONVERT THE MENACE WEED INTO WEALTH*”

A FORMALDEHYDE-FREE RESIN FOR ENGINEERED WOOD COMPOSITES AND OTHER APPLICATIONS

RESINS / GLUES IN USE

Worldwide, now-a-days in the industry, **Amino-formaldehyde / Urea- formaldehyde (UF)** based resins are the best performing on the basis of cost and ease of use. **Urea-Melamine resins** offer water resistance with more Melamine offering higher resistance. It is typically used in external applications, with the colored resin darkening the panel. Other improved versions like, **Resorcinol resins** can be mixed with **Phenolic resins** (**Phenol-formaldehyde, PF**), but that is more often used with Marine plywood applications. In addition, more recently, few other non-formaldehyde resins have been introduced; these include, **Polymethylene diphenyl diisocyanate (pMDI)**, **Epoxy resin**, or **Poly vinyl chloride (PVC)**.

Particleboard or *chipboard* is manufactured by mixing wood particles or flakes together with a Resin and forming the mixture into a sheet. Resin is then sprayed as a fine mist onto the particles. Any of the above Resin would be used depending on various factors like nature of use, type of particle board including thickness, cost, etc.

The formed sheets are cold-compressed and then compressed again, under pressures between 2 and 3 megapascals (290 and 440 psi) and temperatures between 140 and 220 °C (284 and 428 °F) to set and harden the glue.

The boards are then cooled, trimmed and sanded. They can then be sold as raw board, or surface improved through the addition of a wood veneer, or laminate surface.

The much **lower cost** of sheet goods (particle board, medium density fiberboard, and other engineered wood products) has helped to displace solid wood from many cabinetry applications. **90% of Particle boards manufactured** worldwide make use of **Urea-formaldehyde resin** as the glue for lowering the cost.

THE SAFETY FACTOR CONCERNS ABOUT FORMALDEHYDE RESINS

Safety concerns exist for both manufacturing and use. Fine dust and chemicals are released when particleboard is machined (e.g., sawing or routing). Cutting particle board can release **formaldehyde**, carbon monoxide, hydrogen cyanide in the case of amino resins, and phenol in the case of phenol-formaldehyde resins.

The other safety concern is the **slow release of formaldehyde over time**. Concerns about the high indoor levels of formaldehyde in new manufactured homes led the United States Department of Housing and Urban Development to set construction standards (in 1984). Particle board (PB), Medium density fiberboard (MDF), Oriented strand board (OSB), and laminated flooring have been **major sources of formaldehyde emissions**. Thereupon, PB and MDF became available in "no added formaldehyde" (NAF) labels, but **were not in common use** as of 2015. Many other building materials such as furniture finish, carpeting and caulking **give off formaldehyde**, as well as urea-formaldehyde foam insulation, which is **banned in Canada for installation in a residential closed cavity wall**. **Formaldehyde** has been classified by the WHO as a known **human carcinogen**.

THE NEW RESIN FROM WATER HYACINTH - ONLY CELLULOSE

Poly fibrillated cellulose Resin (**pFC**), generated from Water hyacinth through the patented process, **contains almost 100% CELLULOSE** and **NO FORMALDEHYDE**. Hence, any Particle board, Chip Board, or Tiles manufactured would be **100% SAFE** (from Formaldehyde), and **GREEN**.

PROPOSAL OVERVIEW

The proposed project is for the **manufacture of Fibrillated cellulose containing pulp** that can be converted into Particle board, Medium Density Fiberboard (MDF), Chip board, Floor tiles, etc., where the **Fibrillated Cellulose Resin** will act as the **binding material / glue** for the fillers like saw-dust or clay, thereby the product can be used in many applications substituting wood, plywood, plastic or FRP.

The most important aspect of the process, [which is modified form of a patented Process (India Patent No. 244800)], is that the raw material for the process is the plant material, Water hyacinth.

The technology utilizes Water hyacinth for manufacturing wood substitutes, namely**:** **1) Particle board / Chip board, with Lamination,**

2) Medium Density Fiber board (MDF),

3) Floor tiles,

4) Wall tiles, and

5) Ceiling boards.

Particle board, Chip board, etc., can be laminated with Melamine-formaldehyde resin, wood veneer or some other novel surface coating to suit any specific properties, like Fire resistance, abrasion resistance, surface smoothness, color, designs, etc.

(There is NO CONTENT OF FORMALDEHYDE that can EVOLVE, in any of these products)

With the discovery of petroleum, the world had seen a drastic shift from the natural, environment-friendly materials of general use, to the synthetic, petroleum-based, but environment damaging and polluting products. Through the last 50 years, the world could experience the negative impacts of these products. Now, the human race is after corrective measures; as part of the campaign, scientists are in search of a substitute for plastics for use in everyday life. In this regard, the scientists are trying to find materials derived from starch, a natural product, to substitute plastic, especially as packing and packaging materials. The material, which we have developed, belongs to this class, in a way.

In the Patented Process being utilized by ***Pentoreum Innovations Pvt. Ltd.***, **all the components of Water hyacinth plant is used, practically removing only the water content**. The raw materials are sourced from mature plants by collector / harvesting machines now available, or manually. Now-a-days, different types of systems are employed, from simple collectors to those with additional chopping and / or grinding mechanisms.

END PRODUCT DESCRIPTIONS

The following are the end products that can be generated / manufactured from the Water hyacinth by the modified *Process,* and would be an input into other industries, especially in construction and housing.

The pulp obtained from the Modified *Process* consists of a gelatinous mass of cellulose nanofiber and macro-fiber of the Water hyacinth plants. The water content is reduced by filtration or centrifugation. The pulp thus obtained is then mixed with other required materials as per the quality needed and dried in molds to the end-product.

[*A dried sheet of the* ***Poly-fibrillated cellulose Resin*** *of 0.35 mm average thickness (and having no other additives), has a* ***tensile strength of 29 N/mm^2****; the* ***elongation at break point for the material is 17.93%*** *and the measured* ***modulus at various elongations are: 5% - 13.90 N/mm^2, 10% - 21.93 N/mm^2 and 15%- 26.96/V/mm^2***].

Tests including Transmission Electron Microscopy (TEM) of the gelatinous mass as well as the dried sheets/films, and the physical properties have shown that the material generated contains **fibrillated cellulose fiber** and also, **cellulose nanofiber**. Cellulose Nanofiber is now being made from **wood pulp** through the “Electrospinning” process, using certain organic solvents for dissolving the cellulose fiber and then passing the solution of cellulose through tiny pores under very high electric potential. In our process, instead of wood, or petroleum-based plastics / resins, or even glass fiber, Water hyacinth, the polluting noxious plant, which contains Cellulose only, is made use of.

The major drawback is the lower yield, of about 5%, by mass of the product. But ***Fibrillated cellulose fiber*** **as well as** ***Cellulose nanofiber*** **in the pulp act like monomers for the formation of a polymer network, like other organic polymers, ie., polyethylene, polystyrene, PVC, and the resins, namely, phenol-formaldehyde or urea-formaldehyde** (which are the polymers used in particle board, chip board or similar pressed boards). **The pulp then mixed with the filler, which can be another wood- waste like saw dust, or china clay, etc., is polymerized in suitable molds to produce the end product**.

The **Particulate Materials used for forming the composite** are:

Wood chips used to produce **Chip board,**

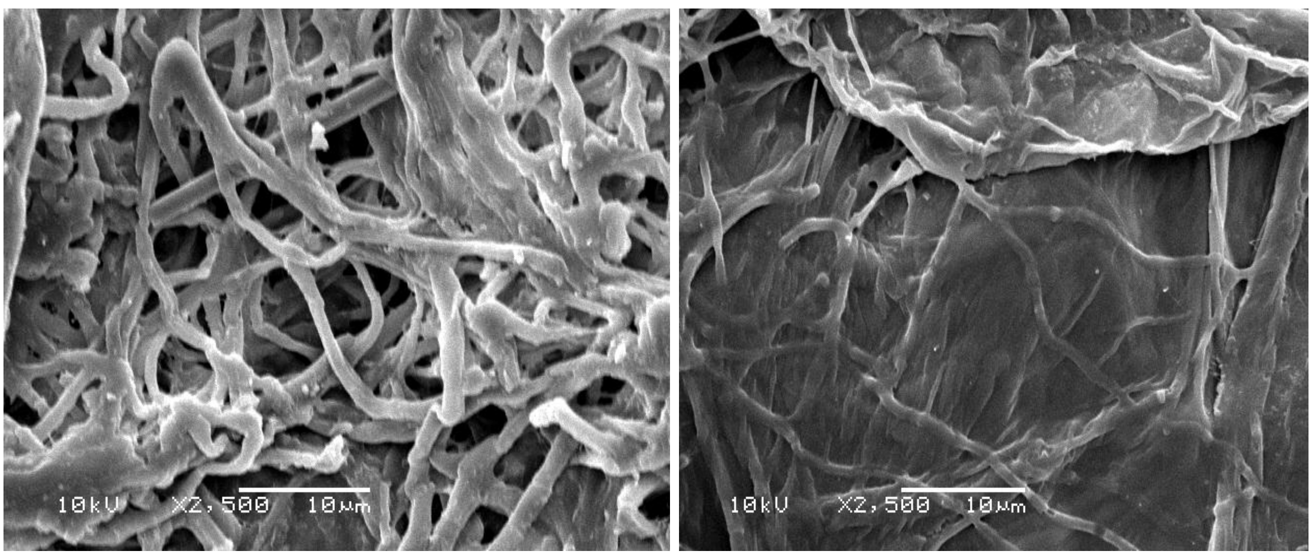
Powdered Saw dust, wood powder, or **dried, chopped and crushed water hyacinth**, can give **particle board or MDF**, and

China clay can give very hard boards, that can be used as **floor, ceiling and wall Tiles**, with suitable thickness.

Other modifications are also possible with filler variations and use of suitable moulds.

The process requires NO high temperature and very high pressure, as required in the polymerization for the particle boards which uses synthetic resins.

The logistics for the manufacture has to be developed for minimum mass transportation of the raw material, as water can be partially eliminated at the source itself.



Poly Fibrillated Cellulose Resin films – Scanning Electron Microscope (SEM)

CURRENT STATUS

PROCESS AND PRODUCT PATENTS

1. PARTICLE BOARD MADE OF CELLULOSE NANOFIBER PREPARED FROM WATER HYACINTH [India Patent 314150]; Patentee: Prof. Varkey Mathew. Date of Grant: 13th June 2019.

2. Process for Making Polymeric Material of Cellulose Nanofiber from Wastes of Plantain and Banana Plants [India Patent 244800]; Patentee: Prof. Varkey Mathew, Mr. Cheloor Unnikrishnan Nair and Mr. Padmanabhan Sivasankaran.

TECHNICAL AND ECONOMIC FEASIBILITY

The technology as explained already is comparatively simple, with minimal energy requirement. Further, due to large-scale availability, the cost of the raw material would be very low. In fact, removal of the Water hyacinth, the material that we require, is great help to humanity, especially for those who are dependent on such water bodies, and indirectly to the humanity at large. [*According to data available with the UN and different Governments, hundreds of thousands of square kilometers of water resources are covered with this invasive plant and their quantity is alarmingly increasing*]. [References on *Water hyacinth menace* and images on Water hyacinth menace: Special notification issued (April 2013) by United Nations Environmental Program, titled **'Global Environmental Alert Service, GEAS']**.

The cellulose nanofiber, (which is also obtained alongwith Fibrillated cellulose) now manufactured and utilized is derived from wood and some other dry farm wastes like wheat, maize and waste cotton, with the help of organic solvents and high electric potential, **electro-spinning process**. But in our *Process*, only aqueous solution is employed, using non- toxic catalysts. After the process, the catalyst materials may be removed by washing before molding, but in the manufacture of these boards the washing can be avoided, and so the derived product is **non-toxic** and **'green'**.

TEM studies show that the aqueous suspension (gelatinous) of the product contains fibrillated cellulose fiber and cellulose nanofiber having diameter of 2 — 50 nm (nanometer); reaction conditions can provide varying quantities with more specific qualities of the nanofiber content.

MARKET FEASIBILITY

The material as mentioned, prepared from an invasive weed, with the qualities of a "green", environment friendly product will be of great demand. The boards manufactured find application in the construction / housing industry for substituting costly wood, metal, fiberglass reinforced plastic, and other plastics.

With some modifications like lamination with Melamine, wood veneer, or other modern novel coatings, can find extensive use in the production of tables, cup-boards, partitions, floor, ceiling and wall paneling, etc., as heat insulation materials for pipelines, as sound dampening material for auditoriums, automobile, electronic, electrical, and other manufacturing industries, as packing material for various industrial products, etc.

More importantly, just like cellulose nanofiber, this material can be made use of in advanced scientific gadgets and equipment. Simpler technology of manufacture and greater availability can enable the scientists to make a good number of new products.

The products being perfectly natural, eco-friendly and biodegradable, these are excellent substitutes for most of the present-day plastic and synthetic products in use universally. In all advanced countries as well as in developing countries, one of the major problems confronting environmentalists is the non- biodegradability of the present-day bottles, plates and packing materials. The hazards caused by these synthetic and plastic materials are very many. PVC is known to cause carcinoma bladder; lead or chromium in the plastics causes a lot of diseases including impotency; allergy related diseases, especially for the skin, are very common among those using plastic/synthetic products. In short, what we intend to produce on a large scale is tomorrow's necessity.

One most important factor to be considered is the reduction in the use of plastics. The products that are generated would be the ideal substitute for plastic and paper. The introduction of the material would reduce the demand on petroleum, petrochemicals and, softwood also.

The very important aspect of the process is the production of Cellulose nanofiber, which is now being accepted as the genuine material to replace and find use in many a nature- friendly application. The future industries will be mainly relying on nanotechnology, in which a major part will be of cellulose nanofiber and poly fibrillated cellulose resin. The nanotechnology industry is expected to have an investment of $2.5 trillion by 2025 and a good portion should belong to fibrillated cellulose - cellulose nanofiber materials.

The world is after eco-friendly consumer items and this is especially true in the case of items of everyday use. In the USA the piling up of coke bottles over the years has become a great hazard on account of their bio-non-degradability. The threat forced the Du Pont Company to invent a biodegradable plastic material and they have somewhat succeeded in developing a plastic that can degrade in five years' time. All major automobile manufacturers like of Daimler Benz are currently emphasizing close to 100% recyclability of the materials that go into the production of vehicles. In other words, pile up of non-degradable materials on the surface of the earth is sure to adversely affect health and living conditions of human beings and others on the planet. To start controlling this happening, industries all over the world are in the search of natural materials to substitute as many synthetic materials in use as possible. It is in this background that the promoters took up the present program of finding methods and techniques to produce various consumer items from waste materials, especially, weeds and other natural plant materials.

PROJECT VISION

The products are derived from Water hyacinth with maximum potential through Process invented by Prof. Varkey Mathew. Once this item is standardized, it will be possible to start production units all over the world, consequently generating enormous employment opportunities for both unskilled as well as qualified people.

The raw material is mostly available in the developing countries. Making use of the raw material would be of great importance in many ways:

1. Poverty alleviation in the developing countries of Asia, Africa, South and Central Americas, as a result of the labor requirement in collection, transportation and processing; no additional investment needed on the part of the farmers, laborers and the administration.

2. The utilization of the invasive weed in millions of tons per year, can prevent, to a certain extent, global warming; also, the materials would be able to substitute harmful petroleum products including plastics, with the biodegradable organic material.

3. The initial intermediate product generated, fibrillated cellulose fiber - cellulose nanofiber mixture, can find tremendous applications through various products that can be generated; hence a lot of studies and research would be required using this cellulose fibers produced by the Process, for applications in many fields.

4. The water sources now under threat of extinction worldwide can get regenerated into sources of good water, fishing, transportation, etc. Pollution of water will get reduced to some extent and if continuously removed but not completely cleared, and there is scope for purification of polluted water.

Further research and studies are being conducted for other products for varying uses and applications.

IMPORTANT MILESTONES

With respect to the establishment of the new manufacturing chain throughout the world, we suggest the implementation of the following infrastructure and institutions:

1. One or more Research Laboratories for studying the optimized conditions for the preparation and manufacture of Fibrillated Cellulose fiber, cellulose nanofiber in the gelatinous form, studies on preparation and manufacture of products of Fibrillated Cellulose, (and/or cellulose nanofiber) for various applications with or without fillers/additives. Determination of properties of the products generated also to be done in the laboratory for new applications.

2. A Pilot Plant for the production of Fibrillated Cellulose Resin based Particle boards, a unit for processing about 10 tons of raw material per day to be established. Further, install full- fledged factories for larger quantities, wherever needed, throughout the world.

3. Institutions for training the personnel required in the nanotechnology industry, especially in Fibrillated Cellulose fiber (and cellulose nanofiber) manufacture, and processing of these to make various end products.

OWNERSHIP

The R&D company, **Pentoreum Innovations Private Limited**, will be the holder of the technology. With respect to manufacturing plants, separate units to be established as separate companies, which can be joint ventures with other interested persons or firms, and established by Pentoreum Innovations Pvt. Ltd.; for different regions in our country different firms to be established, as per the requirement. Companies can also be formed as ‘Public - Private’ partnership firms, as and when required, with Government / Local Self Government support.

PROJECT COST & START-UP SUMMARY

PREAMPLE

Mixture of Fibrillated cellulose and Cellulose nanofiber, in the pulp form, are excellent raw materials for a wide spectrum of industries. The project covers a process which results in commercial production of the above items at reasonable costs.

ESTIMATES

Calculation is for a manufacturing plant of **300 tons capacity** (means 300 tons of Water hyacinth is processed to get the Cellulose Pulp, per day, in three shifts); additional filler will be used, and for removal of larger quantity every day, 300 tons of Water hyacinth can be dried after cutting and grinding, to be used as filler. But the quantity of water hyacinth as filler may change, or other fillers may be used, but **capacity of the plant** will be considered as "**300 tons capacity**" for our calculations.

A. Land, Building, Water & Electrification

1. Land and Development.	
5 acres of land, is suggested.	
Cost of land:	Rs. 5,000,000.
Development, leveling, fencing, etc.:	Rs. 2,000,000.
2. Buildings: 200 sq. meters; mostly without side walls. Materials used: bricks, steel structure, aluminium roofing, etc.:	Rs. 2,000,000.
3. Water supply, Sanitation, etc.,	Rs. 1,500,000.
4. Electrification	Rs. 1,500,000.
TOTAL	**Rs. 12,000,000**.

B. Machinery

1. Hydraulic press (2-ton rating)	Rs. 500,000.
2. 2 nos. Cutting and sheering machine	Rs. 500,000.
3. 2 nos. Grinding machines	Rs. 8,000,000.
4. 1 no. Boiler unit (1000 lit capacity)	Rs. 2,000,000.
5. 1 no. Centrifuge / Filtering Unit	Rs. 2,000,000.
6. 3 nos. Storage tanks (5000 lit capacity)	Rs. 1,000,000.
7. Moulding, Drying and Melamine Coating Unit	Rs. 6,000,000.
7. Transportation and installation charges	Rs. 1,000,000.
TOTAL	**Rs. 21,000,000**
GRAND TOTAL (A + B)	**Rs. 33,000,000**

PRODUCTION COSTS

For Costing, the Product to be marketed is considered as "Particle board" OR "**Medium Density Fiberboard (MDF)**". The Selling Price of **'Laminated (with Melamine on both surfaces) MDF'** with **thickness 20 to 25 millimeters**, in India is about Rs. 55/- per Square Foot, though Rs. 35/- and Rs. 175/- prices are also quoted.

Since, our product is "Formaldehyde-Free" this can get/demand higher price; but let us fix **Factory Sales Price as Rs. 20/-**

Cost of production (Per Day)

1. **Raw material:** Collection from site, loading on to the vehicle, transportation and unloading at the plant site (300 + 300 tons x Rs. 300)
   Rs. 180,000.

2. **Power:** (a) Electricity — Rs. 50,000.
   (b) Fuel (Firewood / LS/HS diesel, etc.) — Rs. 20,000.

3. **Labour:** — Rs. 130,000.

4. Reactant Chemicals, Catalyst, etc,. (300 tons x Rs. 400): — Rs. 120,000.

5. Overheads, including Effluent Treatment, etc.: — Rs. 30,000.

TOTAL: Rs. 530,000.

The quantity of Particle Board / MDF that can be produced is 100 sq. ft. of 25mm. thick board, per ton of raw material (used to make pulp), ie., Per day, from 300 tons, the Total production would be: 300 x 100 sq. ft. = 30,000 sq, ft.

Cost of Production for 30,000 sq. ft. Particle board = Rs. 530,000.

Cost of Production of ONE SQ. FT. of Board = 530,000 /30,000 = Rs. 17.7/-

Cost of Production before interest and Depreciation:

Cost of production = Rs. 17.70 per sq. ft..

The Selling price = Rs. 20.0 per sq.ft., (Min.)

Total Income, per day (3,000 sq. ft. x Rs. 20.0) = **Rs. 600,000.**

Daily Income over expenditure = Rs. 70,000.

Projected Yearly Income (Rs. 70,000 x 300 days) **= Rs. 21,000,000**.

PROFIT AFTER DEPRECIATION AND TAX

A. Yearly Gross profit based on 300 days working: Rs. 21,000,000.
B. Less Interest on Loans (@ 10%) = Rs. 3,300,000.
C. Depreciation at 10% (on machinery) = Rs. 2,100,000.
D. **Net Profit after depreciation and Interest = Rs. 15,600,000.**
E. Income Tax at 30% = Rs. 4,680,000.

Cash Generation

Depreciation Added Back = Rs. 2,100,000.

Net Cash Generated: = Rs. 17,700,000.

Profit as Percentage of Capital = <u>53.64%</u>

PRODUCTS

In the initial phase the product being manufactured would be Laminated Particle Board; the lamination will be with Melamine - Formaldehyde Resin; the product will be "Formaldehyde-free", with Cellulose, as the Resin and filler. Further, using wood powder as the 'filler' for Medium Density Fiberboard (MDF), which is made of pure cellulose and Formaldehyde-free also.

PRODUCT DESCRIPTION

Laminated Particle Board: Made out of **Poly-Fibrillated cellulose Resin**, which is made using Water hyacinth, and **Filler**, saw dust, large grain, powdered waste wood or similar waste of plant/ wood origin, and then laminated with **Melamine-formaldehyde** Resin sheet or Paper.

Medium Density Fiber board [MDF]: Contains **Wood Powde**r as the **Filler** in **Poly-Fibrillated cellulose Resin. The Board** will be workable, and can be cut and shaped as per the requirements.

The most important factor is that, these Particle Boards contain only "Green" materials and NO formaldehyde evolving Resin content, and hence "healthy".

TECHNOLOGY AND R&D

The basic technology is based on the Patent, i.e., India patent 413150, awarded to Prof. Varkey Mathew. This was developed after doing research, personally, for the last 15 years.

The raw material is the fresh, raw, Water hyacinth plant as a whole, including the roots, leaves and stem (bulb). Water hyacinth has to be collected from the water body using weed harvesting machine, which is available in different sizes and capacities for collection. The first stages of processing can be done immediately after collection so that the mass can get reduced by about 40% and transportation would become less expensive. The processing involves (i) **Chopping** into pieces of about one centimeter in length, and (ii) **Crushing**, when the material becomes softer and lighter due to removal of water. The crushed material can be transported in containers to the factory for further processing.

The other alternative is, transporting the collected plant material to the factory where it can get chopped and crushed, and the remaining processing done continuously.

The crushed raw material is then **fed into a boiler along with the required quantity of catalyst mixture** and some water, about 500 - 700 liters of water per ton, so that the water can be sufficient for smooth boiling and (iii) **Boiling** for 20 -30 minutes. The boiled / 'cooked' mass is drained and excess water (retaining sufficient water for the mixing of fillers) would be (iv) **Filtered or Centrifuged** off to generate the pulp of "fibrillated cellulose". The pulp is then (v) **Mixed with the Filler** and then spread into moulds or on conveyor system (with little High pressure for compactness of the composite), for (vi) **Polymerization- cum- Drying** with further provision for (vii) **Lamination** with melamine-formaldehyde resin.

Different fillers are used for various products: (a) **Powdered** (for uniform particle size) **saw dust** or any granular waste wood, or vegetative cellulose fiber material used for **Particle board with both surfaces laminated**; and (b) **well powdered wood / waste hard wood** can be used for manufacturing Medium Density Fiber Board (MDF).

FUTURE PRODUCTS

(a) **Floor Tiles, or Ceiling board / Side-wall panel board** can be made by using china clay as the material for composite formation.

(b) Another material for making **hard and strong moulded products** is the **Poly-fibrillated cellulose Resin** itself. Further research in the molding of such products is needed for finalizing the technology, say by including additional reinforcement like nylon fiber/fabric or steel wires/ mesh, etc, to make it strong / hard enough to compete with other hard materials like steel, FRP, plastics like PVC, etc.

Laminated particle board from poly-fibrillated cellulose resin composite

Poly-fibrillated cellulose resin

Moulded poly-fibrillated cellulose resin composite

Tiles made of poly-fibrillated cellulose resin composite

DEVELOPMENT REQUIREMENTS

Machinery: The following will be the requirement when Water hyacinth is used as the raw material for the generation of the Resin, Poly-fibrillated cellulose. (a) Water hyacinth harvester machine for the continuous supply of Raw material for production of Resin; (b) Chopping - cum - Crushing machine; (c) Mixing Equipment for catalyst (heat liberated during the process may be recovered); (d) Boiler for boiling about 3000 - 4000 liters of mixture in one batch or Continuous-flow boiler Equipment; (e) Filtration or Centrifuging (removing excess water) Equipment; (f) Mixing unit for uniform mixing of the pulp with filler, like, saw dust / wood chips / wood powder / china clay; (g) Moulding unit, either as mould for board of size 8 ft x 4ft, or Continuous spreading unit of width 4 ft, having pressure application System; (h) Polymerization - cum - Dryer for the moulding of boards, or continuously produced board, where cutting system also for keeping the size; (i) (Melamine) Surface Coating and Sizing Unit; and (j) Effluent Treatment unit for purifying the effluent from the filter / centrifuge, by neutralization, and removal of lignin by oxidation, etc. The end products to be dispatched to Godown.

In addition, (k) Transportation arrangement for raw material either as the collected plant or after chopping and crushing, and (temporary) (l) Storage arrangement for the raw material also to be facilitated.

SWOT Analysis

Strengths

1. The raw material used is the noxious, invasive weed, Water hyacinth, which has become a menace in more than 60 countries, affecting the lives of half of the world population.
2. The Resin, **Poly-fibrillated cellulose**, is a new form of cellulose fiber, generated from 'fibrillated cellulose fiber', having properties of Cellulose nanofiber / Nanocellulose fiber.
3. The raw material plant is consumed completely, including the roots and stem/bulb, so that NO portion that can pollute the environment would be left behind in the water source.
4. The end product being manufactured, Particle board, will NOT contain any component that would give out carcinogenic Formaldehyde, like the existing resins, Urea-formaldehyde or Phenol-formaldehyde. Thus, the new Resin is 100% "Green" and healthy for use indoors.
5. The processing utilizes only non-toxic chemicals, though complex, in aqueous medium, and hence no pollution of environment through effluents, after removal of small quantities of plant lignin.
6. NO high pressure or high temperature needed for the formation of the 'Polymer' in the molding of the Particle board, thus, manufacturing process consumes comparatively lower energy.

Weaknesses

1. Difficulty in collecting the raw material from small rivers, or lakes, especially in Kerala conditions,
2. Market for the new product to be found out by competing with existing brands of laminated particle / chip boards and also of MDF.
3. As the raw material, water hyacinth, contains high water content, transportation cost would be very high,
4. The solid content of cellulose fiber in the raw material is very less, (about 6% only), the production cost for unit mass will become comparatively high.

Opportunities

1. Project would be very effective for the removal of Water hyacinth menace from the water resources and get these water bodies cleared of the weed;
2. Greenhouse gas, carbon dioxide, generated by various means can get "Fixed" into the plant cellulose in large quantities, by converting the cellulose fibers as Boards or Tiles; a saving factor against Global Warming;
3. As the boards are 'Formaldehyde free' there will be NO EMISSION OF CARCENOGENIC Formaldehyde, and makes this board most suitable, healthy and 'green', for indoor construction, as for partition, cupboards, shelves, etc.
4. The removal of Water hyacinth carpets from the water bodies, its transportation and processing require human labour, and so job opportunities will open up for semiskilled and unskilled laborers throughout the developing countries where unemployment is a burning problem.
5. Removal of Water hyacinth mats from the water resources will generate the jobs that got lost due to its infestation, like drinking water availability, fishing, transportation, tourism, etc.

Threats

1. The existence of lots of 'engineered wood' manufacturers selling the formaldehyde resin containing boards and MDF worldwide would be very competitive for the marketing of the new brand.
2. The need for designing and construction of machinery adaptable for the specific raw material and for moulding, polymerization and drying of the pulp mix (pulp and filler mix) to form the composite product.
3. The collection of the raw material and its transportation would need much human labor, especially in locations where the same remains almost scattered in smaller lakes, ponds, canals, or rivers.

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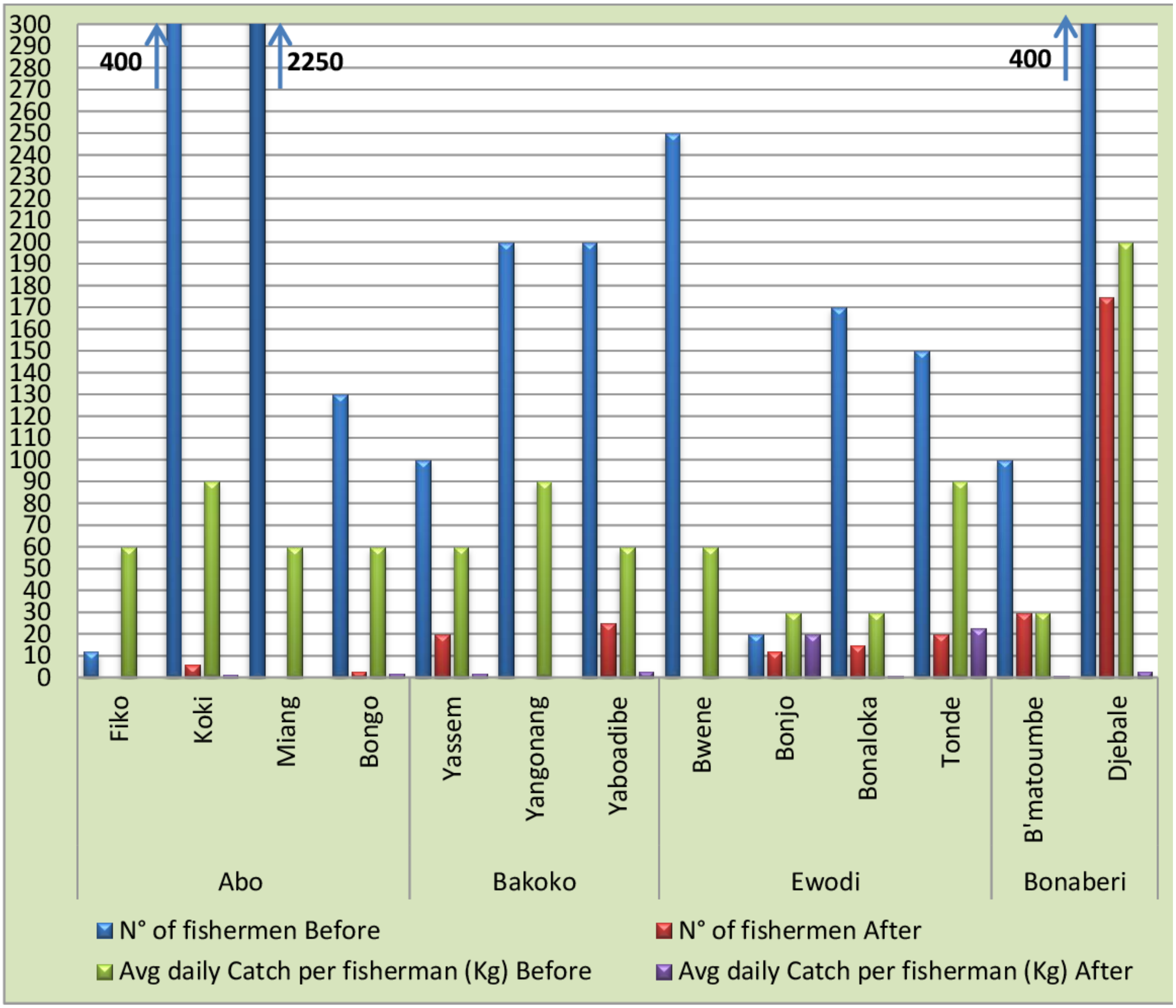
ANNEXURE 1



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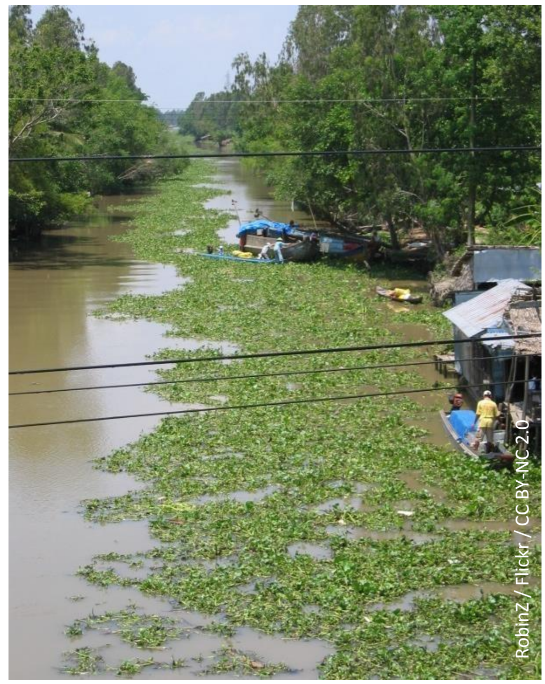
April 2013

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 (Téllez 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).

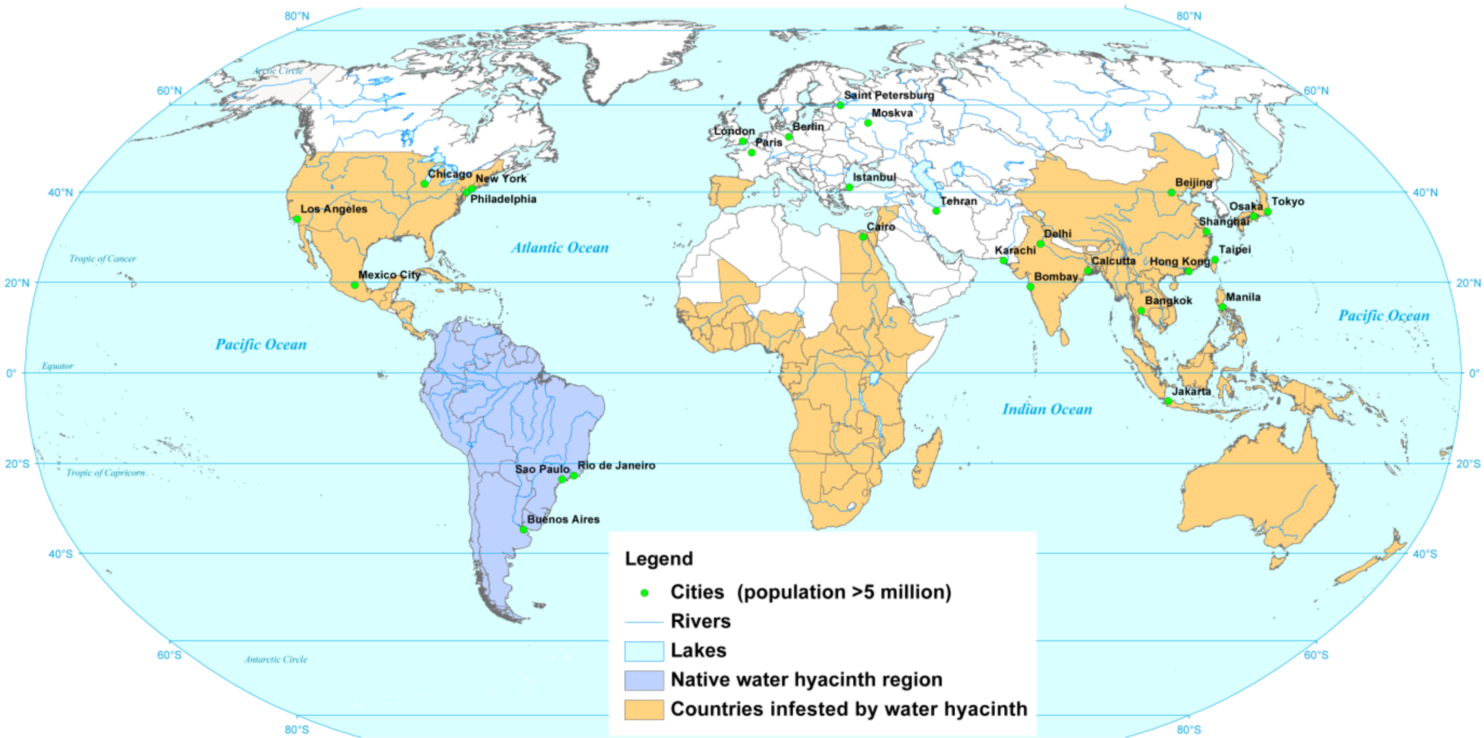
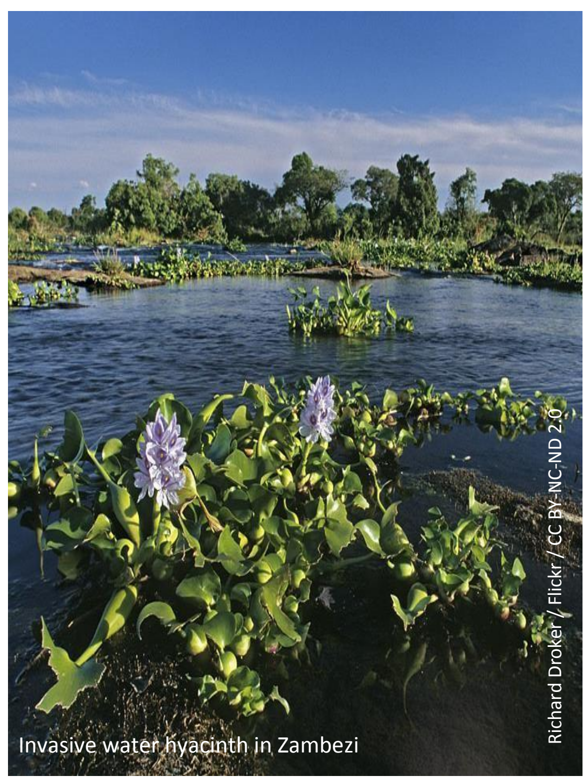


Figure 1. Global distribution of water hyacinth (Map redrawn by UNEP/DEWA from Téllez *et al.* 2008).

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



Invasive water hyacinth in Zambezi

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 (MWBP/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

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*

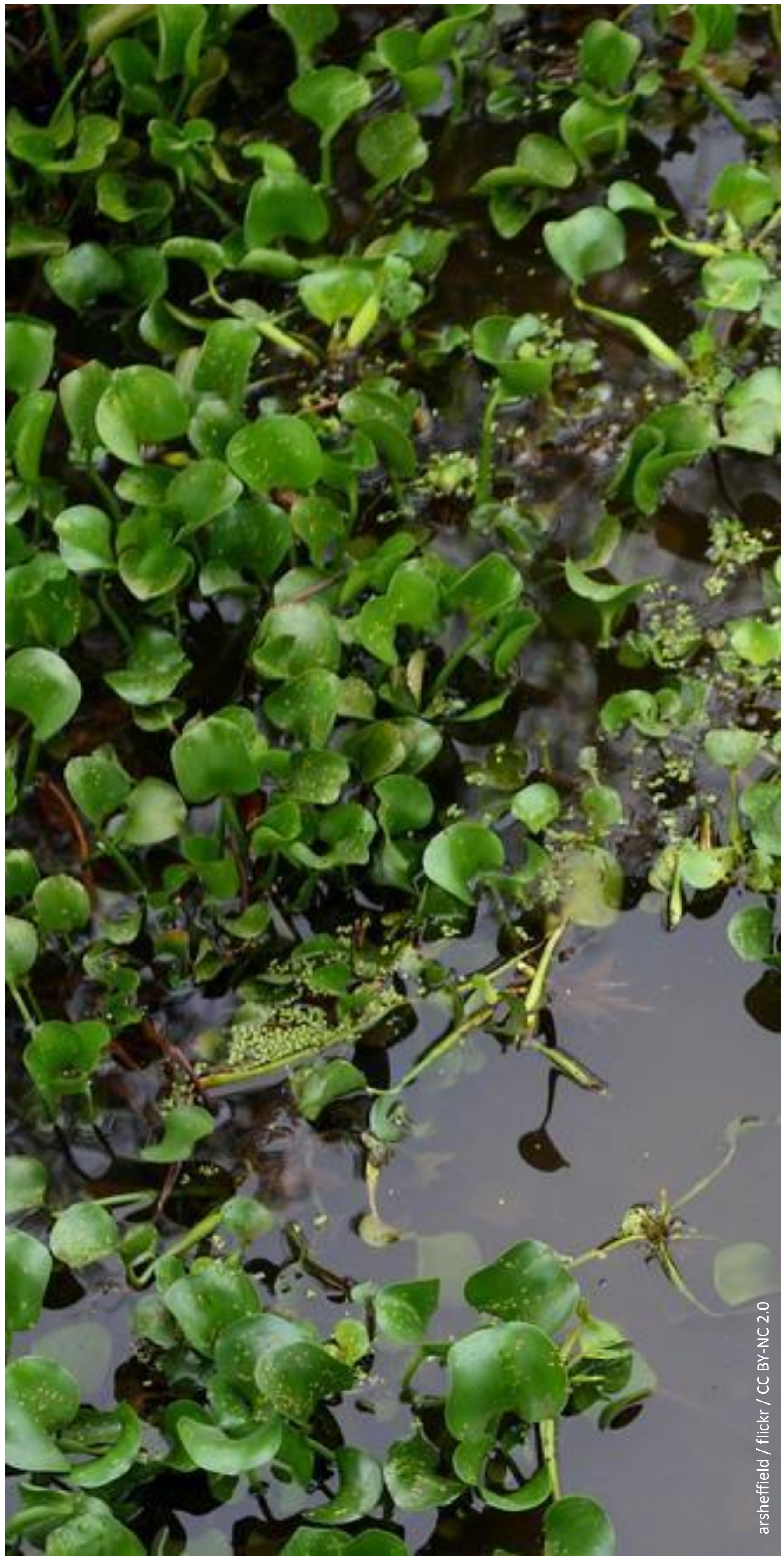
Floating mats of water hyacinth support organisms that are detrimental to human health. The ability of its mass of fibrous, free-floating roots and semi-submerged leaves and stems to decrease water currents increases breeding habitat for the malaria causing anopheles mosquito as evidenced in Lake Victoria (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).



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. <u>Biological control</u>

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 (Niphograpta 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).

Water hyacinth weevils

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).

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

Control of water hyacinth using fungal pathogens has greatly stimulated interest in the management of the weed. Several fungal species among theme *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).

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

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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