Aquatic weed classification, environmental effects and the management technologies for effective control in Kerala, India

Jayan P. R., Nithya Sathyanathan

(*Department of Farm Power Machinery and Energy, Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram, Kerala-679573, India*)

Abstract: Aquatic weeds, the unabated plants completing life cycle in water, are a serious menace to the environment. Dense colonies of aquatic weeds are observed in the southern regions of Kerala which mainly includes Ernakulam, Kottayam, Idukki and Alappuzha districts. The noxious aquatic weeds invades inland water masses, estuaries inshore regions of seas and are now abandoned. The rapid and excessive growth of aquatic weeds in varied and wide environmental condition limits the sustained performance of many drainage and irrigation system, reducing the productivity of agricultural land. Aquatic weeds are classified into emergent, floating and submerged weeds according to the various habitats. Many species are found in Kerala which were originally introduced into botanical gardens. The major aquatic weeds found in Kerala include *Salvinia spp.*, *Eichhornia crassipes, Pistia stratiotes, Alternanthera spp.*, *Azolla*, common duckweeds, *Hydrilla verticillata*. Reduction or elimination of aquatic weeds is possible through well planned management strategies which includes preventive and control (biological, physical, chemical, eco-physiological) measures. A successful weed control program depends on the resources available, the weeds present and the ability to carry out effective control methods. Operational research and /or pilot projects have to be initiated in the problematic areas on long term basis, using technical recommendations derived from research experiments.

Keywords: aquatic weeds, classification, effects, management technology

DOI: 10.3965/j.ijabe.20120501.010

Citation: Jayan P R, Nithya Sathyanathan. Aquatic weed classification, environmental effects and the management technologies for effective control in Kerala, India. Int J Agric & Biol Eng, 2012; 5(1): 76－91.

1 Introduction

Expansion of irrigation facilities, along with consolidation of the existing systems, has been the main part of the core strategy for increasing production of food with sustain and systematic development of irrigation grains. The irrigation potential in India has increased from 22.6 million hectares (mha) in 1951 when the process of planning began to about 102.77 mha at the end of the tenth plan. There is need for greater development of irrigation resources to increase food-crop production to meet the rapidly growing needs of the people. The average annual water availability of the country is assessed as 1869 billion cubic metres[1]. As we exploit ever increasing quantities of water, there is a collision course with rapidly spreading infestations of water weeds. As the irrigation facilities are expanded, the infestations of weeds multiply rapidly and today they are often the greatest cause of inefficient use and loss of water. Today, a large part of the one million hectare of inland water-area in this country is threatened by the invasion of noxious aquatic weeds. In many areas of Kerala, inland water masses, estuaries and also inshore regions of the sea are infested on a large scale by weeds. This grows very fast and it affects pisciculturists, as well as paddy

Received date: 2011-08-31 **Accepted date:** 2012-03-19

Biography: Nithya Sathyanathan, MTech (Environmental Engineering and Management), Research Associate, Project-DIFM Package for Kerala. Email: nithyasathyanathan@gmail.com.

Corresponding author: Jayan P. R., PhD (Farm Power Machinery), Associate Professor & Head, Department of Farm Power Machinery & Energy, Project Director (DIFM), Kelappaji College of Agrl. Engg. & Technology, Tavanur, Malappuram, Kerala-679573, India. Tel: +91-494-2687990; Fax: +91-494-2686214; Email: jayan.pr@kau.in; prjayan2003@yahoo.co.in.

cultivators. The weed species associated with lowland and deepwater rice are essentially aquatic, and can also be found in other water resources[2].

Some of the main canals, and the network of drainage and seepage channels, are so badly infested with these weeds that they reduce the capacity of water flow from 50%-80%. Aquatic weeds are a potential danger to the entire water system because they clog grates, valves, and sprinkler heads. Because of the diverse climatic conditions and the wide range of rainfall, some species of aquatic weeds persist in many areas and pose critical and continuous problems. Several irrigation and hydroelectric projects are endangered by infestation of dams and reservoirs with their massive growth of aquatic weeds[3]. Use of some of these weeds as nutrient sources for fish feed formulation will not only at least partly replace the rather expensive, conventional commercial aqua feeds and assist the pisciculture of this region, but might restrict the alarming growth of these weeds that are affecting the ecosystem.

2 Aquatic weeds

Aquatic plants are the basis of a water body's health and productivity. They are unabated plants which grow and complete their life cycle in water and cause harm to aquatic environment directly and relatively to eco-environment. Many aquatic plants are desirable since they may play temporarily a beneficial role in reducing agricultural, domestic and industrial pollution[4]. Aquatic weeds in India belong to various taxonomic groups and ranges from simple unicellular and multicellular plants to highly complex multicellular plants[5]. Aquatic weeds mostly propagate by vegetative means. They play a useful role of providing continuous supply of phytoplanktons and help fish production. They are also beneficial as physical stabilizers of banks and bottoms of these waterways and promisingly produce oxygen via photosynthesis and assimilation of pollutants via growth[6].

3 Classification of aquatic weeds

Aquatic weeds are classified according to various habitats which form their eco-environment and become conducive for their growth, reproduction and dissemination. Three types of aquatic weeds are found in Kerala:

1. Emergent weeds
2. Floating weeds
3. Submerged weeds

Emergent weeds grow in shallow waters and situations existing near the water bodies where water recedes and rises with the seasons or regular releases from a large water body or reservoir.

Floating weeds are observed in the surface of the large, deep and shallow depths of water bodies; deep continuous flowing canals; continuously flowing rivers; large ponds tanks, etc. Some of the weeds in this ecosystem freely float and move long distances, while some of them do float on the water surface but anchor down to soil at the bottom of the water body. These weed species make loss of water through evapotranspiration in addition to obstruction caused in flow of water. They are classified into two sub-groups as free floating and rooted floating weeds.

Submerged weed species germinate or sprout, grow and reproduce beneath the water surface. Their roots and, reproductive organs remain in the soil at the bottom of the water body. These weeds damage the maximum, because they are not visible on the surface and impede the flow of water varying upon the degree of their intensity and growth. Most of these weeds are found in shallow and medium deep water bodies and continuous flowing canals and drainage ditches.

The dominant weeds of the aquatic environment of India are given in Table 1.

Table 1 Major aquatic weeds in India

Type of weeds	Plant species
Emergent	*Typha angustata* *Ipomea carnea* *Eclipta prostrata* *Paspalum maritimus* *Phragmites karka* *Polygonum glabrum*
Floating	*Eichhornia crassipes* *Salvinia molesta* *Lemna polyrhiza* *Nymphaea nauchali* *Jussiaea repens* *Azolla pinnata* *Nymphaea stellata* *Nelumbo nucifera* *Ipomea aquatica* *Pistia stratiotes*

Type of weeds	Plant species
Submerged	*Hydrilla verticillata* *Potamogeton pectinatus* *Potamogeton crispus* *Potamogeton perfoliatus* *Myriophyllum spicatum* *Zanichellia palustris* *Ceratophyllum demersum* *Vallisneria spirallis*

4 Aquatic weed distribution in Kerala, India

The prominent species of aquatic weeds in Kerala are *Salvinia spp., Eichhornia crassipes, Pistia stratiotes, Alternanthera spp.*, Azolla, common duckweeds, *Hydrilla verticillata etc*. Their characteristic features and distribution pattern are discussed.

4.1 *Salvinia spp. (Water fern)*

Water ferns are free floating aquatic weeds of Brazilian origin. It reached India perhaps through introduction into botanical gardens. It was first observed in 1950s in Veli Lake, Trivandrum, Kerala and assumed pest status since 1964[7]. It covered large water areas within a few months. In only five years after its introduction, it has become a menace both to navigation and rice farming[8]. It has both direct and indirect effects on the aquatic environment, especially due to its habit of choking rivers, canals, lagoons and other water bodies. The most-affected crop plant is rice, where Salvinia infestations can interfere with cultivation and reduce yields by competing for available nutrients[9]. It is so competitive that it has replaced *Eichorrnia crassipes* and *Pistia stratiotes* weeds. Irrigation supply to paddy is also hindered in about two lakh hectare areas due to these weeds.

It has become established as a dreadful weed occupying large areas of open water, causing navigational problems, interfering with irrigation and fishing, rendering the water unfit for human consumption, and facilitating mosquito breeding. The hydrogen sulphide generated in the decaying weed-mass in the water is destructive of generative equipment in hydroelectric installations, blocks intake apertures of ships, and damages engines of small motor-boats. In addition, the weeds cause reduction in the stored water of reservoirs, owing to excessive evapo-transpiration, while thick mats of *Salvinia molesta*, which later form large floating islands supporting secondary and tertiary colonizers, may be instrumental in the gradual drying up of natural and man-made water-bodies[10]. During tidal movements, especially in the backwaters and estuaries, the large quantities of these weeds are transported to the inshore regions of the sea and they pollute the beaches and intertidal zones, thus affecting the littoral fauna. The inshore benthic community is also affected to a great extent by the settlement of dead and decaying Salvinia.

Figure 1 *Salvina molesta* infested water bodies

The area occupied by Salvinia at times is so vast that physical removal involves considerable labour and cost. Chemical control would involve the use of large quantities of chemicals which may pose a threat to the inland and estuarine fauna. In Kuttanad area alone, which is considered the rice bowl of Kerala, some 75 000 acres of canals and another 75 000 acres of paddy fields are affected by this weed. It chokes rivers, canals, lagoons, and covered Kakki and Idukki reservoirs; navigation, irrigation, fishing, shell collection and other operations were hindered. In some areas cultivation of paddy had to be abandoned on account of Salvinia infestation[11].

4.2 *Eichhornia crassipes (*Water hyacinth)

Water hyacinth, popularly known as *kulavazha*, is one of the most invasive and gregarious aquatic weeds of Kerala. Although it reproduces mostly by offshoots, seeds too play a major role in the survival and colonization of water hyacinth[12]. In Kerala, it is widely seen in the paddy fields, lakes, streams and channels, making large areas uncultivable, inaccessible and non-navigable. Water hyacinth also interferes with hydropower generation and obstructs water flow in irrigation channels; besides, facilitating rampant mosquito breeding in the aquatic systems, and fostering water-borne diseases. During the last decade or so, water hyacinth spread throughout Kerala causing widespread problems to the public who use these water bodies and other static water resources[13]. The alleviation of this problem, therefore, will greatly benefit the people whose livelihood security and health are threatened by the spread of this weed.

Figure 2 Waterways choked with water hyacinth

Among the multiple factors causing the aquatic weeds' growth, the geographical and climatic factors like topography, depth of water bodies, extent of silting and water qualities are the most important. International experience[14,15] shows that the plant's reproductive capacity, adaptability, nutritional requirements and resistance to adverse environments make it impossible to eradicate, and difficult to control.

4.3 *Pistia stratiotes* (Water lettuce)

Pisia stratiotes are naturalized in India and South East Asia. It is a free floating plant with rosettes with densely pubescent leaves and numerous roots. They are perennial or annual, usually seen in fresh water bodies, brackish water or salt water. They propagate by berries, seeds or detached rosettes, mostly dispersed by water but fruits may be eaten by animals and spread the seeds.

Figure 3 *Pistia stratiotes*

4.4 *Alternanthera spp. (Alligator weed)*

Most of the species are found in tropical warm regions of the world. It a perennial herb, stem often forming tangled masses in water or along the shore. It is regarded as a valuable food for live stock particularly pigs, used as green manure, vegetable and in medicine.

Figure 4 *Alternanthera philoxeroides*

4.5 *Azolla pinnata* (Water velvet)

Azolla pinnata is native to much of Africa, Asia from China to Japan, India and the Philippines, and parts of Australia. It is an aquatic plant, found floating upon the surface of the water. It grows in quiet and slow-moving water bodies, because swift currents and waves break up the plant. This is a small fern with a triangular frond measuring up to 2.5 cm in length which floats on the water. The frond is made up of many rounded or angular overlapping leaves each 1 or 2 mm long. They are green, blue-green, or dark red in color and coated in tiny hairs, giving them a velvety appearance. The hairs make the top surface of the leaf water-repellent, keeping the plant afloat even after being pushed under. A water body may be coated in a dense layer of the plants, which form a velvety mat that crowd out other plants. The hair like roots extends out into the water. The leaves contain *Anabaena azollae*, which is a symbiont that fixes nitrogen from the atmosphere that the fern can use. This gives the fern the ability to grow in habitats that are low in nitrogen. The plant reproduces vegetatively when branches break off the main axis, or sexually when sporocarps on the leaves release spores.

It is a pest of waterways because its dense mats reduce oxygen in the water. The weevil *Stenopelmus rufinasus* is used as an agent of biological pest control to manage *Azolla filiculoides*, and it has been found to attack *A. pinnata* as well. Rice farmers sometimes keep this plant in their paddies because it generates valuable nitrogen via its symbiotic cyanobacteria. The plant can be grown in wet soil and then ploughed under, generating a good amount of nitrogen-rich fertilizer. The plant has the ability to absorb a certain amount of heavy metal pollution, such as lead, from contaminated water. It is 25%-30% protein and can be added to chicken feed.

Figure 5 Azolla pinnata infested water bodies

4.6 Common Duckweed (*Lemna minor*)

It is a floating freshwater aquatic plant, with one, two or three leaves each with a single root hanging in the water; as more leaves grow, the plants divide and become separate individuals. The seed is 1 mm long, ribbed with 8-15 ribs. It grows in water with high nutrient levels and a pH of between 5 and 9, optimally between 6.5 and 7.5, and temperatures between 6℃ and 33℃. Growth of colonies is rapid, and the plant frequently forms a complete carpet across still pools when conditions are suitable. It is an important food resource for many fish and birds (notably ducks) because it is rich in protein and fats. Birds are also important in dispersing the species to new sites; the root is sticky, enabling the plant to adhere to the plumage or feet while the bird flies from one pond to another.

Figure 6 Duckweed infested water bodies

4.7 *Hydrilla verticillata*

It is one of the most notorious submerged aquatic weed forming masses growing in static or slowly flowing water, often very abundant and dominant in large areas. It is a submerged perennial herb rooted with long stems that branch at surface where growth becomes horizontal and dense mats form. Thick mat like growth block sunlight penetration to native plants growing below. It seriously affects water flows and water use. Its heavy growth may obstruct boating, swimming and fishing in lakes, rivers and blocks withdrawal of water used for power generation and agricultural use.

Figure 7 *Hydrilla verticillata*

5 Aquatic weeds as an environmental menace

Aquatic weeds occurring in flooded rice fields and other arable lands constitute a serious menace to agriculture. In agriculture, the weeds cause huge reduction in crop yields, increase the cost of cultivation, reduce input efficiency, interfere with agricultural operations, impair quality, and act as alternate hosts for several insect pests, diseases and nematodes. They compete with crop plants for various inputs/resources like water, nutrients, sunlight etc[16]. They are not only potential sources of invasion to croplands, but cause flooding, seepage, evapo-transpiration loss, decreased water delivery and silting in irrigation channels[17]. Invariably aquatic plants become over abundant or unsightly and require control[18].

Figure 8 Weeds attacked waterways of Kumarakom, Kerala

The environmental problems created by aquatic weeds are:

- *Ideal for mosquito breeding*: Aquatic weeds create situations which are ideal for mosquito growth. The mosquitoes are sheltered and protected from their predators by aquatic weed roots and leafy growth and are responsible for the spread of malaria, yellow fever, river blindness and encephalitis.
- *Meagre fish production*: Fish production is greatly affected by the presence of floating and submerged aquatic weeds. Isolated weed beds may be tolerated, providing shelter and shade for fish, but when the growth becomes thick and covers entire water body, it becomes lethal for fish growth. Fish suffocates from the lack of oxygen and dies.
- *Foul smell*: The decomposition of huge amounts of biological mass creates condition where carbon dioxide and carbon monoxide are produced and released to the atmosphere creating foul smell unpleasant to public.
- *Choking water bodies*: Unwanted growth of aquatic weeds hinders the movement of boats and the decomposition of weed material consists of siliceous material and other insoluble salts which settle on the bottom of the water body. Dense weed growth slows the flow of water in rivers, canals and drainage ditches allowing silt to settle out and gets deposited on the bed of the water body. This increase in silt deposition raises the bed level and finally affects the life of lakes, dams, tanks, etc.
- *Deteriorating water quality*: Aquatic weeds cause taste and odour problems and also increase biological oxygen demand because of organic loading. They increase the organic matter content of water which affects the strength of the concrete structures when used as curing and mixing water.
- *Water-logging*: Aquatic weeds impede the free flow of water which may contribute to increased seepage and may cause rise in water-tables in the adjoining areas which leads to water logging. This also causes saline or alkaline conditions in the soil and gives rise to many other terrestrial weeds.
- *Tremendous spreading of weeds*: Submerged and floating weeds propagate at a tremendous rate. The surface floating weeds get interwoven and

form dense mats that move downstream. Often these moving mats pack up against bridges and structures creating enormous pressure that sometimes results in serious damage. Over time, if left unchecked, the weed mats become so dense that people and animals can walk on them, although at the risk of injury or drowning.

Aquatic weeds interfere with the static and flow water system. They cause tremendous loss of water from water bodies like lakes and dams through evapo-transpiration. In flowing water system, aquatic weeds impede the flow of water in irrigation canals and drainage channels thereby increasing evaporation damage structures in canals and dams, clog gates, siphons, valves, bridge piers, pump, etc. Impediment in flow of water may result in localised floods in neighbouring areas. The harmful effects are:

- Reducing water storage capacity in reservoirs, tanks, ponds
- Impeding flow and amount of water in canals & drainage systems
- Reducing fish production
- Interfering with navigation and aesthetic value
- Promoting habitat for mosquitoes

Since rice (*Oryza sativa* L.) is a major cultivated crop in Kerala, weed problems in rice culture are of great concern. Nearly 40 000 hectares of rice land around Vembanad lake and large areas along the canal systems of Kottayam, Alleppey, and Ernakulam in Kerala State are severely infested. The rice crop suffers severely from competition when infested by aquatic weeds during the initial stage of growth. The losses may range from 30% to 60%. The prevalent method of flooding the field for rice cultivation magnifies the threat of aquatic weed infestation by way of the incoming waters.

The velocity of flowing water is reduced by about 30% - 40% due to the presence of aquatic weeds. Floating and deep rooted submerged weeds interfere with navigation. Water hyacinth and Alligator weed grow profusely and create dense mats which prevent the movement of boats and at times even large ships. Therefore, considering the losses caused, it is essential to keep aquatic weeds under control in water bodies, flow water systems, ponds and tanks so that these systems can be utilized to best of their efficiency.

6 Aquatic weed management

Aquatic weeds share some common characteristics that contribute to their success as weeds such as their prolific growth rates, high seed-output, multiple modes of propagation including clonal and sexual propagules (by vegetative fragments, tubers, turions, and rhizomes), and high vegetative and physiological plasticity that imparts intense competitiveness and environmental fitness[19,20]. These traits contribute to the difficulty and complexity of aquatic weed management.

Management of aquatic weeds consists of two approaches, namely, preventive and control of existing infestation.

The success of preventive weed management programs depends on the weed species, its means of dissemination and the amount of effort applied. It usually requires community action through the enactment and enforcement of appropriate laws and regulations. Aquatic weed control is complicated because of lack of absolute ownership of a water body. Frequently, approval is required from public health departments, the water surveyor and fish and wild life agencies. Interaction of various agencies is a prerequisite for the success of an aquatic weed control programme. Type of aquatic weeds flora and their intensity influence the damage caused by them. The habitat and the type of aquatic weed flora influence the technique of weed control. In broader sense, weed control means keeping the weeds at a level where they do not cause economic damage. Aquatic weed can be brought under control to manageable limits by various methods. Broadly, these methods can be grouped under four types:

(1) Physical or mechanical methods

(2) Eco-physiological alterations

(3) Biological methods

(4) Chemical methods

The detailed descriptions of the methods are discussed.

6.1 Preventive methods

Management of aquatic weeds in water reservoirs, canals, drainage systems, ponds etc. consists of following system approaches of aquatic weed management i.e., following prevention, eradication and control techniques based on the habitat and type of weed flora present in a given situation. The success of preventive weed management programmes depends on the weed species, its means of dissemination and the amount of effort applied. It usually requires community action through the enactment and enforcement of appropriate laws and regulations. There is in need of strict implementation of quarantine laws in India for the effective aquatic weed management.

6.2 Aquatic weed control

6.2.1 Manual and mechanical control

Traditional practice of aquatic weed removal manually is inadequate to keep them under control. It is difficult to standardise manual labour operations due to various weeds, biomass, and efficiency of workers in terms of work output resulting in varied costs for comparing this method from one area to another[21].

In India where labour is cheap, manual methods are often employed to remove weeds. In small water bodies, traditional methods of hand picking, uprooting of emergent and marginal weeds and cutting them with scythes are considered suitable. In West Bengal weed cutting launches by using V shaped sickles for cutting *Colocasia* and other tall weeds in shallow waters. Power winches are employed in Assam to clear shallow waters thickly infested with water hyacinth. Recently diesel operated winches are used in Orissa to eradicate dense rooted submerged vegetation. Marginal weeds could also be controlled by grazing and deepening of the marginal shelves; floating weeds can be prevented from spreading by draining, desilting and by erecting barriers[22]. The traditional method now practiced in Kuttanad area consists of draining the paddy field, collection of weeds into heaps and then dragging them on coconut leaves to the border bunds (Figure 9 (a), (b)) [23].

Physical removal of weeds is the oldest and the most common method used all over the world. The equipments used for the physical control have to be modified. Physical control of aquatic weeds is free from residue of pollution problems. However, repeated removal of massive quantities of vegetation from a water body removes large quantities of nutrients from it. This may reduce food production in the primary as well as secondary trophic levels. Physical weeding is a non-selective process so that the chances of establishment of a specific weed are remote. Mowing, crushing, raking, burning and mechanical chaining, dredging and netting are some of the well known physical methods.

(a)

(b)

Figure 9 (a) *Salvinia* piled into small heaps (b) Sledging the heaps to boarder bunds

- *Dredging*

The dredge is equipped with a bucket or with a weed fork or other special tools. It removes most of the weeds, but it takes out a lot of mud in the process. The weed fork drags out plant growth, but leaves most of the mud behind. Although the operation is efficient for complete removal of weeds, the process is slow, untidy and expensive.

- *Drying*

Drying is a simple, inexpensive and satisfactory method for controlling submerged aquatic weeds. Water is withdrawn from the pond or ditch or drained from the ditch bottom and the top of submerged weeds will dry up after several days of exposure to sun and air. Drying may be reported to control regrowth from roots or propagules in the bottom mud or sand. Drying is ineffective against emerged weeds which are rooted in the bottom.

- *Mowing*

Mowing is done to control weeds on the ditch banks. Small patches of shoreline emerged weeds are cut with scythes or swords. For cleaning the large ditch banks, power equipment need to be used where the banks are relatively smooth and not too steep. The effects of mowing are usually short lived.

- *Hand cleaning*

In sparsely infested areas, hand cleaning may be the most practical method of aquatic weed control. The man use heavy knives and hooks to cut and remove the accumulated weed growth. The Kerala State Electricity Board succeeded in getting rid of *Salvinia* by manual removal in 1977 from the Kakki reservoir but at a very considerable cost [24].

- *Chaining*

A heavy chain is attached between two teams or tractors on opposite banks of the ditch. As they move, the chain drags over the weeds and breaks them off. The method is effective against submerged and emerged weeds. Chaining is not usually done until a ditch is severely clogged and is repeated at regular intervals. Chaining is limited primarily to ditches of uniform width, and accessible from both sides with tractors

- *Burning*

Burning is used to control ditch bank weeds. Best results are obtained by first searing the green vegetation followed by complete burning after 10-12 days. In searing, a hot flame is passed over the vegetation at such a rate which only wilts the plants without charring.

- *Cutting*

A mechanical weed cutter is used to cut the submerged weeds at 1-5m deep in the water. It consists of a sharp cutter bar operated hydraulically from a boat. The harvested weeds float to the water surface and are removed manually or by using sieve buckets. This is inexpensive and relatively more effective.

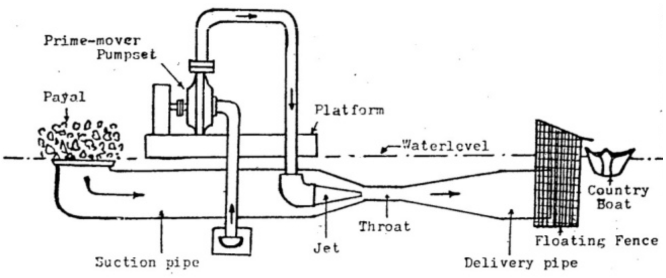
- *Water weed cutters and harvesters*

In high discharge canals and very large water bodies weed cutters/harvesters are used to control rooted submerged weeds. Under water cutters are normally attached to a motorboat. The equipment consists of sharp and strong cutter bars with heavy reciprocating blades, sliding against a fixed blade. Harvesters cut and pick up the weeds from water body and convey these to shore simultaneously. Under water weed cutters were employed at Kota (India) to clear Chambal canal from aquatic weeds[25]. At the Central Institute of Fisheries Technology (CIFT), a portable machine gadget has been developed which can clear both floating and submersed weeds at the rate of 1-1.5 ha per day.

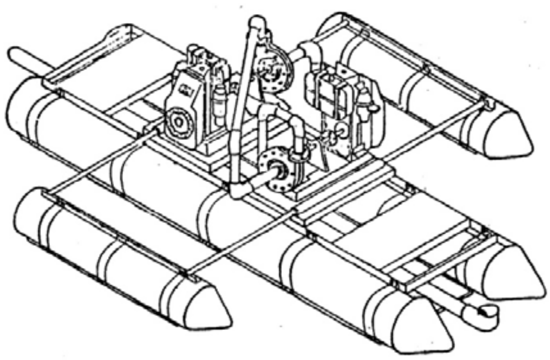
Floating booms made of bamboo poles tied with ropes and nets are used for encircling a portion of the weed infested area and bringing the trapped weeds ashore. During the floods, the weed blankets move down the water course and reach the sea where they get destroyed easily in saline water [26].

A novel fluidization technique for harvesting the *Salvinia* weed was proposed based on the principle of a high capacity water jet device to improve the discharge capacity of the conventional irrigation pumpsets [27]. They suggested that a portable pumpset can be used as a primemover to produce the primary flow which will induce the weed to move through an ejector system into the collection tank.

Kerala Agricultural University has developed a *Salvinia* harvesting machine which utilises conventional pumpsets as the prime mover. A high capacity check device build into the machine sucks, fluidises and pumps out the weed material to the desired height or location. A 10 horsepower machine achieved a harvesting rate of 16 tons/h for continuous operation. With this machine, the harvesting cost will be in the order of $ 2 - 3 per hectare as compared to $ 20 - 30 per hectare for manual removal[28]. The four major components of this machine are a twin pontooned floating platform on which harvester is mounted, an engine driven high head pump set which serves as the prime mover for the ejector system, a high capacity jet device which multiplies the pump discharge by about four times, and a floating container placed at the delivery side of the ejector system for collecting weed (Figure 10 (a), (b)). The prototype ejectors were modified for better performance of removing the weeds in one hectare in 10 hours[29].



(a)



(b)

Figure 10 (a) Schematic of *Salvinia* harvesting mechanism (b) Isometric view of *Salvinia* harvesting machine[29-30]

The harvester developed by M/s Kelachandra Precision Engineers, Kottayam, Kerala (Figure 11) consists of a steel barge fitted with conveyor belts and is driven by a marine diesel engine of sufficient capacity for operating the hydraulic system. Navigation is by propellers or paddle wheels. The steel fabricated hull of 6-7 m long, 2.5-3.0 m wide and 0.6 m height enables it to traverse through shallow and narrow waters. The system consists of 3 conveyor belts. The first to collect the weeds onto the barge, the second for storage and the third for discharge onto land or to a transport barge.

Figure 11 Aquatic weed harvester developed by M/s Kelachandra Precision Engineers, Kottayam, Kerala

The harvester works on hydraulic power generated from a diesel engine of suitable capacity driving a hydraulic pump which supplies oil under hydraulic pressure to various motors and cylinders operated by DC valves. The paddle wheel motors are independently controlled for forward and reverse motions and for turning. The harvester is capable of turning on its own axis with zero turning radius which makes it easily maneuverable. The speed of the craft is about 5-7 km/h. The harvester is capable of removing 40-80 tonnes of weeds per day if 2-3 cycles are performed in an hour. Cost varies from \$70,000 - \$1,50,000 depending upon the size. Since the harvester is fully indigenous, replacement of parts and servicing can easily be handled and delivered. The additional attachments for the harvester includes transport barges used on larger waterways to shuttle weed loads to shore thereby increasing the efficiency of a harvesting program and shore conveyors deployed at the water edges serving as an unloading link between land and water.

Limitations

- Provides temporary relief from aquatic weeds.
- Physical removal by machines often induces their dissemination to new sites.
- Repeated physical removal depletes the water body of its nutrients, reducing growth of planktons.
- It is dependent on human labour, work efficiency, under water weed harvesters, lifting and transport of aquatic weeds from water body to points of disposal.

6.2.2 Eco-physiological alterations

Aquatic weeds can be controlled by (a) water level manipulation (b) manipulation of light intensity, manipulation of nutrient availability and competitive displacement.

The various eco-physiological alterations include:

- *Drying or water level manipulations*: Most of the aquatic weeds respond quickly to changes in water level. Control is achieved by either dehydration of the vegetation or by exposure to low temperatures. Planting of trees on the banks of canals may create shade to reduce light intensity hence checking the weed growth. Drying or water level manipulation is generally practiced in flowing water system like irrigation canals, drainage ditches.

- *Light*: Growth of submerged aquatic plants in small tanks and ponds can be checked by reducing light penetration. Use of fiber glass screens, coloring chemicals have also been tried for intercepting solar radiation reaching the water.
- *Breaking of anchorage*: The weeds which are anchored and in growing form should be checked so that they can be successfully managed. The side walls of the infested area may be covered with coloured polyethylene to exclude all light penetration and facilitate early decomposition of plant materials.
- *Competitive displacement*: It includes the replacement of harmful vegetation by relatively less harmful and beneficial vegetation. Extensive research has to be done in this approach. Besides direct competition, growth is also suppressed by some plants by shading effect.

6.2.3 Biological control

Technologies employing natural systems, biological organisms, bio-pesticides would gain importance to overcome or reduce the dependence on herbicides, wherever possible. The increasing cost of labour and materials and the risk of polluting our aquatic environments by the continued use of chemicals make it imperative to use suitable biological methods for the control of aquatic weeds[31].

Any plant feeding organism may be used to control aquatic weeds, providing it does not harm plants of economic value or create undesirable imbalances in plant community. The control of submerged, emerged, and floating weeds can be done using pathogens, fishes, insects. Maximum degree of success with classical biological agents in India has been achieved in biological control of aquatic weeds (55.5%) followed by homopterous pests (46.7%).

Three shipments consisting of 600 adults of *Cyrtobagous salviniae* were supplied to Kerala Agricultural University, Thrissur, for multiplication and field release in Kerala in 1983. Releases in Kerala, resulted in establishment of the weevils in ponds/tanks at Panancherry, Elanjikulam, at Vembanad lake and canals such as Athirampuza and Moncompu. Maniyamparampu-Thalayolaparampu canal extending for a stretch of about 15 km. The population of Salvinia was drastically reduced in irrigation canals in Thrissur and Thiruvananthapuram to Shoranur canal. Kerala Agricultural University, Thrissur, and the Department of Agriculture, Kerala, distributed country boat loads of weevil infested weed mats in all parts of Kuttanad for hastening biological control of *S. molesta* in Kerala. Within a span of three years after release and establishment of *C. salviniae*, most of the canals abandoned due to the weed menace have become navigable once again. There is considerable saving in the time taken for navigation through canals and amount of fuel consumed by motorboats. Population of the weed is thin and scanty in most of the paddy fields in the release areas. Already about 2 000 km^2 areas of the weeds have been cleared by *C. salviniae*. By 1988 in the case of paddy cultivation, where $ 5 had to be spent per hectare for manual removal, the savings on account of labour alone were about $ 1.5 Lakhs annually.

Plant pathogens have characteristics that make them desirable candidates as biological control agents for aquatic weeds. They are : (1) numerous and diverse (2) host specific (3) easily disseminated and self-maintaining (4) capable of limiting population without eliminating the species (5) non-pathogenic to animals[32].

In India, *Neochetina bruchi* and *Neochetina eichhorniae* coexist on water hyacinth in the same habitat in about 1:0.04 ratio (unpublished data). Spectacular success has been achieved at Hebbal tank in Bangalore (India) causing 95% control within a span of two years, Loktak lake in Manipur[33] and several ponds in Jabalpur[34]. However, there were several instances where weevil releases have been a total failure, for example Kengeri tank in Bangalore[35].

Orthogalumna terebrantis was field released from 1990 at Alleppey, Botjetty, Chakka, Kokkalai, Kottayam, Kumarakom, Moncompu, Marathodu, Thrissur, and Thiruvananthapuram in different spots at each of the water bodies. *O. terebrantis* established all over the release sites and spread far and wide across the vast stretches of Kuttanad backwaters of Kerala. The mite was more efficient in water bodies where weevils, *Neochetina spp*. have established. *O. terebrantis* has established in Kerala and Karnataka and it complements the two exotic weevils in hastening the collapse of water hyacinth. In Kerala where *N. eichhorniae* and *N. bruchi* are slow in managing water hyacinth, *O. terebrantis* on its own is providing effective suppression of water hyacinth in certain areas. The impact is more pronounced in partially shaded areas or under bridges.

There are innumerable reports of excellent control of Parthenium by the Mexican beetle[36] and that of water hyacinth by Neochetina spp.[37]. A noctuid caterpillar *Namagana pectinicoris* causes extensive damage to this weed and is an potential bio-control agent[38]. A list of the successful biocontrol agents against some of the problem aquatic weeds are given in Table 2.

Table 2 Organisms used for biological control of aquatic weeds

Type of organism	Name of the weed	Biocontrol organism
Arthropods	*Alternanthera phioxeroides*	*Agasicles hygrophila*
	Salvinia molesta	*Cyrtobagous salviniae* and C. singularis
	Eichhornia crassipes	*Neochetina eichhorniae* and *N. bruchi* *Orthogalumna terebrantis* *Sameodes albiguttalis*
	Pistia stratiotes	*Neohydronomous puichellus* *Epipsammia pectinicornis*
	Hydrilla verticillata	*Parapoynx dimunutalis* *Bagous* spp. *Hydrellia* spp.
Fungi	*Eichhornia crassipes*	*Alternaria alternata* *A. eichhorniae* *Cerespora rodmanii* *Fusarium eguisetii*
	Hydrilla verticillata	*Fusarium roseum* culmorum
	Pista stratiotes	*Cercospora* sp. *Scierotium rolfsi*
	Salvinia molesta	*Myrothecium roridum*
	Alternanthera phioxeroides	*Alternanthera alternantherae*
Phytophagous Fish	Different aquatic weeds	*Ctenopharyngodon idella* *Hypothalamichthys molitrix* *Tilapia melanopleurea*

6.2.4 Chemical methods

Chemical methods employs chemical herbicides which enables control of aquatic weeds quickly and efficiently, albeit temporarily. The present generation of aquatic herbicides is generally safe when used according to the labeled directions.

An herbicide should have certain specifications for its use in different types of aquatic environments.

- It should have high degree of phytotoxicity to kill weeds fast.
- The chemical should degrade or dissipate from water immediately after the action on weeds.
- Technology should be available for their use in static or flow water systems.
- It should be environmentally safe for humans, fish and other aquatic fauna. Many herbicides are harmless to fish at concentrations required for control of weeds.

Apart from physical methods, chemical methods employing hormone weedicides have been widely used against floating and emergent weeds because of their non-poisonous characters, moderate costs and suitability in most types of water. The usefulness of a few other weedicides/algicides against specific infestations including submerged weeds/algal blooms in confined water have been demonstrated.

Aquatic weeds can be controlled effectively by use of herbicides. The time and method of herbicide application varies with the type of weed flora and the habitat in which the weeds are to be controlled. Control of aquatic weeds by herbicides is generally easier, quicker and usually cheaper, when compared to mechanical methods. The use of herbicides has the disadvantage of being in water as residue and more especially in areas where there is no control on water use. Not all herbicides can be used for weed control in aquatic environment.

However, several negative features of chemical control must be considered in decisions to use this method of control. The cost of controlling some weeds, especially to poor or small communities or less-affluent countries, could be daunting. Although some weeds can be chemically managed to keep lakes and ponds weed-free for several months or even years, regrowth of the weeds is a common problem. Any re-treatment should take into account the magnitude of the weed problem, economics of additional herbicide application, and potential for cumulatively exceeding the permissible residue levels. Misuse of herbicides, deliberate or due to a lack of understanding of proper use, as well as worker protection, are frequent concerns. Misuse can damage the surrounding habitats. Even proper use of herbicides can cause nutrients to be released from decaying vegetation into the water and trigger temporary algal bloom, depress oxygen level, and cause fish kill, especially during hot months. The amount and persistence of chemical residues in treated waters and the increase in the amounts of organic matter that sediments are two other problems. Many herbicides and algaecides require either waiting periods of several hours or days before the water can be used; more stringent restrictions may apply if the water is used for drinking, irrigation, recreation, or fishing. This will inevitably disrupt the use of the treated water[39].

A list of the common herbicides used for aquatic weed control is given in the Table 3.

Table 3 Herbicides used in aquatic weed control

Herbicide	Type of weeds controlled	Dose
Sodium arsenite	Submerged weeds	5 – 8 mL L^{-1}
Copper sulphate	Submerged weeds + algae	0.5 – 2.0 mg L^{-1}
Hydrogen peroxide	Submerged weeds	10 – 20 mg L^{-1}
Dalapon	Emergent grass weeds	18-25 kg ha^{-1}
2,4D	Free floating and emergent weeds	2-10 kg ha^{-1}
	Submerged weeds	1 mg L^{-1}
Dichlobenil	Submerged and emerged floating weeds	1-2 mg L^{-1}
Diuron	Algae, submerged floating and emergent weeds	0.5-1.5 mg L^{-1}
Triazines	Algae, submerged and free floating weeds	0.05 – 1.0 mg L^{-1}
Paraquat	Floating and emerged weeds	
Diquat	Submerged and floating weeds Floating and emerged weeds	0.50 mg L^{-1} 1.0 kg ha^{-1}
Endothall	Submerged weeds	0.5-2.5 mg L^{-1}
Fluridone	Submerged and floating weeds	0. 1 - 1.0 mg L^{-1}
Glyphosate	Emergent and floating weeds	1.8-2.1 kg ha^{-1}

6.2.5 Integrated weed management

The results of many investigations and experience in different parts of the world have demonstrated that an integrated weed management is the best alternative to control aquatic weeds in the long term. Successful aquatic weed management is based on defined management objectives followed by careful assessment of the needs of the site[40]. It coordinates the use of environmental information, weed biology and ecology, and all available technologies to control weeds by the most economical means, while posing the least possible risk to people and the environment[41]. Effective integrated weed management combines preventive, cultural, mechanical and biological weed control methods in an effective, economical and ecological manner. The achievement of these programs is recommended when different strategies could improve the result obtained by a single method, and producing less damage to the environment.

6.3 Economics of aquatic weed control

Economics of any operation has two distinct monetary aspects: (a) input costs and (b) output value, price and or utility. In case of aquatic weed control, while probably input costs can be calculated in monetary terms as Rupees per unit area/length per year, output vale is not always possible to calculate at least not easily as in case of field weed control. There are many reasons for it. The ecological, aesthetic and recreational benefits imparted to a water body in response to an aquatic weed management programme cannot be measured for the purpose of calculation of its economics of cost benefit ratios which are incalculable gains.

The input costs are usually much easier to calculate on annual basis. In case of large mechanical weed control procedures, non-recurring and recurring contingencies have to be considered. In case of herbicidal control, while costs of herbicides are more or less stable in relation to the dozes used, their application costs are very highly variable depending upon kind of water body and their physical situation. In canals/lakes, expenditure on boats are to be normal costs of application. Since usually the aquatic weed management programmes are on yearly basis with more than one operation, a detailed accounting for each operation has to be maintained.

Thus, factors that control economics of aquatic weed management; it cannot be based on usual short term experiment basis. Operational research and /or pilot project have to be initiated in the problematic areas on long term basis, using technical recommendations derived from research experiments [42]. The total cost per year for manual control comes approximately $ 490/ha/year and that of mechanical weed control costs to $ 910/ha.

The Kuttanad Package for Kerala with a total cost outlay of $ 366 million was approved by the Govt. of India based on the report of Dr. M.S Swaminathan Research Foundation. It aims to mitigate ecological decay and economic distress prevailing in the Kuttanad region covering the districts of Kottayam, Alappuzha and Pathanamthitta. One of the important recommendations of the MSSRF mentioned in Task 4 is the total elimination of aquatic weeds in Kuttanad by adopting a systematic program and concerted follow up action for three years which would physically remove the weeds and cleanse the waterways for which $ 6 million has been provided in the package. So far about 25 651 cubic metres of weeds have been removed from Thakazhy, Kodamthuruthu, Kuthiathode, Vechoor and Kumarakom areas of Kerala and converted to environmentally friendly vermicompost[43].

7 Solution to aquatic weed problem

The rapidly growing problem of weeds in the aquatic ecosystem of India demands more serious attention. Extensive researches to develop suitable technique that are effective, economical and environmentally acceptable are critically needed.

Following steps should be taken:

- Conduct an extensive and intensive survey to establish the distribution, prevalence and economic impact of noxious aquatic weeds in India.
- Establish a strong National Research Project on management of problem. Areas of research should include ecological studies, biological, chemical and mechanical methods of control, and methods of economic utilization of aquatic plants.
- Create aquatic weed control awareness among the population by means of films, posters and new items.

Technology training programs, field researches emphasizing the needs of the country are required for effective control of aquatic weeds[44]. The provisions of government incentives to develop and practice novel methods in utilization of aquatic weeds will be greatly helpful in controlling the aquatic weeds in a non polluting way, and restoring water bodies to their intended uses. Many employment opportunities can be provided by industries related to the use of aquatic plants, which can resolve the prevailing unemployment problems in rural villages. Research should be directed to find new methods of harvesting and processing aquatic weeds for better exploitation of these resources[45].

The weed management technologies have not reached the farmers at the same pace as happened in case of varieties, fertilizers and insecticides. One of the main reasons is that unlike other pests, the losses caused by weeds are invisible and many a time these are ignored by the farmers in spite of the fact that they cause maximum losses. Lack of awareness regarding losses caused by weeds and ways to control them are still the major reasons for poor adoption of weed management technologies. Therefore, there is a great need to popularize the cost-effective weed management technologies.

8 Conclusions

The challenges confronted by the weed researchers are many and multi-pronged with limited opportunities requiring a concerted and multi-disciplinary effort to tackle the future weed problems. Some of the important emerging areas which require intensified and in depth research efforts are the effect of global climate change on crop-weed interactions, protocol development for weed risk analysis, weed management in precision as well as organic agriculture, herbicide tolerant crops, and use of remote sensing techniques in weed management and variable rate technology for herbicide application. At the same time, there is an urgent need to enhance funding, both public and private towards weed management research. There is enough economic justification not only for the investment, per se made in the field of weed control but also for its enhancement.

Acknowledgement

We acknowledge the supports rendered by the staff of Kelappaji College of Agricultural Engineering and Technology, Tavanur and All India Co-ordinated Research Project on Weed Control, College of Horticulture, Thrissur for providing the necessary information on the aquatic weed management technologies available in Kerala.

[References]

[1] India 2009. A Reference Annual. Research, reference and training division. Publications Division. Ministry of Information and Broadcasting, Government of India. 2009. http://www.publicationsdivision.nic.in/others/india_2009.pdf. Accessed on [2011-07-25].

[2] Napompeth B. Biological control of paddy and aquatic weeds in Thailand. In: Proc. of International symposium on biological control and integrated management of paddy and aquatic weeds in Asia. Tsukuba. Japan, October 20-23, 1992c; pp 249-258. National Agriculture Research Center, Tsukuba, Ibaraki, Japan www.agnet.org/library/bc/45011/bc45011.pdf. Accessed on [2010-07-12].

[3] Zettler F W, Freeman T E. Plant pathogens as biocontrols of aquatic weeds. Annual review of Phytopathology, 1972; 10: 455-470.

[4] Lancar Lidia, Krake Kevin. Aquatic weeds and their management. International Commission on Irrigation and Drainage. 2002. http:/www. icid.org/ eed_report.pdf. Accessed on [2011-06-03].

[5] Choudhary P R, Pandey R A, Bal A S. Macrophyte infestation of water bodies and methods of lake restoration. Conservation and management of aquatic resources. Daya Publishing House. 1998. Chapter 15. 200-241.

[6] Naskar Kumudranjan. Aquatic and semi-aquatic plants of the lower Ganga delta: its taxonomy, ecology and economic importance. Problems caused by aquatic weeds. Daya books. 1990. 408 pages. 34-37.

[7] Joy P J. Ecology and control of Salvinia (African Payal) the molesting weed of Kerala (Technical Bulletin No. 2). Kerala Agricultural University, Trichur. 1978. 40pp.

[8] John Tinker. Waterweeds: flies in the irrigation ointment. New Scientist. Reed Business Information, 1974; 69(890): 64pp, 748.

[9] Thomas K J. The extent of Salvinia infestation in Kerala (S. India): Its impact and suggested methods of control. Environmental Conservation, 1979; 6: 63-69.

[10] Singh S P. Biological suppression of weeds. Technical Bulletin No. 1, Biological Control Centre, National Centre for Integrated Pest Management, Bangalore, India. 1989; 27 pp.

[11] Singh S P. Some success stories in classical biological control of Agricultural Pests in India. Asia- Pacific Association of Agricultural Research Institutions. 2004. http://www.apaari.org/wp-content/uploads/2009/05/ss_2004_02.pdf. Accessed on [2011-07-18].

[12] Charudattan R. Regulation of microbial weed control agents. In: Biological Control of Weeds with Plant Pathogens. R. Charudattan and H.L. Walker (eds.). Wiley, New York, 1982. pp 175-188.

[13] Singh S P. Biological control of invasive weeds in India. In: Proc. Workshop on Alien weeds in Moist Tropical Zones: Banes and Benefits. K.V. Sankaran, S.T. Murphy and H.C. Evans (eds.), Kerala Forest Research Institute, Peechi, India, 1999. pp 11-12.

[14] Harley K L S. The role of biocontrol control in the management of water hyacinth, Eichhornia crassipes. Biocontrol News and Information, 1990; 11(1): 11-22.

[15] Gutierrez E, Arreguín F, Huerto R, Saldaña P. Aquatic weed control. Int. J. Water Resources Development, 1994; 10: 291-312.

[16] Varshney J G, Prasad Babu M B B. Future scenario of weed management in India. Indian Journal of Weed Science, 2008; 40 (1&2): 01-09.

[17] Suresh C Jain. Aquatic weed management in India. FAG Fellow, J.N. Agriculture University campus. Indore, Madhya Pradesh. www.apms.org/japm/vol13/v13p6.pdf. Accessed on [2011-06-15].

[18] Subhendu Datta. Aquatic weeds and their management for fisheries. Senior Scientist. CIFE Centre, Salt Lake City, Kolkata, West Bengal, India. http://www.scribd.com/doc/22049534/Aquatic-Weeds-and-Their-Management-for-Fisheries. Accessed on [25-07-11].

[19] Spencer W, Bowes G. Ecophysiology of the world's most troublesome aquatic weeds. 1990. In: Aquatic Weeds the Ecology and Management of Nuisance Aquatic Vegetation. Eds A H Pieterse & K J Murphy, pp. 39-73. Oxford University Press: New York.

[20] Langeland K A. *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae), "The perfect aquatic weed." Castanea, 1996; 61: 293-304.

[21] Ramaprabhu T, Ramachandran V. Developments in aquatic weed control research in India relating to fisheries. Journal of Aquatic Plant Management, 1984; 22: 97-100.

[22] Silas E G. Indian Fisheries. 1947-1977. Issued on the occasion of the fifth session if the Indian Ocean fishing commission held at Cochin from 19th to 26th October. 1977. Available: http://eprints.cmfri.org.in/5447/1/04.pdf. Accessed on [2011-06-14].

[23] Sankaranarayanan M R. Mechanical control of the floating type aquatic weed *Salvinia molesta* (African Payal). MSc. Thesis. Department of Agricultural Engineering. College of Horticulture, Vellanikkara, Thrissur, Kerala. 1987.

[24] Thomas K J. The extent of *Salvinia* infestation in Kerala (S. India). It's impact of suggested methods of control. 1979. Environ. Consv. 6. 12-42

[25] Gupta O P. Aquatic weed control. World crops, 1973; 25(4): 132-190.

[26] Samuel J. Development of *Salvinia* harvesting machine. Paper presentation at seminar held at College of Agriculture., Vellayani, Kerala. December 1980

[27] Samual J and Jacob J. Prospects for mechanical control of *Salvinia* in Kerala. 1977. Paper presented in the symposium on rice research at the Rice Research Station, Pattambi, Kerala (Unpublished)

[28] Kerala Agricultural University. Kelappaji College of Agricultural Engineering and Technology, Tavanur. Available: http://www.kau.edu/kcaettavanur.htm. (Accessed on 2011-05-12).

[29] Hajilal. M.S. Design and development of a high capacity *Salvinia* harvester. MSc. Thesis. Department of Irrigation and Drainage Engineering. Kelappaji College of Agricultural Engineering and Technology. Tavanur, Malappuram, Kerala. 1987.

[30] Sankaranarayanan M R, John Thomas K, Hajilal M S. *Salvinia* Harvesting Machine-A mechanical device to control African Payal. 1985. Proc. ISAE SJC. Vol 1.II-72-75

[31] Philipose M T. Fifty years of aquatic weed control in India. Edited by C. K . Varshney, International Hydrological Decade. 1976. Aquatic weeds in South East Asia. In: proceedings of a Regional Seminar on Noxious Aquatic Vegetation. Springer. 215-222.

[32] Freeman T E. Biological control of aquatic weeds with plant pathogens. Aquatic Botany, 1977; 3: 175-184.

[33] Jayanth K P, Visalakshi P N G. Introduction and establishment of *Neochetina eichhorniae* and *Neochetina bruchi* on waterhyacinth in Loktak Lake, Manipur. Sci. Cult, 1989; 555: 505–506.

[34] Sushilkumar, Bhan V M. Biological control of water hyacinth by insects. Annual Report 1996–97. National Research Centre for Weed Science, Jabalpur, p 46.

[35] Project directorate of biological control (PDBC). Fifteen years of AICRP on biological control, Bangalore, 1994; 320 pp.

[36] Sushilkumar, Varshney J G. Biological control of Parthenium: present status and prospects. National Research Centre for Weed Science, Jabalpur. 2007. 110 p.

[37] Sushilkumar, Varshney J G. Successful biological control of water hyacinth (*Eichhornia crassipes*) through weevil *Neochetina spp.* in ponds of Jabalpur, Madhya Pradesh, India. In: Abstracts of 12th World Lake Conference, Jaipur, 28th October- 2nd November 2007. 2008.p 51.

[38] Ananthakrishnan T N. Methods and principles of pest control. Biological control. General and applied entomology. Tata McGraw-Hill Education. Science. 2004; 1184: 819-840.

[39] Charudattan R. Are we on top of aquatic weeds? Weed problems, control options, and Challenges. A talk presented at an international symposium on the World's Worst Weeds, November 12, 2001, organized by the British Crop Protection Council, Brighton, United Kingdom.

[40] Sidorkewicj S, Sabbatini M R, Fernandez O A, Irigoyen J H. Aquatic weeds. Editor. Inderjit. Weed Biology and Management, 2004; pp. 115-135.

[41] Sanyal. D. Introduction to the integrated weed management revisited symposium. 2008. Weed Sci. 56:140

[42] Saxena L M, Agarwal S K. Aquatic weeds and strategies for their control. Editors. S K Agarwal and P S Dubey in Environmental scenario for 21st century. APH Publishing. 2003; 198-199.

[43] Available:http://www.kuttanadpackage.in/images/stories/docs/7j-statusreport-kuttanadpackage-12-07-2011.pdf. Accessed on [2011-07-20].

[44] Narayan D, Singh V K. Management of aquatic weeds for sustainable agricultural production. In: International Conference on Communication for Development in the Information Age: Extending the Benefits of Technology for All. Eds. Basavaprabhu Jirli, Diapk De, K. Ghadei and Kendadmath, G.C., Department of Extension Education, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, (India). 2003.

[45] Munasinghe J U, Dilhan M A A B, Sundaramurthy T V. Utilization of aquatic plants: A method to enhance the productivity of water in seasonal tanks in the Anuradhapura District. In: Proceedings of the National Conference on Water, Food Security and Climate Change in Sri Lanka, BMICH, Colombo, Sri Lanka, 9-11 June 2009; 1: 23-32. Irrigation for food security.