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# Aquatic weeds problems and management in India

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**ABSTRACT**

Aquatic weeds are those unwanted vegetation which grow in water and hamper its use. Out of about 160 aquatic weeds, *Eichhornia crrassipes, Ipomoea aquatica, Typha angustata, Ceratophyllum demersum, Salvinia molesta, Nelumbo nucifera, Alternanthera philoxeroides, Hydrilla verticillata, Vallisneria spiralis, Chara* spp., *Nitelia* spp., *Potamogeton* spp. are of primary concern in India. Several irrigation and hydroelectric projects in the country like Nagarjuna Sagar project in Andhra Pradesh, Tungabhadra project in Karnataka and Kakki and Idikki reservoirs in Kerala are suffering with massive growth of aquatic weeds. Weeds enhance rates of evaporation many folds through evapotranspiration than that of open surface, thus cause great loss of water. Water hyacinth makes water unfit due to eutrophication and slows down the flow rate of water besides causing many health associated problems. Aquatic weeds can be controlled by several methods like biological, chemical and physical. Each method has its benefits and drawbacks. There are several popular control mechanisms for preventing the spread or eradication of aquatic weeds. Physical methods are suitable only for small scale infestation but when applied in large water bodies become ineffective due to high cost and regrowth. Chemical control has been practiced against aquatic weeds since long time in India but it is not prevalent. Control of small infestations with herbicides has often been very effective, but is heavily dependent on skilled operators who maintain long-term vigilance for appearance of regrowth or seedlings. In recent decades, there has been a significant increase in the level of nutrients dumped into water from industrial and domestic sources as well as from land where fertilizers are used or where clearance has caused an increase in run-off. Successful attempts have been made to control water hyacinth and water fern by use of exotic weevil *Neochetina* spp. and *Cyrtobagaus salvinae* in different parts India but for several other aquatic weeds, suitable bioagents are not available. Some species of herbivorous fishes (*Tilapia* spp. and *Ctenopharyndon idella*) have been utilized to control some submerged weed especially *Hydrilla* spp. with varying degree of success. This paper describes the aquatic weed problems in India and the efforts made so far for their management by various methods.

**Key words** : Aquatic weed management, Aquatic weeds in India, Biological control, Chemical control, Aquatic weed problem

Presence of plants in the water bodies is essential for the conversion of solar energy into chemical energy for the development of aquatic fauna like fish, prawns *etc*. and for continuous addition of oxygen to water during photosynthesis. Aquatic plants play an important role in aquatic systems because they provide food and habitat to fish, wildlife and aquatic organisms. Unfortunately, some aquatic plants often become a problem by stopping uses of water and threaten the structure and function of diverse native aquatic ecosystems. A lot of resources are often used to control infestations of aquatic weeds because of their unchecked growth which interfere with use of water, increase the risk of flooding and result the conditions that threaten public health. Therefore, it may be defined that aquatic weeds are those unwanted plants, growing in water and complete at least a part of their life cycle in water. When water plants make water bodies unfit and take the shape of noxious aquatic vegetation due to over growth, these may be called as aquatic weeds. In states like Assam and West Bengal, water hyacinth has become a great problem (Bhan and Sushilkumar 1996). Aquatic weeds are also responsible to reduce the available water resources of India by way of excess seepage or evapotranspiration process. The world's total irrigated area was 249.5 mha in 1997 (FAO 1999) which was 17.2% of total arable land. It is this land which provides sustainable and assured productivity of crops and employs high input returns. The continent wise spread of irrigated area indicates that Asia has the maximum irrigated area followed by Europe and Africa. The developing countries as a whole are expected to expand their irrigated area from 202 million hectares in 1997/99 to 242 million hectares by 2030. Most of this expansion will occur in land scarce areas where irrigation is already crucial – South Asia and East Asia will add 14 million hectares each (Faures *et al.* 2000). In India, the per capita average annual freshwater availability has reduced from 5177 cubic meters from 1951 to about 1869 cubic meters in 2001 and is estimated to further come down to 1341 cubic meters in 2025 and 1140 cubic meters in 2050 (Kumar 2003). Keeping in view the loss of water through weeds, it has become essential to manage weeds to save water for human use. Agricultural irrigated land (% of total agricultural land) in India was 35.12 as of 2009. (World Bank 2010). In India, 44 new major irrigation projects, 24 revised major irrigation projects, 45 new medium irrigation projects and 6 revised medium irrigation projects were under appraisal and 75 projects comprising 29 major, 19 medium irrigation projects and 27 flood control projects were accepted for investment clearance by the Advisory Committee (Centra Water Commission 2011).

**Types of aquatic weeds**

Aquatic weeds can be classified according to their habitat and morphological characteristics. The classification and distribution of aquatic weeds in India have been reviewed in past (Gupta 1987, Phogat 1996, Bhan and Sushilkumar 1996, Mathur *et al.* 2005, Varsheny *et al.* 2008). The major weeds can be categorised as submerged weeds, emerged weeds, dispersed weeds, shoreline and ditch weeds, bank weeds, marshland and swamp weeds.

**Problems of aquatic weeds in India**

Out of about 160 aquatic weeds, the following are of primary concern to India: (1) *Eichhornia crassipes* (2) *Salvinia molesta* (3) *Nymphaea stellata* (4) *Nelumbo nucifera* (5) *Hydrilla verticillata* (6) *Vallisneria spiralis* (7) *Typha angustata* (8) *Chara* spp. (9) *Nitella* spp. (10) *Ipomoea* spp. Among these, *Eichhornia crassipes, Salvinia molesta, Hydrilla verticillata, Alternanthera philoxeroides* and *Pistia stratiotes* are five primary aquatic weeds of the world and qualify the status of worst weeds in India too. It is, however, estimated that 20-25% of the total utilisable water in India is currently infested with water hyacinth (*Eichhornia crassipes*), while in the state of Assam, West Bengal, Orissa and Bihar, it was 40% (Gopal and Sharma 1981). By the end of 20$^{th}$ centaury, *A. philoxeroides* had become a growing menace in water bodies in India, Sushilkumar *et al.* 2009). Some important weeds in different states of India are given (Table 1).

**(a) Aquatic weed problems in lakes and reservoirs**

Aquatic weeds may cause following problems: impair commercial navigation; degrade and deteriorate water quality; disrupt hydropower generation; increase flood frequency, duration and intensity; reduce species diversity; increase extinction rate of rare, threatened and

**Table 1. Important aquatic weeds in different states of India**

| State name | Weed species | Type of water body |
|---|---|---|
| Assam, Orissa, West Bengal | *Azolla pinnata* , *Chara* spp. *E. crassipes; Ceratophyllum* spp.; *H. verticillata Ipomoea aquatica; Lemna minor; Monochoria vaginalis Marsilia quadrifolia; Nymphaea* spp.; *Nelumbo* spp.; *Nitella* spp.; *Pistia* spp.; *Najas* spp.; *Ipomea carnea. Salvinia. molesta; Sagittaria* spp.; *Scirpus* spp.; *Trapa bispinosa* | Fisheries, ponds and tanks water works, deep water rice and lakes. |
| Andhra Pradesh, Kerala, Karnataka, Tamil Nadu | *E. crassipes; Cyperus* spp.; *Chara* spp.; *Ipomoea aqatica, H. verticillata; Nymphaea* spp.;*Nelumbo lutea; Nymphoides* spp.; *Potamogeton* spp.; *Najas* spp.; *Salvinia. molesta. Typha latifolia, Vallisnaria americana;* | Lakes and tanks growing fishes, irrigation and drainage systems. |
| Punjab, Bihar, Haryana. Uttar Pradesh, | *Cyperus aquatica; E. crassipes; Hydrilla verticilla ; Ipomoea carnea; Najas* spp.; *Nelumbo nucifera; Nymphaea* spp.; *Phragmites karka; Potamogeton crispus; P. zosterifolius; P. perfoliatus; P. nodosus;P. pectinatus; Chara* spp.; *Ceratophyllum sppspp.; Myriophyllum spicatum; Spirogyra* spp.; green algae.; *Typha angustata; T. latifolia, Vallisnaria americana, V. Spirallis* | Irrigation canals and drainage system, ponds, lakes, fisheries areas and rivers. |
| Gujarat, Madhya Pradesh Rajasthan, | *Chara* spp.; *E. crassipes; Hydrilla verticillata; Ipomoea carnea; I. aquatica; Nymphoides* spp.; *Phragmites karka;Potamogeton crispus; P. nodosus; Typha latifolia; Vallisnaria americana; V. spirallis* | Water storage reservoirs for city water supply system, fisheries development, irrigation canals and drainage system. |
| Jammu and Kashmir. | *Lemna gibba; L. minor; L. trisuleha; Nymphoides peltatum; Polygonum amphibium; Potamogeton* spp;.*Spirodela polyrhiza; Salvinia natans; Trapa natans* | Natural water bodies for storage, aquatic sports and aesthetic value, Lakes |

endangered species; habitat for insect-borne disease vectors; alter animal community interactions; recreational navigation impairment; interfere with safe swimming; change sediment chemistry; interfere with fishing; reduce water storage capacity in reservoirs, tanks, ponds; impede flow and amount of water in canals and drainage systems; reduce fish production, interfere with navigation and aesthetic value; promote habitat for mosquitoes. Malhotra and Ahmed (1996) has categorized aquatic weeds as a growing ecological menace. Thirunaqvukkarsu and Kayarkanni (1996) discussed the environmental impacts of aquatic weeds in India. The famous Kolleru lake in the West Godavari has succumbed to invasion of *E. crassipes, Ipomoea aquatic, Typha Vallisneria*, *Nymphaea* and *Ulothrix* spp.

In several drinking water lakes in Rajasthan, *E. crassipes* is the major weed. Besides water hyacinth, *Trapa, Pistia, Nymphaea, Nymphoides* and *Nelumbo* spp. cover the impounded waters. During 1980s, water hyacinth was a great problem in Pichola lakes at Udaipur which was overcome by the motivation of local people to remove the weed regularly for many years. Now water hyacinth is not a problem in this lake but the lake on the bank side is severely infested with *H. verticillata.* In Bharatpur, aquatic weeds, particularly *E. crassipes* and *H. verticillata*, are potential danger. During last decade of 20th century, water hyacinth was a big problem in Man Sagar lake of Jaipur but now that problem has been overcome by sincere efforts of city authorities through people participation. Sharma and Solomon *et al.* (2005) found water quality affected by weed infestation in Pichhola and Fateh Sagar lake in Udaipur, (Rajasthan). Based on total and fecal coliforms, fecal streptococci and standard plate counts, heavy organic loading in Pichhola was confirmed.

In Orissa, Ansupa lake and Hirakund reservoir were infested with variety of aquatic weeds covering about 85% water-body. *Hydrilla*, *Najas*, *Ceratophyllum*, *Ottelia, Vallisneria* and *Chara* spp. are the problematic weeds in Orissa. Aquatic weeds are major problem in Hirakund area.

In Punjab, floating, emerged and submerged aquatic weeds are major problem in many, reservoirs and wet lands. In Punjab, three wetlands namely Harike, Kanjili Kehhopur-Miani lake and Mand Bharthala in Roper have been threatened by aquatic weeds like water hyacinth, *Potamogeton pectinatus, Hydrilla verticillata etc.* (Ladhar 1996). *Typha* spp. (Kumar and Singh 1996d) and water hyacinth have been a big problem in reservoirs and ponds of Punjab (Sharma and Chandi 1996).

In Tamil Nadu, almost 80% of 39000 tanks are infested with aquatic weeds mainly water hyacinth and *Hydrilla verticillata*. Even very big tanks like Chembarabakkam tank, Dusi-Mamandur tank, Kaveripakkam tank, Veeranam tank *etc*. are also affected. *Ipomoea aquatica* is in the first order among water weeds causing menace in Taamil Nadu. Velachery tank in Chennai, boundary of Pallikkaranai drainage swamp, portion of Adayar river, Buckingham canal and Otterinullah have turned eutrophic due to water hyacinth. There are same conditions with water bodies around Trichy, Madurai, Tirunelveli, Coimbatore, Salem and other towns of Tamil Nadu. The world famous Ootucmund lake was ruined due to infestation of water hyacinth during 1990s.

In Gorakhpur (Uttar Pradesh), about 22 sq km Ramgarh lake was filled with dense growth of *Hydrilla, Najas, Potamogeton, Ceratophyllum* and *Chara* spp. Of these, *Hydrilla* and *Najas* spp. infest the lake round the year while others invade it seasonally. The Gujar lake (110 ha) in Varanasi (Uttar Pradesh) has been invaded by aquatic weeds.

In West Bengal, *E. crassipes* is the foremost aquatic weed. In the southern part of West Bengal, *Typha* is a noxious weed. Aquatic weeds have played havoc in West Bengal in fishery waters, potable waters and in lowland paddy fields. In Palta and Baranagar water bodies, *Eichhornia* and *Lemna* spp., along with some molluscs, blocked the water pipes.

**(b) Aquatic weeds problems in fish ponds and lakes of India**

Most of the freshwater fishes rely on aquatic plants at some point during their lives and prefer specific habitats based on their growth stage. Young fish use aquatic vegetation as a food source, both by directly consuming plants and by foraging for the microfauna associated with the plants, and as cover to hide from predators. Mature fish moves to more open waters to increase foraging success and consume other fish to supplement their diets. Nesting, growth and foraging success of plant-loving fish are influenced by plant composition and density.

Of the 8 lakh ha of freshwater available in India for pisciculture, about 40% is rendered unsuitable for fish production because of invasion by aquatic weeds. Most of the fishery tanks and ponds in and around Bangalore and other cities have been badly invaded by water hyacinth. Some of the weeds like *Eichhornia, Azolla, Nymphaea, Nelumbo, Nymphoides, Hydrilla, Vallisneria, Potamogeton, Najas, Ceratophyllum, Typha* and *Utricularia* spp. are problematic weeds in fishery lakes and tanks of Andhra Pradesh, Assam, Haryana, Himachal Pradesh, Jammu & Kashmir, Maharashtra, Tamil Nadu and Uttar Pradesh in India. Some of the well-known fishery lakes like Barwar, Ramgarh and Guiar lake in Uttar Pradesh, Ansupa lake in Orissa, Ootucmund lake in Tamil Nadu, Kollern lake in Andhra Pradesh, Loktak lake in Manipur and the world famous Dal, Nigeen and Walur lakes in Jammu & Kashmir have been largely invaded by the aquatic weeds. Large number of water bodies, both natural and man made in Assam are infested with aquatic macrophytes, making them unfit for fish culture and other economic uses.

In Assam in beel fisheries situation, water hyacinth has been considered a major problem by National Bank for Agriculture and Rural Development (NABARD). Fish production was found drastically reduced in beels due to infestation of water hyacinth.

Very often a particular phytoplankton species multiply rapidly to form dense masses when environmental conditions and availability of nutrients are most favourable. Such dense growths referred as "water bloom" are responsible for imparting colours to water body like green, reddish brown, yellow green and blue-green depending on the type of bloom forming algae. The algae responsible for temporary blooms mostly belong to the Chlorophyceae (for example, *Chalamydomonas* spp., *Pandorina morum, Volvox aureus, Chlorella vulgaris*), Bacillariophyceae (*Melosira granulata, Synedra ulna*), Dinophyceae (*Peridinium inconspicuum*) and Euglenineae (*Euglena* spp., *Trachelomonas* spp.). The permanent blooms are constituted mostly by Myxophyceae (*Microcystis* spp., *Anabaena* spp., *Raphidiopsis* spp., *Oscillatoria chlorina*). The common filamentous algae *Spirogyra, Pithophora* and *Oedogonium* also make blooms.

The higher aquatic plants that occur in fish ponds belong to various families and genera, but major weed species are floating weeds, (e.g. *Eichhornia, Pistia, Salvinia, Spirodella, Lemna, Wolffia* and *Azolla*); emergent weeds, (e.g. *Nymphaea, Nelumbo, Euryale, Nymphoides, Myriophyllum and Phragmites)* ; submerged weeds (e.g. *Hydrilla, Najas, Potamogeton, Vallisneria, Ottelia and Nechamandr*a) or rootless (e.g. *Ceratyphyllum and Utricularia*); marginal weeds(e.g. *Ipomoea, Jussiaea, Typha, Cyperus, Paspalidium and Eleocharis*); algal weeds, which in fish ponds are either planktonic or filamentous forms. Although, no precise estimates of the losses caused by aquatic weeds are available but it is estimated that submerged aquatic weeds like *Hydrilla, Ottelia, Valisnaria, Najas, Utricularia, Chara etc.* caused 40-60% loss of the cultivable water in Assam, Bihar, Madhya Pradesh, Orissa, Uttar Pradesh and West Bengal making them unsuitable for fish culture. Even the cultivation of the water chestnut (*Trapa bispinosa*) for edible purposes in these states is hampered by the presence of aquatic weeds.

In Nagpur (Maharashtra) aquatic weeds are of major concern in potable waters and pisciculture. In Pune and Kolhapur water hyacinth and recently *P. stratiotes* has become problematic.

In the coastal areas of Orissa, aquatic weeds inflict huge economic losses in rice production and fisheries. Submersed, free-floating and emerged weeds invade ponds and tanks. In the nutrient-rich fish ponds, blue-green algae (mainly *Microsystis* spp.) often cause mass mortality of fish.

In Uttar Pradesh also, aquatic weeds are responsible to hamper the fish production in many ponds, lakes and reservoirs. For example in a 300 ha Kitham lake near Agra, the annual fish production potential worth Rs. 2 lakhs was reduced to almost nil because of large coverage of its water surface by water hyacinth.

In the Tarai area of Uttar Pradesh and Uttarakhand consisting Pilibheet, Barielly, Rampur, Udhamsing Nagar, Nanital *etc.,* the fishery ponds are also losing ground to aquatic weeds like *Hydrilla, Potamogeton, Vallisneria*, *Nelumbo*, *Nymphaea, Typha*, *Saccharum* and *Brachiaria* spp.

### (c) Weed problems in rivers and irrigating canals

In India, many rivers, irrigation canals, lakes, ponds *etc.* are choked by the explosive growth of aquatic weeds, resulting in enormous direct losses. Besides different types of algae, the most important representatives of aquatic weeds in such habitat in India are: *E. crassipes*, (free floating), *N. stellata* (rooted floating), *N. nucifera* (rooted floating), *H. verticillata* (rooted submerged), *T. angustata* (emergent), *Sagittaria* sp., *Potamogeton* sp. (rooted submerged), *P. stratiotes* (free floating), *S. molesta* (free floating), *A. caroliniana, Polygonum* sp., *Cyperus* sp. *etc*. *A. philoxeroides* has become one of the problematic weeds in nearby area of low lands areas in Jabalpur. It blocked the drainage canals of the colonies and irrigations canals badly due to its profuse growth (Sushilkumar *et. al.* 2009).

Bheema river in Maharashtra has become badly infested with luxurious growth of *Pistia stratiotes*. The river track of about 50 km is blocked every year due to rampant growth of *P. stratiotes*. This cause great problem for taking water from rivers for irrigation purposes.

In general, it has been observed that, most canals carry a lot of silt in the flowing water which does not allow photo-synthetic activity in the submerged aquatics weeds. In Punjab, Bhakra canal water is practically free from silt because of sedimentation in Govind Sagar. The weed seeds carried by water from the hills, germinate and get established within a short period of time in clear water due to abundance of light. In India after 1950's, the total land area under irrigation has increased. This increase was made possible by development of river valley projects such as Chambal Irrigation Project, Kota and Bhakra NagaI Canal System. Today, a large part of about one million ha of inland water-area in India is threatened by the invasion of noxious aquatic weeds. Nearly 2100 km of the Bhakra Canal System is badly infested along the bank regions. On the other hand, the flow of water in canals is reduced drastically, 40 to 90% by submersed weeds such as pond weeds *(Potamogeton* spp.) and naiad (*Najas glladalupensis*). Vast swampy areas, ditch banks, drainage channels and flood-control channels are infested with cattails *(Typha* spp.) throughout India which are often designated as India's worst weed (Gupta 2001, Varshney *et al.* 2008). In addition to problems caused by emerged weeds such as cattails, the semi-aquatic weeds such as canary grass *(Phalaris anmdinacea*) and the submersed weed hydrilla *(Hydrilla vcrticillata*) are rapidly infesting large bodies of water. Sushilkumar *et al.* (2009) described alligator weed, one of the underestimated weeds about its spread and damage attributes in canal and drainage system in India. The alligator weed was found in 16 states of India and in some of the states, heavy infestation in aquatic and semi-aquatic situations was recorded affecting drainage system in Jabalpur, Guwahati and Jorhat (Sushilkumar *et al*. 2009). Although an intensive survey of the infestation of the waterways by the aquatic weeds in India yet to be documented.

Holm *et al.* (1991) reported that in the Chambal Project in India, submerged aquatic weeds had cut the flow of water by 80%. Aquatic weeds are great problem in canal systems which have already reduced the designed flow of many of these by 40-50%. This obstacle in flow of water in canals has resulted in forced seepage, water logging and soil salinity. Weeds like *I. aquatica, T. angustata, E. crassipes, Vallisneria* spp., *I. carnea* are prevalent in canals and irrigation systems of Andhra Pradesh, Maharashtra, Rajasthan, Tamil Nadu and Uttar Pradesh states. In Kerala state, *Salvinia molesta*, an exotic weed introduced in 1967 has widely distributed in irrigation canals. In this state, the *Salvinia* is so competitive that it has replaced *E. crassipes* and *P. stratiotes* weeds (Joy 1978). It has become a serious threat to hydroelectric projects, pisciculture and navigation in Kerla.

Irrigation supply to paddy is also hindered in about two lakh hectares area due to aquatic weeds in north-eastern states. Most of the irrigation tanks are infested (80 to 92%) in Assam by the aquatic weeds. In the irrigation systems of Andhra Pradesh, *I. aquatica* has blocked the drainage, channels, causing silting and floods. *Typha* spp. are wide-spread throughout Haryana in ditches, ponds, lakes, drains and marshlands. In the country's pride Bhakra canal in Haryana, a variety of submersed weeds have reduced its carrying capacity. About 2800 km length of Bhakra canal suffers from the aquatic weeds menace. Its clearance by the conventional physical method is estimated to cost millions of rupees annually.

In Rajasthan, aquatic weeds pose the prime problem in the maintenance of water-bodies in the state. In Chambal Irrigation System, aquatic weeds cut the designed discharge of canals by 40-70%, and of their distributaries by over 80%. In the Indra Gandhi Canal project located in the north-western region of Rajasthan, *Typha* spp., and *Parthenium hysterophorus* have covered the entire canal banks. (Gupta 2008)

**(d) Aquatic weed problem in paddy and crop fields**

Vast areas of low land paddy in the north-eastern parts of India, West Bengal and Kerala states have been badly infested with aquatic weeds. While in the north-east, *E. crassipes Chara* spp. *Nittela* spp. and algal scams are nuisance, in the coastal Kerala, *Salvinia* sp., particulary *S. molesta* plays havoc. Irrigation supply to paddy is hindered in about 1.6 lakh ha area in north-eastern India alone. Added to this, several hectares of cultivable flood plains have been succumbed to noxious aquatic vegetation. Cultivation of *Trapa bispinosa* (water chestnut) has also been abandoned in east India because of heavy growth of water hyacinth and other aquatic weeds in water bodies.

Alligator weed has been recorded to extensively invade maize in Palampur, paddy field in Orissa, vegetable crops and maize in Jabalpur (Sushilkumar *et al.* 2009). Alligator weed was also recorded to infest wheat crop in low land areas of Jabalpur. In Kerala, *Salvinia molesta* is the most notorious aquatic weed (Joy 1978) while in deep water paddy fields, *E. crassipes, Ipomoea* and *Scirpus* spp. cause extraordinary crop losses in West Bengal.

**(e) Bridges structure are vulnerable to aquatic weeds**

The surface floating weeds get interwoven and entangled with each other and form dense mats that move downstream. Often these moving mats are lodged against bridges structures creating enormous pressure that sometimes results in collapse of bridge structure. An example of this sort of damage was observed on Kasur Nala near Taran-Taaran in Punjab. Over time such weed mats become so dense that people and animals can walk on them.

**(f) Aquatic weeds problems in hydroelectric projects**

Several hydroelectric projects in the country are endangered by infestation of dams and reservoirs with massive growth of aquatic weeds. For instance, The Bhilai Steel Plant in Madhya Pradesh and the Bokaro Steel Plant in Jharkhand are faced with acute problems of aquatic weeds in their cooling tanks where they prevent proper circulation of water in pipes. Tungabhadra project in Karnataka, Nagrajuna Sagar project in Andhra Pradesh, and Kakki and Idikki reservoirs in Kerala are filled with aquatic weeds up to alarming situations. In Orissa, In a case study, Bisi (1996) calculated huge losses in electricity generation due to aquatic weeds in Chiplima Power House of Hirakund Power System. There was chocking of trash racks due to aquatic weeds mainly of water hyacinth, water lettuce and *Hydrilla*. The power house was stopped for several times for repair. He estimated about 20.9 MU loss of power generation during 1991 to 1996 due to aquatic weeds which caused an annual loss of about Rs 0.793 crores in terms of revenue at the than rate of 0.38 paise per unit as per the tariff of Orissa Hydro Power Corporation.

A great problem of aquatic weeds was faced by the managers of Tata Iron and Steel Company (TISCO), Jamshedpur (Jharkhand) in the upper and lower ponds of the factory during 2001-2004. The main problems were of submerged weeds *Hydrilla verticillata* and floating weed *Lemna minor*. The weeds became a problem to Blower & Pump House Department due to impeding flow of water in the pumps and making machinery non-functional by reaching through water supply system.

### (g) Aquatic weed problems in tourist lakes of India

Lakes are one of the greatest source of recreation for the tourists all over the world. The world famous lakes of Kashmir, namely the Dal, Nigeen and Wular are sick with aquatic weeds. Of the several aquatic weeds, *S. natans* has been so far reported weedy in India only from Kashmir. It covers 2.5 - 6% water surface of most lakes there, though in Gilsar lake, the fern coverage exceeds 30%. The fern is now heading fast into the rice fields. In Dal lakes following aquatic weeds are the problems: Emerged macrophytes: *T. angustifolia, P. australis:* floating macrophytes: *S. natans, Hydrocharis dubia, Nymphoides peltata, Nymphaea* sp., *N. nucifela, P. natans;* submerged macrophytes: *Myriophyllum spicatum, C. demersum, Potamogeton crispus, P. lucens*; phytoplankton: *Navicula radiosa, Nitzschia accicularis, Fragilaria crotonensis, Diatoma elongatum, Scenedesmus bijuga, Pediastrum duplex, Tetraedron minimum, Microcystis aeruginosa* and *Merismopedia elegans*.

Dal lake has witnessed frequent algal blooms. Reoccurrence of such blooms has become a regular phenomenon in the various basins of the lake. In 1991, the reddening of the lake waters due to Euglenoid bloom was first of its kind. A close relationship was observed between chloride and nitrates which almost coincided with those of high euglenoid population. The lack of water flushing, nutrient enrichment and accumulation of free carbon dioxide were the possible causes of the euglenoid bloom in Dal lake. In April 1998, a bloom of Cladophora was recorded in the Pokhribal zone of Nigeen basin of Dal lake which smelled like untreated sewage and chocked the waterways near the exit point of Nallha Amir Khan. The appearance of this 'blanket weed' was due to the chemical enrichment of the lake by incoming sewage. In 1999, two algal blooms were recorded, one by Volvocales and other of *Microcystis aeruginosa* in Hazratbal and Nehrupark basin, respectively giving waters a lush green colour. The *Microcystis* bloom since then has remained perpetual in the lake basin and has engulfed the entire basin area. Besides these, *Spirogyra* bloom is of common occurrence in the Nigeen lake particularly when the exit gate at Nallah Amir Khan remains closed. Peculiar changes have occurred in this basin over a period of time arising out of human incursions. Not only the floating gardens are being expanded unabatedly but 1/3 of the lake area towards Saderbal side has been turned in to marsh supported by thick mats of *Typha* and *Phragmites* and subsequently into land mass (Adnan and Kundanagar 2009, Kundanagar 2010).

*Euryale ferox*, an abundantly found macrophytes in Dal lake has almost vanished and hardly scattered plants could be seen interspersed with *Nelumbo* plants. *Azolla* sp. the exotic species are now the new invaders to the lake and assumed the greater dimensions. The significant changes in the vegetation patterns of the Dal lake and their prolific growth in the open areas are attributed to unabated inflow of effluents, raw sewage and enrichment of the lake sediments particularly due to heavy load of organic nitrogen and phosphates (Adnan and Kundanagar 2009).

Lakes of Otacmund and Kodaicanal in Tamil Nadu were badly infested with water hyacinth and other weeds during the end of 20$^{th}$ centaury. Now try is being made to restore these lakes by government with people's participation. The Ansupa lake in Orissa has been declared a Community Reserve according to the amendment made in the Wildlife Protection Act (1972) in 2003. The dominant phytoplankton in the lakes were *Dinobryon, Tachelomonas, Euglena, Ceratium* and *Cyclotella*.

Loktak lake of Manipur state is also a pulsating lake, which is about 500 sq km during rainy season and 250 Sq. kms during winter and is proud to be the largest fresh water lake in the north-eastern region of India. About 212 plant species belonging to 62 families have been identified in the lake. The principal vegetation types including submergent, emergent and floating macrophytes are characterised by the dominance of *C. demersum, E. crassipes, Nymphaea* sp., *Nelumbo* sp., *Phragmites karka*, *Zizania latifolia, Polygonum* sp., *Scirpus* sp., *Saccharum spontaneum, Setaria pallidefusca, Trapa natans, H. verticillata, Utricularia stellaris, Marsilea quadrifolia* and species of *Polygonum, Vallisneria* and *Trapa*.

Earlier during the 1960s and 1970s, Loktak lake used to have *N. nucifera* (lotus), *Nymphaea stellata* (lily), *Alisma plantago* (Kakthrum), *S. sagittifolia* (Koukha), *S. pallidefusea* (Kambong), *Oenanthe javanica* (Komprec), *Alpinia galanga* (Pullei) *etc.* but today menace of *E. crassipes,* is the major culprits (Suresh 2000). Singh *et al.* (1996) and Singh and Okram (2006). described the environmental and ecological impacts of aquatic weeds in Loktak lake in the form of Phumids.

**Aquatic weed management in India**

Considering the losses caused by aquatic weeds, their management is of utmost importance. Management of aquatic weeds can be grouped under following groups :

(1) Preventive management (2) Physical or mechanical management (3) Cultural and physiological management (4) Chemical management (5) Biological management. There is rarely a situation when weeds can be 'eradicated' but often can be 'prevented' from infesting other areas. Once prevention fails the next step is to treating them in a way that they do not emerge again.

**(1) Preventive management**

Quarantines are legislative tools that may be used to mitigate the effects of weeds. There is need of strict implementation of quarantine laws in India. Preventative weed programmes usually require community action through the enactment and enforcement of appropriate laws and regulations. Quarantine is defined as the restriction imposed by duly constituted authorities whereby the production, movement or existence of plants, plant products, animals, animal products, any other article or material or the normal activity of persons is brought under regulation in order that introduction or spread of a pest may be prevented or restricted. If a pest has already been introduced and established in a small area, a quarantine is necessary so that it may be controlled or eradicated or dissemination stopped in newer areas, thereby reducing the losses that would other wise occur through damage done by the pest (Murphy 1988). In India rivers and irrigation canals appear to be a potential source for spreading water hyacinth, alligator weed and *P. stratiotes* which may be brought under the domestic regulation as suggested by Richard and Humphrier (1995) in other countries. Movement of aquatic plant though trades and need of their prevention was assessed and disussed by Kristine and Galatowitsch (2004).

In India, water hyacinth moves from one state to another through canal systems and rivers. The effective quarantine laws can be enacted by states to check the flow of water hyacinth from one state or city to another state or city. Prevention and rapid response should be top priorities among authorities of water bodies, lake associations *etc.* because these are the most cost-effective and ecologically sound means of protecting aquatic resources from invasive species.

**(2) Manual and mechanical management**

Mechanical control of aquatic weeds primarily consists of removing the weeds physically from the water body. This can be done manually by hand or using hand tools or machine power. Mechanical methods often reduce massive nutrient load of eutrophic water bodies, helping indirectly in diminishing the future weed population. Harvested weeds may have various utilities such as feed, manure, energy source *etc*. and most importantly mechanical methods can be exercised in any localized area of water bodies. An expenditure of Rs.30328/- was incurred in manually removing of *E. crassipes* from four experimental ponds which had an area of 18.18 hectare while Rs.17466 was invested on food-fish-culture after the removal of *E. crassipes* mechanically in Kheda district of Gujrat. A net profit of Rs.14683 was realized (Sharma *et al*. 1989) over manual control.

There are several techniques like ( a) netting (b) barriers (c) chaining (d) water weed cutters to control weeds in aquatic situations. At the Central Institute of Fisheries Technology (CIFT), a portable mechanical gadget was developed which can clear both floating and submerged weeds at the rate of 1-1.5 ha area per day at a cost ranging from Rs 50-60/ha depending upon the intensity of the weeds Varshney and Rzoska (1976). The aquatic weed management through machines has been dealt with in detail by Beedu (1996). Cutting *Typha* manually or mechanically and subsequent submergence give effective control of this weed (Kumar and Chandi 1996d).

Machine that cut and picks up the weeds from water body and convey these to shore simultaneously are called harvester. Under water weed cutters were employed at Kota (Rajasthan) to clear Chambal canal from aquatic weeds (Gupta 1973). Sharma and Chnadi (1996) and Kumar and Singh (1996a) from Irrigation and Power Research Institute, Punjab demonstrated a underwater weed cutter to clear the rooted and non-rooted weeds from the canals in Jalandhar. The cost of weed clearance with this cutter was estimated one third of that with the manual labour. Beedu (1996) from Temba Engineering Limited, Chennai suggested to manage aquatic weeds through machines named Beetle-100 and Turtle-100 developed with the collaboration of Holland suited for Indian conditions. These machines were designed to remove all kinds of weeds for working in shallow water, in rivers, canals, lined canals lakes, ponds, reservoirs, lagoons *etc.* Recently more advance weed harvester machines have been developed by the company.

Some such indigenous aquatic weed harvesters have also been developed at Kochin by Ecotech Environmental and Pteromarine Engineering Pvt. Ltd. and Navgathi Marine Design and Constructions Pvt. Limited.

**(3) Ecological aquatic weed management**

Aquatic weeds can also be controlled by manipulating of water level, light intensity, nutrient availability and competitive displacement. Growth of the aquatic plants in small tanks and ponds can be checked by reducing light reaching their water level.

a) **Drying or water level manipulations:** This method is a simple and effective way of controlling submerged weeds. 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. To kill submersed weeds in the canals of Bhakra Canal System in Haryana (Malhotra 1976) and in Chambal Command Area in Rajasthan (Brezney 1970), exposure to sun was given by draining the water and this practice prevented regrowth for nearly six months.

Drying or water level manipulation is generally practiced in flowing water system like irrigation canals and drainage ditches. Frequent drying and wetting for several days may control the growth of roots and propagules in the bottom soil. This method is not effective for controlling of emergent weeds. Plants were exposed to the sunlight for 7 days by affecting closure of canals. Following the exposure, water was delivered for 2 weeks. Four such cycles were necessary to manage the weeds in canals (Kumar and Singh 1996b).

b) **Light**: Growth of submerged aquatic plants in small tanks and ponds can be checked by reducing light penetration. Use of fiber glass screen is popular in some countries. In an experiment conducted at Irrigation and Power Research Institute of Amritsar (Punjab) in small plastic trough of 45cm dia meter and 22.5 cm height with silt added at base for little more than 7.5cm. The weeds were transplanted and allowed to stabilize. Nutrition was provided through well decomposed farm yard manure. When new sprouts started emerging, the polyethylene film was used to cover troughs for 1,2,3,4,5 i.e. up to 15 days the leaves started falling after six days (Kumar and Singh 1996c).

Planting of trees on the banks of canals may create shade to reduce light intensity hence checking the weed growth. However care should be taken that trees or their appendages do not impede water flow. Light intensity can also be checked by adding dyes to the water. This type of control is more effective in static water such as ponds or tanks where dye remain suspended for a longer time.

c) **Sub-mergence**: *Typha* is one of the most important emergent weed growing all along the unlined canals margins of the water bodies and shallow submersed areas along canals. Cutting of the aerial shoots of *Typha* spp. at flowering stage and keeping the stubble submerged under the water for four weeks controlled *Typha* (Singh *et al.*1976) (Kumar and Singh 1996d).

d) **Competitive displacement**: Planting of Paragrass (*Brachiaria mutica*) in drainage ditches in the Chambal Irrigation Project eliminated *Typha angustata* after 10 to 12 months and yielded green fodder (Mehta and Sharma 1975). Besides direct competition, growth is also suppressed by some plants by shading effect. For example, the growth of *Azolla* in rice fields effectively controls the growth of other weeds.

**(4) Chemical management**

Chemical control through use of registered aquatic herbicides and algicides is a technique that is widely employed by aquatic plant managers in both private and public water bodies throughout the word. Since long time, many herbicides have been tested in many countries to control water hyacinth and other aquatic weeds. No one chemical has been developed so far which would control all aquatic weeds. So, it is essential to know the weed species, appropriate herbicide and their rate and time of treatment. Many countries of Europe and UK are keeping extremely vigilant control on the use of herbicides. In developed countries, herbicides have been exclusively registered for control of different types of aquatic weeds mentioning water use after days of spray of herbicides. In India, herbicides yet to be registered exclusively for aquatic weed control, nevertheless, these are being used to mange different types of aquatic vegetation.

Application methods depend on the chemical properties of the herbicide and its formulation. Herbicides which diffuse in water quickly can be applied in a concentrated form while others must be diluted and then sprayed evenly over the surface to ensure uniform distribution. Most herbicides are applied as high volume sprays by hand. Boats are used in big reservoirs, tanks, lakes and large ponds where water is still and weeds are to be controlled belong to emerged and floating types. In the case of canals and drainage systems, tractor drawn sprayer can be used for spraying herbicides. In the case of emerged and floating weeds, the herbicides are applied as a normal post emergence spray when weeds are in active growth phase. In case of submerged weeds, herbicide application before the plants reach full maturity is advised preventing deoxygenation of water through the rapid breakdown of dying plant material resulting in harm to fish populations. Calculation of herbicides in different aquatic situations have been given in detail by Gupta (2001).

Herbicides are being used with restrictions in different countries depending upon the type of aquatic weed flora and water use. Effect of these herbicides is also to be seen on other aquatic environmental factors which are associated with herbicide use. A single herbicide that controls weeds as well as being safe for all possible uses of the treated water is yet to come. However, in developed countries, there is now a large number of herbicides available keeping in mind the major weed problem, use of water system and the effect of chemicals on aquatic food chain down stream.

Several chemicals have been tried against water hyacinth with varying degree of success. Some notable contributions in the field are that of Mitra (1948), Ramachandran and Ramaprabhu (1968), Misra and Das (1969), Ramachandran *et al.* (1973) and Patnaik (1980). The herbicide 2,4-D (2,4-dichlorophen oxyacetic acid) is most effective for control of water hyacinth. The smaller floating weeds like *Spirodela, Lemina* and *Azolla* can be fully controlled with 0.1 kg/ha of 'Gramoxone' (paraquat) as reported by Patnaik (1976). Srinivasan and Chacko (1952) reported control of *Nymphaea* with 2,4-D ethyl ester while Singh (1962) reported control of *Nelumbo* and *Euryale* with 2,4-D sodium salt. Mitra and Banerjee (1966) attained considerable success in controlling *Nymphaea* and *Nymphoides* by applying copper sulphate pellets. The primary submerged weeds which infest fish ponds are tap grass (*Vallisneria*), water plantain (*Ottelia*), bushy pond weed (*Najas*), coon tail (*Ceratophyllum*), bladder wort (*Utricularia*), *Hydrilla* and *Nechamandra*. Philipose (1963) found sodium arsentte at 46 ppm effective against *Hydrilla* and *Najas* without killing fish. Rooted submerged weeds like *Hydrilla, Vallisneria, Najas* and *Nechamandra* were controlled by localized application of copper sulphate pelleted with mud at the rate of 35 kg/ha as advocated by Mitra (1977). Spraying with 2,4-D amines and esters ranging from 3.4 to 13.5 kg a.i./ha proved effective against a number of grasses, sedges and rushes as reported by Philipose (1968). Panchal and Sastry (1976) found application of diuron at the rate of 4 kg/ha along with 1 l/ha paraquat to clear *Typha angustata* at the pre-flowering stage and 2,4-D (sodium salt) at the rate of 8 kg/ha to control *Ipomoea aquatica*.

Patnaik and Ramachandran (1976) recorded full control of *Microcystis* bloom by application of 0.3 mg/l simazine. The dose was non-toxic to animal life of the pond. An organic copper complex 'Cutrine' was observed to be effective with dose 2 mg/l against *Anabaena, Microcystis* and *Peridinium* as reported by Patnaik (1980).

The most effective and economic method of control of *E. crassipes* was by application of herbicide 2, 4-D. The fish species composition improved qualitatively and quantitatively when *E. crassipes* was treated with diquat or terbutryn whereas a low catch of fish was recorded in the untreated areas (Olaleye *et al.* 1993). The cost of 2, 4-D 4 kg/ha and paraquat 1kg/ha treatment for controlling *E. crassipes* was found to be Rs.460/ha which was 61% lower than that of manual removal costing of Rs.1200/ha (Raju and Reddy 1988). Sharmna and Chandi (1996) used 2,4-D at the rate of 200-300 PPM to control water hyacinth in Hudiara canal, Tung Dhab drain, Verka drain and Muradpur drain in Punjab. They incurred 5 times less expenditure in chemical control than the manual control of water hyacinth. Kannan and Kathiresan (2002) demonstrated effective control of water hyacinth with glyphosate at 2.20 kg/ha dose without much reduction in water quality in terms of pH and DO. Muniyappa *et al*. (1995) found that the mortality on fishes was also the least with glyphosate. At 32 days after treatment of paraquat 0.90 kg/ha, 79% mortality of *E. crassipes* was achieved.

Maliwal *et al.* (2005) found application of glyphosate at 1.53 to 2.05 kg/ha effective to control of water hyacinth. They observed that paraquat controlled the weed immediately after spray, however these were resprouted from the left out live traces of weeds.

Metsulfuron-methyl (MSM) at the rate of 20 and 24 g/ha was considered most effective and safest herbicide to control aquatic and terrestrial form of alligator weed without affecting fish (Sushilkumar *et al*. 2008, 2008a). Sushilkumar *et al.* (2008a) reported that 2,4-D (1.5 kg/ha) and glyphosate(2.0 kg/ha) caused almost 100% superficial killing of alligator weed at 10 and 15 days after application (DAA), respectively. MSM was most effective at 0.024 kg/ha, however, 0.020 kg/ha was at par with glyphosate (3.0 kg/ha) and 2,4-D (2.0 kg/ha). In plot experiment, little regrowth was noticed in higher doses of glyphosate, 2,4-D and MSM. Repeat application of same herbicides after 90 days of first application revealed no significant difference in regrowth at 30 DAA, however, significant difference appeared at 60 and 90 DAA. Effect of MSM (0.020 kg/ha) was at par with higher dose of glyphosate (3.0 kg/ha) on regrowth after repeat application. In naturally infested area, no regrowth appeared in higher doses of glyphosate (3.5 and 4.0 kg/ha) up to 180 DAA, while glyphosate (3.0 kg/ha) and 2,4-D (2.5 kg/ha) were at par with MSM (0.020 kg/ha) at 360 DAA. This information may aid in the development of more effective management of alligator weed by herbicide application.

Effect of paraquat, 2,4-D and glyphosate was evaluated at Jabalpur on first stage growth of water hyacinth in relation to water quality parameters and fish mortality. All three herbicides influenced the water quality parameters (Kaur 2003). Sushilkumar (2011) demonstrated the effect of chemical and biological integration to control water hyacinth in a village pond of about one hectare. One thousand bioagent weevils of *Neochetina* spp. were released as initial inoculation in the pond over an area of 3000 m followed by application of three herbicides namely 2,4-D (1.5 and 2.0 kg/ha), glyphosate (2.0 and 2.5 kg/ha) and paraquat (0.7 and 1.0 kg/ha) in adjoining area after 15 days of bioagent inoculation. After 9 months of biological and chemical integration, the first cycle of complete control was achieved. This early collapse of weed within a period of 8-9 months could be possible due to integration of herbicide and bioagent which would otherwise have taken minimum 28-36 months by the bioagent alone. After some time, again water hyacinth population increased due to new germination from buried seeds or from the left remains of water hyacinth. This second cycle of water hyacinth was again collapsed by 21 months due to integration of one spray of herbicides after one month of regrowth.

### (4.1) Effect of herbicides on non-target species

When pesticides contaminate water, can be harmful to the fish and other living organisms that live there. Herbicides can also be toxic to fish. According to the Environmental Protection Agency (EPA),USA, studies showed that trifluralin, an active ingredient in the weed-killer 'Snapshot, "is highly to very highly toxic to both cold and warm water fish (Koyama 1996). The weed-killer "glyphosate" was also acutely toxic to fish (Folmar *et al*. 1979). The toxicity of glyphosate may be due to the high toxicity of one of the inert ingredients of the product. In addition to direct acute toxicity, some herbicides may produce sublethal effects on fish that lessen their chances for survival and threaten the population as a whole. Glyphosate or glyphosate-containing products can cause sublethal effects such as erratic swimming and labored breathing which increase the fish's chance of being eaten. 2,4-D caused physiological stress responses in sockeye salmon (Little, 1990).

Dad and Tripathi (1980) found adverse effect of some herbicides on fishes. In India, 2,4-D was extensively used to control water hyacinth in Punjab by Irrigation and Power Research Institute, Amritsur during last decade of $20^{th}$ century. Nevertheless, no ill effects of 2,4-D on human beings worked for 6-8 hours continuously for about 15 days was reported (Kumar 1996). They also not reported any mortality of fishes of size 2.2 ro 22 cm when observed up to 12 month after inoculation of fingerlings treated with 2,4-D ethyl ester at 300 ppm. Kaur (2003) observed fish mortality (20%) in 2,4-D at 1.5 and 2.0 kg/ha treated tanks infested with water hyacinth followed by glyphosate (13.3% at 2.0 kg/ha and 26.6% at 2.5 kg/ha). In paraquat (0.5 and 1.0 kg/ha) treated tanks, no mortality was found. In tanks having no weeds buy treated with higher doses of 2,4-D, glyphosate and paraquat, caused 0, 10 and 0% fish mortality, respectively. This indicated that reduction in water quality could be attributed to metabolic processes and to the decomposing organic matter after water hyacinth death instead of direct effect of herbicides. No fish mortality was observed in ponds at Jabalpur when treated in large area with recommended does of glyphosate, 2,4-D and metsulfuron-methyl to control lotus infestation (Sushilkumar *et al*. 2005).

2,4-D containing products have been shown to be harmful to newts, frogs, crabs, shellfish and other aquatic species in some other countries. Diuron is also highly toxic to aquatic invertebrates. Oxadiazon was found to severely reduce algae growth. Algae is a staple organism in the food chain of aquatic ecosystems. Studies looking at the impacts of the herbicides atrazine and alachlor on algae and diatoms in streams showed that even at fairly low levels, the chemicals damaged cells, blocked photosynthesis, and stunted growth in varying ways (Annon 2000).

Atrazine, one of the most commonly used herbicides in the world, has been shown to affect reproduction of fish, according to a new U.S. Geological Survey study (Annon. 2010).

Integration of biological and herbicidal methods has been widely recommended (Haags 1986; Center, *et al*. 1999). The host specific water hyacinth weevils, *Neochetina* spp. are the most important biocontrol agents used against water hyacinth (Julien 2001) with notable success in India, Australia, South Africa and USA. Similarly chemical control which typically involves spray application of herbicides like glyphosate, 2,4-D, diaquat and paraquat are widely in use and cause relatively rapid decline in water hyacinth weed mat. Some of the chemical formulations may have harmful effect on non-target organisms including the water hyacinth weevils especially if integrated management of water hyacinth is being attempted. Visalakshy, (1992) found deleterious effect of commonly used herbicdes on mite, *Orthogalumna* *terebrantis* (Acarina: Galumnidae). Kannan and Kathiresan (2002) also reported negative effect of herbicidal control on fish growth and water quality. Chattopadhyay *et al.* (2006) found mortality of zooplankton and *Azolla* within 7 days at the 7.5 l/ha dose of herbicide. They also found mortality of fishes up to 90 days after herbicide application to control submerged weeds.

Praveena *et al.* (2007) studied the effect of four herbicides (paraquat, pretilachlor, glyphosate, and 2,4-D Na salt), and a herbicidal mixture (anilofos+2,4-D EC) on growth and sporulation of *F. pallidoroseum* in vitro conditions. Pretilachlor (1.0, 0.25, 0.06, and 0.02 kg/ ha), 2,4-D (1.0 and 0.25 kg/ha), and 2,4-D+anilofos (0.4 and 0.1 kg/ha) completely inhibited fungal growth and sporulation, while paraquat and glyphosate (0.01 kg/ha) showed a lesser extent of growth inhibition (68 and 62% of control respectively). Lower concentrations of paraquat (0.05 and 0.01 kg/ha), glyphosate (0.8, 0.2, 0.06, and 0.02 kg/ha), 2,4-D (0.06 and 0.02 kg/ha), and anilofos+2,4-D (06 and 0.02 kg/ha), however, supported *F. pallidoroseum* growth.

Sushilkumar *et al* (2008) studied the effect of three most used herbicides against water hyacinth on *Neochetina* spp. Significant impact of herbicides was observed on the mortality of the weevils. When herbicide was sprayed on both the leaves and weevils, 3.3% mortality was seen on all doses of glyphosate, paraquat and the lower (0.5x) dose of 2,4-D while higher dose (x) caused significantly high mortality of 20% by 24 hours. 2,4-D at a higher concentration caused 53% mortality followed by paraquat (50%) when herbicide was sprayed directly on weevils. Glyphosate caused the lowest mortality among the three herbicides tested. This study reflects that direct hit of high dose of herbicides may cause higher mortality of bioagent.

Ray *et al.* (2008d) further confirmed the effect of two commonly used herbicides, glyphosate and 2,4-dichlorophenoxy acetic acid at three recommended doses on *Neochetina* spp. and phytopathogen, *Alternaria alternata*. The herbicides were sprayed on the water-hyacinth weevils and added to the nutrient media of *A. alternata*. 2,4-D caused higher weevil mortality (6.7, 13.3 and 15.6%) as compared to glyphosate (3.3, 5.6 and 11.1%), at three doses over 72 h. There was also a decrease in feeding in the herbicide treated leaves. When the weevils were allowed to move freely between the herbicide treated and untreated plants, higher orientation of the weevils was found on the untreated water hyacinth than on the treated ones. Neither of the two herbicides actually killed the fungus but both inhibited its growth. Glyphosate though, delayed mycelial growth yet stimulated sporulation while 2,4-D inhibited both growth and sporulation. Glyphosate at low concentration did not affect the virulence of *A. alternata*, while fungi grown on 2, 4-D amended plates lost their virulence.

Gnanavel and Kathiresan (2008) did not observed *Neochetina* spp. mortality due to the plant product at the highest concentration (25%) under an integration of bioagent and plant product method of control. They did not observe any histological alterations in cuticular membrane, fat body, foregut, midgut, hindgut, salivary gland and testis were also not observed.

**(4.2) Effect of herbicides on water quality**

Although, Kannan and Kathiresan (2002) reported most effective control of water hyacinth with imazathapyr, however, they found that the water quality was highly affected and the same imparted highest fish mortality. The ponds which were infested with aquatic weeds generally showed lower turbidity, pH, temperature, dissolved oxygen and higher free carbon-dioxide, total alkalinity, nitrate, phosphate and chloride than weed free ponds (Radhakrishnan and Bhuyan 1977). Treatment of glyphosate and 2,4-D (2.0 kg/ha) and metsulfuron-methyl (12 g/ha) for control of lotus in a pond at Jabalpur also reduced dissolve oxygen and pH and increased the COD. (Sushilkumar *et al*. 2005).

Extensive work on testing of herbicides and their effect on water quality and fish mortality has been carried out against another floating weed *Alternanthra philoxeroides* (alligator weed). Results showed that different herbicides behaved differently to control weed as well as to affect water quality, fish and insect mortality. Highest mortality of fish occurred in 2,4-D followed by glyphosate and metsulfuron-methyl. Water quality parameters were also found to be influenced differently with the disintegration of weeds at different days after spraying of different type of herbicides in different doses. Metsulfuron methyl emerged as safest herbicides to control alligator weed in terms of weed control, fish and insect mortality and water quality (Sushilkumar *et al.* 2003, Sushilkumar *et al*. 2008a).

Studies have been carried out at Directorate of Weed Science Research, Jabalpur on effect of glyphosate in different doses on water quality of irrigation and drinking water in context to water hyacinth control (Sushilkumar 2008). Herbicide was sprayed in 25, 50 and 100% area of waterhyacinth surface in different treatments with the bioagents. Glyphosate was also spread only on water surface without the weed or bioagents. In control, only waterhyacinth was kept without any treatment. Observations were taken for bioagent population, fish mortality, water hyacinth population, and water quality parameters like pH, dissolved oxygen and Biological Oxygen Demand (BOD). No fish mortality in first week after herbicide treated tank was observed except only 5% mortality after 20 days which may be correlated with the decaying of weeds due to herbicide action. pH increased 7.4 to 9 after herbicide treatment corresponding to area of glyphosate treatment. No change in dissolved oxygen (DO) was observed up to 5 days in tanks treated with herbicide but onwards it decreased corresponding to area of tank treatment. Maximum decrease in DO was observed between 25 to 45 days in tanks where 100% area of water hyacinth surface was treated with herbicide. DO was highest in herbicide treated tank without weed (9-10 ppm). There was no decrease in DO in these tanks which suggested that decline in DO is correlated with decomposition of water hyacinth. There was reduction in electrical conductivity (200) in 100% glpyhosate treatment with no weed while it was around 430 µs/cm with weed treatment. This indicates that glyphosate alone may reduce the conductivity of fresh water. There was no major difference in other treatments.

**(4.3) Herbicide residue in water and fish**

Sushilkumar *et al.* (2008) evaluated persistence of 2,4-D, metsulfuron-methyl and glyphosate from the sediments when applied at recommended doses to control alligator weed. They found that persistence of metsulfuron-methyl was directly dependent on application dose. The persistence of herbicides increased with increased rate of application. 2,4-D residues dissipated completely by 15 and 45 days from 0-15 and 15-30 cm soil depth at 2.5 kg/ha. Glyphosate and metsulfuron-methyl persisted up to 45 and 60 days, respectively.

Sondhia (2008) deducted residues of sulphosulfuron in the fishes after 10 days exposure to herbicides in aquariums which was later on dissipated to below MRL value. Sondhia (2010) detected 0.075 to 0.011 and 0.074 to 0.226 µg/g of butachlor and oxyflurofen, respectively from the fish samples collected after 10 and 60 days interval from the runoff water collected in the pond.

**(5) Biological management**

Biological management of aquatic weeds is a broad term for the exploitation of living organisms or their products to reduce or prevent the growth and reproduction of weeds. Biological control is one of the safest approaches keeping in view the environmental consequences. Owing to increasing awareness about the ill effects of chemicals, now more emphasis is being given to search for non-chemical approaches. 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 the plant community. Biological control is more complex than chemical control because it requires (a) long term planning (b) multiple tactics and (c) manipulation of cropping system to interact with the environment. Biological control can be an economically sustainable, environmentally safe and long-term option to manage certain targeted aquatic weeds in multi-use waters. Invasive aquatic weeds that colonize vast areas of water bodies in monotypic stands are ideal targets for biological control. Julien (1989) has attempted to work out the total releases made against weeds by biological agents. He found that after 13 releases of agents for classical control of weeds in the first decade of $20^{th}$ century, the number of releases per decade increased nearly exponentially. The rate of effectiveness declined from 29% of all releases up to 1980 to 25% of all releases up to 1985. The most widely used biocontrol organisms with a proven record of success were fish and insects (Table 2). Herbivorous snails have been tested, but they have not shown good effectiveness or safety to merit consideration as biocontrol agents for aquatic weeds (Cowie 2001).

Biological agents are increasingly being seen as a feasible solution to the problem. The research effort in the use of fish (particularly the grass carp) to control excessive aquatic weed growth in irrigation canals has steadily gained ground in recent years. It is estimated that the cost of developing and deploying a single classical biocontrol agent is between $ 4 to 6 million and the process requires between 3.5 and 20 scientist-years (Center *et al.* 1997). On the other hand, biocontrol programme can yield enormously favorable returns on investment. Comparative figures for chemical and mechanical control of aquatic weeds are not available, but Pimentel *et al.* (1993) projected a smaller 1:4 return for all chemical pesticides, including herbicides, used in crop protection. Teague and Boroson (1995), based on 1991 figures, estimate a return of $ 4.16 per every $ 1.00 spent on chemical pesticides in agriculture. Thus, based on cost-benefit considerations, biological control certainly ranks higher than other forms of proven aquatic weed control. In case of Parthenium, a problematic terrestrial weed in India, the total benefits by the biological control in six years was estimated Rs 62.34 million; 15585 per cent benefit over initial investment (Sushilkumar 2006). McFadyen (2008) has also discussed in detail the economic return from biological control. Despite solid scientific and empirical foundations of biological control, it is difficult to assure success in every case. Even after careful research and testing, many classical biological control agents fail to provide a level of control desired by different stakeholders. This could be due to the inability of the organism(s) to establish permanently and spread, inadequate capability to suppress the weed populations, or a number of other factors related

**Table 2. Successful examples of insect/fish bioagents in the world. Remarks have been give about the possible import of bioagents in India.**

| Aquatic weed | Insect bioagents | Status in India and remarks |
|---|---|---|
| 1. Alligator weed (*Alternanthera philoxeroides)* | *Agasicles hygrophila* (Flea beetle) | It is a floating weed but in shallow waters it takes roots in hydrosoil.<br>The bioagent is native to South America. It destroys foliage of the weed.<br>Urgent need to import in to India |
| 2. Waterhyacinth (*Eichhornia crassipes*) | *Neochetina eichhorniae*<br>*N. bruchi (Hyacinth weevils)*<br>*Orthogalumha terebrantis* (Hyacinth mite)<br>*Sameodes albiguttalis* (Hyacinth moth) | All the four bioagents are native to Argentina.<br>Weevil and mite have been released in India, established and successfully controlling WH<br>Need to be imported |
| 3. Salvinia (*Salvinia molesta*) | *Cyrtobagus salvinae*. (Curculionid weevil) | Native to Brazil.Released in Kerala, established and controlled the weed |
| | *Paulinia acuminata* (Grass hopper) | Released but did not established |
| 4. For many submerged and floating weed | *Ctenopharyngodon idella* grass carp | Native of China<br>Imported, widely established and controlling weeds in India |

to the weed, the organism, or the environmental (Julien and White 1997). Moreover, not all weeds are likely to be easy targets for biocontrol. *H. verticillata*, for instance, has not been adequately controlled in the USA even after nearly 10 years following the release and establishment of four non-native agents, *Bagous affinis* and *B. hydrillae* (tuber weevils; Coleoptera: Curculionidae) and *H. pakistanae* and *H. balciunasi* (leaf-mining flies; Diptera: Ephydridae) and the presence of a native or naturalized moth, *Parapoynx diminutalis* (Lepidoptera: Pyralidae). Likewise, the fungal pathogens tested so far have not proven consistently effective in controlling submerged weed targets in field trials. The various approaches of biological control are briefly discussed as below:

### (5.1) Use of insects in biological control of aquatic weeds

In view of the seriousness of the problem and ineffectiveness of other control methods, in 1982, three exotic natural enemies *Neochetina bruchi, N. eichhorniae* and *Orthogalumna terebrantis* (a mite) were introduced in India. Host specificity of the weevils was tested and they were found safe for evaluation and field testing (Jayanth 1987, 1988). In India spectacular success has been achieved at Hebbal tank in Bangalore causing 95% control within a span of two years (Jayanth 1988), Loktak lake in Manipur (Jayanth and Visalakshi 1989) and several ponds in Jabalpur (Sushilkumar and vashney, 2007). However, there were several instances where weevil releases have been a total failure, for example Kengeri tank in Bangalore (Anon. 1994).

Water fern or *Salvinia molesta* is a free floating water weed of Brazilian origin. It was first observed in 1950s in Veli lake, Trivendrum, Kerala and assumed pest status since 1964 (Joy 1978). In 1982, the curculionid weevil *Cyrtobagous salviniae* Clader and Sands of Brazilian origin was introduced from Australia. In 1983-84 field experiments were conducted at Lal bagh, Bangalore where the C. *salviniae* adults were released in *Salvinia* infested water lily pond. The cultures of *C. salviniae* supplied to Kerala met with similar success. Bioagent was established in all released sites and in some areas resulting 99% suppression of the weed in 12-16 months. The weevil cleared over 1000 sqkm of water surface in Kuttanad area within two years of its introduction (Joy 1986). Kannan and Kathiresan (1999) reported varied numbers of weevils required to control different growth stages of water hyacinth. Ray *et al.* (2009) studied minimum required inoculation load of weevils of *Neochetina* spp. on three growth stages of water hyacinth, based on fresh biomass, plant height and number of leaves. The small growth stage was controlled early corresponding to the increase in number of weevils per plant. Four and eight weevils could control the small growth stage in 50 and 40 days while 8, 12, 16 and 20 weevils could control in 10 days only. Middle growth stage was completely killed in ten days by 16 and 20 weevils per plant while 4, 8 and 12 weevils per plant took 70, 60 and 50 days, respectively. The large plants could not be controlled even with the inoculation pressure of 20 weevils per plant. This study suggested that comparative high number of inoculation load of *Neochetina* spp. should be release for control of large size of water hyacinth in a water body.

Biological control status of aquatic weeds in India has been reviewed by Sushilkumar (1993), Bhan and Sushilkumar (1996), Jayanth (1996), Singh (1989, 2004), Varshney *et al.;* 2008 and Vishalakhsi and Sushilkumar (2008).

Singh (2004) categorized maximum degree of success (55.5%) in biological control of aquatic weeds followed by homopterous pests (46.7%) and terrestrial weeds (23.8%). For the biological suppression of water hyacinth, exotic weevils *Neochetina eichhorniae* and *N. bruchi* were successfully colonized since 1983 in different water bodies in Andhra Pradesh, Assam, Gujarat, Haryana, Himachal Pradesh, Kerala, Madhya Pradesh, Maharashtra, Manipur, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal including Loktak Lake (Manipur), Indira Gandhi canal (Rajasthan) Tocklai river (Assam), Mula Mutha river, Pune (Maharashtra) and Pichola Lake, Udaipur (Rajasthan). These efforts have resulted in establishment of the weevils in different parts of the country. The annual savings due to suppression of the weed by the weevils was estimated to be Rs. 11.2 lakhs in Bangalore alone. Exotic weevil, *Cyrtobagous salviniae* was first colonized successfully on water fern, *Salvinia molesta* in a lily pond in Bangalore in 1983-84. Within 11 months of the release of the weevil in the lily pond the *Salvinia* plants collapsed and the lily growth, which was suppressed by competition from *Salvinia* resurrected. Subsequent releases in Kerala, resulted in establishment of the weevils in ponds/ tanks/canals/lakes and within a span of 3 years, most of the canals abandoned due to the weed menace have become navigable once again. About 2,000 sqkm area of the weed was cleared by *C. salviniae*. By 1988 in the case of paddy cultivation, where Rs. 235 had to be spent per hectare for manual removal, the savings on account of labour alone were about Rs. 6.8 million annually (Singh 2004). In world scenario, at least three aquatic weeds have been successfully brought under the banner of biocontrol, using specific insect bioagents. Among these water hyacinth and water fern have also been successfully controlled in India (Table-2).

**(5.2) Biological control of weeds using pathogens**

Weeds can be controlled by pathogens like fungi, bacteria, viruses and virus like agents. Among the classes of plant pathogens, fungi have been used to a larger extent than bacteria, virus or nematode pathogens. In some cases, it has been possible to isolate, culture, formulate and disseminate fungal propagules as mycoherbicides. So far, not even a single successful mycoherbicide has been employed against any aquatic weed in India in spite of many reports of fungal pathogen infesting many aquatic weeds severly (Aneja *et al*. 1993, Kauraw and Bhan 1994a, Ray *et al.* 2008b). Hasan and Ayers (1990) reported that interaction between the biotroph/necrotroph occurs at the infection site of biotrophs, where infection by one pathogen makes the host more susceptible to secondary infection. Such type of synergistic relationship of two pathogens can provide biological and economical feasibility by the use of mixtures of two or more fungi for effective control of one or more weeds. The combined effect of various pathogens was more effective than any of the pathogens tested alone.

During survey from 1992-1994 in and around Jabalpur in different months, two fungi *Acromenium zonetum* and *Alternaria* sp. from infected leaves of water hyacinth were isolated (Kauraw and Bhan 1994a). A series of surveys were conducted throughout Haryana in 1988-92 to identify naturally occurring fungal pathogens of water hyacinth by Aneja *et al.* (1993). Infection of water hyacinth leaves by *F. chlamydosporum* was observed. Naseema *et al.* (2001) investigated the efficiency of *F. equiseti* and *F. pallidoroseum* and their toxins for the management of water hyacinth. An increase in the intensity of infection was observed when the spore load was increased to 1010 and 1011 spores/ml.

Babu *et al.* (2003a,b) isolated, characterized and bioassayed the fungal pathogen *A. alternata* isolated from diseased water hyacinth plants from India. No crop tested was susceptible to the fungus. In another study Babu *et al.* (2003c) developed an improved high performance liquid chromatographic (HPLC) method for the detection and quantitation of host-specific AA-toxin produced by *A. alternata*. They concluded that the toxin may be used as a broad-spectrum herbicide to control many floating aquatic weeds.

Praveena and Naseema (2004) recorded 21 fungi from Kerala out of which 17 were pathogenic to water hyacinth. Among these, *Myrothecium advena* was a new report on water hyacinth. Furthermore, *M. advena* and *F. pallidoroseum* caused more than 50% infection of the weed and was considered to hold promise as biological control agents of water hyacinth. Babu *et al* (2004) examined the feasibility of rice seeds as solid substrate for the mass production of *A. alternata*. Conidia production and virulence of *A. alternata* were found affected by temperature, light and incubation period. In an effort to develop potential mycoherbicide, Naseema *et al* (2004) evaluated mycoherbicide from *F. pallidoroseum* and cashew nut shell liquid (CNSL) in a greenhouse and natural lake in Aakkulam (Thiruvananthapuram, Kerala) conditions. In the greenhouse trial, 97.8 and 82.2% damages were recorded for the wettable powder (WP; 40%) formulation of the fungus at 5 and 10% concentrations, respectively, on the weed pre-sprayed with CNSL. In the infected lake, the application of 5% WP formulation (pre-sprayed with 5% CNSL) developed typical blighting symptom on the 4th day and recorded 83.4 - 94.5% damage at 7th days after treatment.

Saleem and Naseema (2005) evaluated the efficacy of spore suspensions and cell-free metabolites of *A. eichhorniae* and *F. pallidoroseum* against water hyacinth. The cell-free metabolites of the fungi (each at 10 ml per plant) were also sprayed singly or in combination. They found that the combined application of the fungi resulted in greater infection (58.6%) than the application of *F. pallidoroseum* (54.8%) or *A. eichhorniae* (50.4%) alone. The application of the cell-free metabolites of both fungi resulted in a disease intensity of 55.4% (49.6 and 52.3% infection when the cell-free metabolites of *A. eichhorniae* and *F. pallidoroseum* were applied, respectively). Naseema *et al.* (2005) characterized *F. oxysporum* (isolates 1 and 2), *F. moniliforme* (isolate 3) and *F. pallidoroseum* (isolates 4, 5 and 6) isolates from water hyacinth and one *F. pallidoroseum* isolate from insect (isolate 7) by random amplified polymorphic DNA markers technique.

Praveena *et al*. (2006) analyzed bioherbicidal potential of phytotoxin produced by *F. pallidoroseum* in vitro which was isolated from fourteen-days-old filtrate of the fungi. The role of fusaric acid in symptom development was confirmed by application of the purified toxin on in vitro cultured plants. It has been found that phytotoxin isolated from fungi and developed as mycoherbicide are effective in laboratory conditions but are ineffective when applied in natural conditions. Therefore, Singh *et al*. (2006) tried management of water hyacinth with a mycoherbicide from *F. pallidoroseum* in natural lake conditions. In water hyacinth infested lake, application of 5% concentration of wettable powder (WP) formulation of *F. pallidoroseum* developed typical blighting symptom on the 4th day and recorded 83.4 to 94.5% damage by 7th day. This study indicated that WP formulation of *F. pallidoroseum* may be an effective mycoherbicide for the management of water hyacinth and safe to other aquatic fauna and flora. They advocated further study on this aspect. Sriramkumar *at al.* (2008) argued the need of introduction of more effective pathogens against *E. crassipes* weeds in India. They categoriesd introduction of the first plant pathogen, *Puccinia spegazzinii* against *Mikania micrantha* H.B.K. in India a great success. With the mechanism in place for the importation, quarantining and release of pathogens, it is envisaged that more introductions will be made in the future.

Ray *et al.* (2008c) during surveys of water hyacinth infested water bodies in Jabalpur, isolated 31 endemic pathogens of these, *Alternaria alternata* followed by *Curvularia lunata*, *Fusarium pallidoroseum*, *Alternaria eichhorniae* and *Rhizoctonia solani* were found to be highly pathogenic. Among them they found *A. alternata*, a potential pathogen against water hyacinth (Ray *et al.* (2008a). It was demonstrated that combined use of virulent pathogens may cause more damage. Ray *et al.* (2008c) studied the combined impact of various pathogens for integrated management of *E. crassipes* (Mart.) Solms. The combined effect of various pathogens was more effective than any of the pathogens tested alone.

For mass production of mycoherbicide for biological control of water hyacinth, Praveena and Naseema (2008a) conducted a study to determine the effects of liquid substrates. Their study showed that groundnut oil cake extract recorded maximum mycelial weight of *F. pallidoroseum, F. equiseti* and *Colletotrichum gloeosporioides* [*Glomerella cingulata*]*,* but sporulation and spore viability was less, when compared with other substrates. Coconut water and jaggery water supported the maximum sporulation and retained the spore viability for a period of one month. Praveena and Naseema (2008b) further studied to develop formulations of *F. pallidoroseum* and to integrate it with Cashew nut shell liquid (CNSL) in the management strategy of water hyacinth. On the basis of this study, they concluded that among the three formulations developed, wettable powder was best effective formulation with increased shelf life. The efficacy of wettable powder formulation could be enhanced by pre spraying water hyacinth with CNSL.

**(5.3) Use of aquatic mammals and rodents**

Introduction of manatee (*Trichechus inunguis*) and the rodent (*Myocastou coypus*) both known to feed on aquatic vegetation had earlier been suggested as possible biocontrol agents against aquatic weeds, but the slow reproductive rate of the former and the omnivorous feeding of the latter have discarded their trials. The Manatee has been extensively used for aquatic weed control in Florida and Surinam. So far, no such attempt has been made in India.

**(5.4) Use of snails**

Promising results have also been obtained utilizing snails *Pomacea canaliculata* Lamer, against the aquatic weed, *Anachaares alensa* in Brazil and *Marisa cornuarietis* in Florida. Good results have also been observed against aquatic weeds like *Ceratophyllum demersum, Najas guadalupensis* and *Potamogeton illinoensis* which were controlled completely. *Pistia stratoites* and *Alternanthera philoxeroides* were partially controlled while *Eichhornia crassipes* was not completely eaten but its growth and flowering were greatly retarded by root pruning action of the snail. Joshi *et al.* (2006) advocated the need of these bioagents to introduce in India but so far no effort has been made.

**(5.5) Use of fish**

Grass carp is native to the large river systems of Eastern Asia (China, Siberia) and has been distributed worldwide for use as a food fish and for biological control of aquatic weeds. Natural reproduction of this fish is limited on a world-wide basis due to river modification and reservoir construction, but grass carp are easily produced in aquaculture using artificial means. Hickling (1965) has dealt in detail the use of fish in biological control of aquatic vegetation. Among the several species of herbivorous fishes which feed on aquatic weeds, the more important are; *Tilapia melanoplaura; T. zilli; T. nilotica;* and *Puntiase gonianatus*. The Russians consider fish as more valuable and more permanent agents for weed control than mechanical or chemical. They are using the grass carp, *Ctenopharyngodon idella* and *Hypophthal michthys molitrix* extensively. The former is said to be the more effective species. It feeds on a wide range of aquatic weeds and its food plants include *Potamogeton, Lemna, Ceratophyllum, Elodea, Hydrilla, Hydrocharis, Typha, Phragmitis, Enhydrias, Vallisneria* and *Myriophyllm*. The *C. idella* fish has been employed for weed control in China, Hungary, Japan and India. Successful management of submerged aquatic weeds in the power canal and Hampi Foreway of the Tungbhadra Project has been done by using fishes (Tyagi and Gireesha 1996). They stocked about 6000 grass carps in Power Canal and Hampi Forebay in 1984 of Tungabhadra Project. The quantity of aquatic submerged weeds which was of about 3-8 kg/meter$^2$ area of the bed of the canal reduce to 0.3 to 1 kg/m$^2$ within a year of release of grass carp. The number of plants which used to be 1200-1500/m$^2$ also reduced to 100 to 300 plants/m$^2$. The size and weight of the grass carp also increased from 15-20 cm and 40-60 gms to average 42 cm and 1 kg, respectively within a period of 6 months.

Grass carp feed voraciously on *Hydrilla, Azolla, Nechamandra*, and *Lemna* spp. in India. This fish merits further extensive trials for the control of submerged weeds in India. In general, grass carp prefers submerged aquatic macrophytes, including important submerged weeds such as *H. verticillata, Chara* spp., *Najas guadalupensis, E. densa Potamogeton* spp., *C. demersum*, *Myriophyllum* spp. and *Vallisneria,* floating weeds *Wolffia* spp., *Lemna* spp., *Spirodela* spp. and *Azolla caroliniana,* and grasses and cattails. The floating and emergent plants *E. crassipes, P. stratiotes, Nymphaea* spp. and *Nuphar luteum* are least preferred (Sutton and Vandiver, 1995). As a non-selective herbivore, grass carp can be used to manage several aquatic plants collectively to maintain plant coverage at empirically determined levels. It can also be used in combination with chemical control, as well as other control methods. The cost of aquatic weed control with the triploid grass carp in Florida, USA ranges from about $ 50 to $ 620 per hectare (Wattendorf, 2001).

The efficiency of controlling *H. verticillata* using grass carp was studied in three trials during 1993-94 in Costa Rica (Rojas and Aguero, 1996). Grass carp (987 kg/ha) reduced *H. verticillata* biomass in nearly 62 m$^3$ with in 21 days. In another trial 1264 and 2042 kg/ha of the fish completely eliminated the weed after 30 days. In third case, 1000 kg/ha of carp only reduced *H. verticillata* volume in 19 m$^3$ after 66 days. The equilibrium point between weed regrowth and biomass consumed by the carp occurred at a ratio close to 0.03. Jhingran (1968) reported grass carp to feed voraciously on *Hydrilla, Azolla, Nechamandra* and *Lemna* spp.

Grass carp *C. idella* is a poor breeder in the warm water. Therefore, it is bred artificially for weed control purposes in India and released in the water when fingerlings are 100g each. About 1500 fingerlings must be released per hectare area of water. Large-scale stocking of grass carp in irrigation and drainage canals in Egypt proved to be successful at controlling weeds and increasing the protein production in Egyptian waterways (Van Zon 1984). Costs in the USA for chemical control were found to be many times higher than for using grass carp. In Florida, it was estimated that 15 000 hectares of *Hydrilla* were treated with chemicals at a cost of US$ 9.1 million whereas the cost of grass carp stocked at 35 fish/ha would have cost US$ 1.71 million at 1977 prices (Haller 1978). In California, the cost of maintaining weed free canals with chemicals was estimated to be in excess of US$ 150 000 a year, but with the introduction of grass carp into the canals the costs have fallen to just US$ 15 000 per annum (Fish Farming International 1988). In addition to the economic benefits, the use of grass carp is a longer lasting measure. There is vast scope of releasing of grass carp in aquatic weed infested irrigation canal systems of India to reduce the aquatic weed intensity.

**(5.6) Biological management of aquatic weeds through allelochemicals**

The concept that some plants may be allelopathic to certain weeds is receiving increased attention in the search for weed control strategies. A lot of literature is available on allelopathy which has been defined as "the direct or indirect harmful effect on one plant or another through the production of chemical compounds that escape into the environment". Most of the research has been concentrated on determining the effects of decomposing crop residues on succeeding crops, inhibition of crop production by weeds and crop-to-crop interaction. Kauraw and Bhan (1994) demonstrated the effect of dry *Cassytha* powder (0.5, 1.0, 1.5 and 2 per cent respectively) on water hyacinth plants grown in plastic tubs. All the treatments showed reduction in number of leaves and biomass in treated as compared to untreated check. Cassytha powder (1 to 2% w/v ) could completely kill the leaves and reduced the biomass. Chaturvedi and Sharma (1998) did not find allelopathic effect of litter extract of *Lantana camara* on water hyacinth.

Inhibitory effect of parthenium (*Parthenium hysterophorus L.*) leaf residue on growth of water hyacinth was established by Pandey *et al.* (1993). Investigations were undertaken on relative toxicity of twelve allelo chemicals to nine aquatic weeds including water hyacinth. P-hydroxybenzoic acid was lethal to the aquatic weeds water hyacinth, *Pistia, Salvinia, Azolla, Lemna, Spirodella, Hydrilla, Ceratophyllum* and *Najas* at 50-100 ppm. Results showed that the *Cassytha* sp. residue was lethal at and above 0.75%, w/v, to all aquatic weeds. Further work also established the potential of allelochemicals on water hyacinth and *salvinia molesta* in particular and on other aquatic weeds in general (Pandey 1996, 1996b).

The allelopathic potential of the native plants of India have been investigated, through a series of laboratory, green house and field experiments, for exploitation as components of a water hyacinth management programme. Kathiresan (2000) advocated the use of plants having allelopathic potential. Kathiresan (2005) reported that dried powder of the leaves of *Coleus amboinicus* at 40 g/l as a water suspension killed water hyacinth within 24 h reducing the fresh weight by 80.72% and the dry weight by 75.63% within one week. The lowest dose required to kill the whole plant was 10 g/1. *Coleus* powder was injurious to cut leaves of water hyacinth even at 0.1 g/1 dose as it was absorbed directly. On further work on this plant, Gnanavel and Kathiresan (2007) conducted an experiment to compare the effect of manuring, drying methods and soaking time on the allelopathic potential of *Coleus amboinicus/aromaticus* on *Eichhornia crassipes*. None of the fertilizer levels applied to the *Coleus amboinicus / C. aromaticus* [*Plectranthus amboinicus*] was found to affect the allelopathic effect of *Coleus*. Among the different methods of drying of *Coleus* leaves, shade drying for 25 days followed by oven drying at $65^0$C for 2 h was the most effective method in reducing the fresh weight and chlorophyll content of *E. crassipes*. Kathiresan and Dhavabharathi (2008) screened residues of 60 rice cultivars for their allelopathic inhibition on water hyacinth in laboratory bio-assays as well as in micropond tests. The cultivar BPT proved highly allelopathic to water hyacinth and caused reduction of 47.7% in weed biomass in lab bioassay and 45.6% in microponds. Rice cultivar ADT-36 was moderately allelopathic and reduced the weed bio-mass by 33.4 and 32.0% in laboratory bioassay and micro-pond, respectively.

## REFERENCES


Adnan Abubakr and Kundangar, MRD 2009. Three decades of Dal lake pollution – restoration. *J. Ecol. Env. Cons.* 15 (4): 825-833

Anonymous. 1994. *Annual Progress Report*. Project Directorate of Biological Control, Bangalore, India.

Anonymous. 2000. Ecologist says effect of herbicides on aquatic environment needs research. *U.S. Water News Online, July.* http://www.uswaternews.com/ archives/arcquality/tecosay7.html.

Anonymous. 2010. Commonly used atrazine herbicide adversely affects fish reproduction *U.S. Geological Survey Release*

Aneja KR, Srinvas B and Kaur M. 1993. Evaluation of *Fusarium chlamydosporum* as a biocontrol agent of water hyacinth (*Eichhornia crassipes*) (Mart.) Solms. 145-149; In: *Integrated Weed Management for Sustainable Agriculture. Proceedings of Indian Society of Weed Science International Symposium*, Hisar, India, 18-20 November 1993. Vol. II, Hisar, Haryana, India.

Babu RM, Sajeena A, Seetharaman K. 2003b. Bioassay of the potentiality of *Alternaria alternata* (Fr.) Keissler as a bioherbicide to control water hyacinth and other aquatic weeds. *Crop Protection,* 22(8): 1005-1013.

Babu RM, Sajeena A, Seetharaman K, Ebenezar EG, Raja AS, Biji KR and Prakash MS. 2003a. Isolation and characterization of phytotoxic substance from *Alternaria alternata* - a leaf blight pathogen on *Eichhornia crassipes*. *J.Ecobiology,*15(4): 315-318.

Babu RM, Sajeena A, Seetharaman K, Rangasamy P, Ebenezer EG and Vidhyasekaran P. 2003c. *Alternaria alternata* toxin detection by fluorescence derivatization and separation by high performance liquid chromatography. *Phytoparasitica* 31 (1): 61-68

Babu, RM, Sajeena A and Seetharaman K. 2004. Solid substrate for production of *Alternaria alternata* conidia: a potential mycoherbicide for the control of *Eichhornia crassipes* (water hyacinth). *Weed Res.* 44(4): 298-304

Beedu Deepak Rao. 1996. Aquatic weed management through machines. 179-184. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Bhan VM and Sushilkumar. 1996. Eco-friendly approaches in aquatic weed management. 191-201. In : *Proceedings of Workshop on " Aquatic Weeds-Problems and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Bisi PK. 1996. Losses of generation in Chiplima Power House of Hirakumd power system due to aquatic weeds in power channel/foreway- A case study.136-140. In : *Proceedings of Workshop on " Aquatic Weeds-Problems and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Brezny O. 1970. *Draft of final technical report on aquatic weed control in Chambal Commanded area in Rajasthan*: 68 p.

Center TD, Dray FA, Jubinsky GP and Grodowitz MJ. 1999. Biological control of water hyacinth under conditions of maintenance management: can herbicides and insects be integrated? *Environ. Manager,* 23 (2): 241-256.

Center TD, Frank JH and Dray FA. 1997. Strangers in Paradise. 245-266. In: *Biological Control*. (Eds. Simberloff DDC Schmitz and TC Brown) Island Press, Washigton DC.

Central Water Commission 2011. *Annual Report 2010-2011*. www.cwc.gov.in/.../17_10_2011Final%20Draft%20AR%202010-11.

Chaturvedi N and Sharma KP. 1998. A bioassay study on the possible influence of *Lantana camara* L. leaf leachates on *Eichhornia crassipes*. *Tropical Ecol.* 39: 2, 277-278.

Chattopadhya A, Adhikari A, Adhikary SP and Ayyappan S. 2006. Evaluation of butachlor for control of submerged macrophytes along with its impact on biotic components of fresh water systems. *Iran J. Environ. Health. Sci. Eng*. 3(2) 103-108

Cowie RH.2001. Can snails ever be effective and safe biocontrol agents? *Int. J. Pest Manag.,* 47: 23-40.

Dad NK, and Tripathi PS. 1980. Acute toxicity of herbicides to freshwater fish and midge larvae, *Chironomus tentans. Environ. Int*. 4:435–437.

FAO. 1999. Irrigation in Asia in figures. *FAO Water Report No 18,* Rome.

Fish Farming International. 1988. Centro de Informacion del Ministerio de Industria Pesquera de Cuba. Vol. 15

Folmar LC, Sanders HO and Julin AM. 1979. Toxicity of the herbicide glyphosate and several of its formulations to fish and aquatic invertebrates. *Arch. Environ. Contam. Toxicol.* 8: 269-278.

Gnanavel I and Kathiresan RM. 2007. Impact of integrated biological control of water hyacinth (*Eichhonnia crassipe*s (Mart.) Solms) on water quality and fish mortality. *Research J.Agri. Biol. Sci.*: 3(1): 21-23.

Gnanavel I and Kathiresan RM. 2008 Effect of integrated biological control on *Eichhornia crassipe*s (Mart.) Solms and its impact on insect histology. *Crop Research* (Hisar): 35(3): 273-276.

Gopal B and Sharma KP. 1981. *Water hyacinth (Eichhornia crassipes) the most troublesome weeds of the world.* Hindasia Publisher, New Delhi, 129p.

Gupta, OP. 1973. Aquatic weed control. *World Crops*, 25 (4): 132-190

Gupta OP. 1987. *Aquatic weed management : a text book and manual*. Today and Tomorrow's Printers and Publishers, New Delhi

Gupta OP. 2001. *Weedy aquatic plants: their utility menace and management*. Agrobios (India): 273 p.

Gupta O.P. 2008. *Weedy aquatic plants: their utility, menace and management.* Agrobios, Jaipur: 286p.

Haag KH. 1986. Effective control of water hyacinth using *Neochetina* and limited herbicide application. *J. Aquatic Plant Manag.,* 24: 70-75.

Haag KH.1986. Effective control of water hyacinth using *Neochetina* and limited herbicide application. *J. Aquaic Plant Manag.,* 24: 70-75.

Haller WT. 1978. *Hydrilla, a new and rapidly spreading aquatic weed problem*. Agricultural Experiment Station, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida, USA.

Hasan S and Ayers PG. 1990. The control of weeds through fungi: principals and prospects. *New Physiologist,* 115: 201-222.

Hickling CF. 1965. Biological control of aquatic vegetation. *PANS* 11: 237-244.

Holm LG, Plucknett DL, Pancho JV and Herberger JP. 1991. The *world's worst weeds, distribution and biology.* Krieger Publishing Company, Malabar, Florida, U.S.A.

Jayanth KP. 1987. Suppression of water hyacinth by the exotic insect *Neochetina eichhoriae* in Bangalore, India. *Curr. Sci.*, 56, 494-495.

Jayanth KP. 1988. Biological control of water hyacinth in India by release of the exotic weevil *Neochetina bruchi*. *Curr. Sci.*, 57:(17) :968-970.

Jayanth KP. 1996. Biological control of aquatic weeds in India - progress and prospect. 122-129. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Jayanth KP and Visalakshi PNG. 1989. Introduction and establishment of *Neochetina eichhorniae* and *Neochetina bruchi* on water hyacinth in Loktak Lake, Manipur. *Sci. Cult.* 555: 505-506.

Jhingran VG. 1968. *Synopsis of biological data on catla*. FAO Fisheries Synopsis No. 32, Rev. 1, Rome

Joy PJ. 1978. *Ecology and control of Salvinia (African Payal), the molesting weed of Kerala.* Technical Bulletin No.2. Kerala Agricultural University , Trichur, 40pp.

Joy PJ. 1986. *Salvinia* control in India. *Biocontrol News Infor.*, 7: 142.

Joshi Ravindra C and Sebastian Leocadio S. (Eds). 2006. *Global advances in ecology and management of golden apple snails.* Publisher Philippine Rice Research Institute, 588p.

Julien MH. 1989. Biological control of weeds worldwide: trends, rates of success and the future. *Biocontrol News Info*. 10 (4): 299–306.

Julien MH. 2001. Biological control of water hyacinth with Arthropods: a review to 2000, 8-20. In: *Biological and integrated control of water hyacinth, Eichhornia crassipes,* (Eds. Julin MH, Hill MP, Center TD and Jianqing Ding). ACIAR Proceedings 102.

Julien M. and White G. (Eds). 1997. *Biological control of weeds: theory and practical applications*. Canberra, Australian Centre for International Agricultural Research (ACIAR), Monograph No. 49, 192 p.

Kathiresan R and Dhavabharathi J. 2008. Rice allelopathy for weed management in aquatic ecosystems. *Allelopathy J.,* 22(2): 413-416.

Kathiresan RM. 2000. Allelopathic potential of native plants against water hyacinth. *Plant Prot.*, 19: 705-708.

Kathiresan RM. 2005. Allelopathy for bio-control of water hyacinth. *Proceedings of the 4th World Congress on Allelopathy- Establishing the Scientific Base*:- Wagga-Wagga New-South Wales, Australia, 21-26-August, 2005; 64-70

Kannan C and Kathiresan RM. 1999. Biological control at different growth stages of water hyacinth. 1–8. In: *Proceedings of the First IOBC Global Working Group Meeting for Biological and Integrated Control of Water Hyacinth*. (Eds. M.P. Hill, M.H. Julian, T.D. Center). Harare, Zimbabwe, November16–19, 1998. PPRI Pretoria South Africa.

Kannan C and Kathiresan RM. 2002. Herbicidal control of water hyacinth and its impact on fish growth and water quality. *Indian J. Weed Sci.* 34, 92-95.

Kaur Simendeep. 2003. *Impact of herbicides on water quality and fish mortality in relation to water hyacinth control.* M.Sc. thesis, NRC Weed Science, Jabalpur, India.

Kauraw LP and Bhan VM. 1994. Efficacy of *Cassytha* powder to water hyacinth and of marigold to Parthenium population. *Weednews*,1(2): 3-6.

Kauraw LP and Bhan VM. 1994a. *Annual Report*, National Research Centre for Weed Science, Jabalpur

Koyama J. 1996. Vertebral deformity susceptibilities of marine fishes exposed to herbicide. *Bullt. Environ. Contam. Toxicol.,* 56:655–662.

Kristine Maki and Galatowitsch Susan. 2004. Movement of invasive aquatic plants into Minnesota (USA) through horticultural trade. *Biological Conservation* 118 (3),:389–396

Kumar CP. 2003. *Fresh Water Resources*: A perspective. National Institute of Hydrology, Roorkee ,India (Uttaranchal)

Kumar M. 1996. Effect of 2,4-D Used to eradicate water hyacinth on drop, fish and animal life. 71-77. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Kumar M and Singh J. 1996a. A mechanical underwater weed cutter for submerged weeds in irrigation channel. 21-23. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Kumar M and Singh J. 1996b. Management of aquatic weeds in irrigation system. 28-35. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Kumar M and Singh J. 1996c. Feasible methods to control of submerged aquatic weeds. 53-60. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Kumar M and Singh J. 1996d. Problems of *Typha* sp. and its control. 47-52. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Kundangar MRD. 2010. Thirty years of Dal lake pollution. *Greater Kashmir, Srinagar*, 5 June 2010.

Ladhar SS. 1996. Management and control of aquatic weeds in wetlands of Punjab (case studies of Harike and Kanjli wetlands). 36-46. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Little EE. 1990. Behavioral indicators of sublethal toxicity of rainbow trout. *Arch. Environ. Contam. Toxicol*. 19:380-385.

Malhotra AK and Ahmad Afroz. 1996. Combating aquatic weeds - a growing ecological menace. 6-10. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Malhotra S.P. 1976. *Haryana's efforts to irrigate its high areas*. Irrigation Department Haryana,Chandigarh, 1-20

Maliwal PL. Hussain Iqbal and Mundra SL. 2005. Control of water hyacinth through versatile herbicides. 208-213 In: *Aquatic weeds: problems, control and management* (eds. Mathur SM, Mathur AN, Trivedy RK, Bhatt YC and Mohnot P.)

Mathur SM, Mathur RN, Trivedy RK, Bhatt YC and Mohonot P (Eds.) 2005. *Aquatic weeds: problems, control and management.* Himanshu Publications, Udaipur, India

McFadyen R. 2008. Return on investment: determining the economic impact of biological control programmes. In : *Proceedings of the XII International Symposium on Biological Control of Weeds;*' held at La Grande Motte, France, 22-27, April 2007 (eds. M. H. Julien, R. Sforza, M. C. Bon, H. C. Evans, P. E. Hatcher, H. L. Hinz, B.G. Rector). CAB International , Wallingford, UK.

Misra, G and Das N.1969. Studies on the control of aquatic weeds of Orissa. response of water hyacinth to two hormone weedicides, 2,4,5-T. *Hyacinth Control J.*, 8 : 22–23.

Mitra GP. 1948. Eradication of water hyacinth by methoxone on a field scale trial. *Sci. Cul.* 14(4) : 143–145.

Mitra E. 1977. *A report on copper sulphate treatments of fishery ponds for the control of weeds. 1952–1970.* Central Inland Fisheries Research Institute Bulletin No. 26, pp 1–26.

Mitra E and. Banerjee AC. 1966. Studies on the use of copper sulphate in pond soils for the control of rooted aquatics. *Proc. Indian Sci. Congr*. 53(3) : Abstr. 38.

Muniyappa, TV, Manjunatha V and Sureshbabu V. 1995. Efficacy of post emergent he D.K. Pandey (1996a) Phytotoxicity of sesquiterpene lactone parthenin on aquatic weeds. *J. Chem. Eclo.* 22 (1), 151-160.

Murphy KJ. 1988. Aquatic weed problems and their management: a review. II. Physical control measures. *Crop Protection* 7: 283–302.

Naseema A, Praveena R and Salim AM. 2004; Ecofriendly management of water hyacinth with a mycoherbicide and cashew nut shell liquid. *Pakistan J. Weed Sci. Res.,* 10(1/2): 93-100.

Naseema A, Praveena R, Balakrishnan S and Peethambaran CK. 2001.Management of water hyacinth with fungal pathogens. 263-268. In : *The BCPC Conference:Weeds,2001,*Volume 1 and Volume-2.Proceedings of an international conference held at the Bright on Hilton-Metropole-Hotel,-Brighton,UK,12-15-November-2001.

Naseema A, Salim AM, Krishnan GRP and Rajmohan 2005. R Molecular characterization of *Fusarium pallidoroseum*, a potent biocontrol agent of water hyacinth. *Plant Disease Res.* (Ludhiana): 20(2): 210-212.

Olaleye VF, Akintunde EA and Akinyemiju OA. 1993. Effect of herbicidal control of water hyacinth on fish composition and abundance in the Kofawei creek, Ondo State. *J. Environ. Manag., 38* (2): 85-97.

Panchal YC and Sastry KSK. 1976. Studies on chemical control of *Typha angustata* (Bory and Chaub) in Tungabhadra Project area. 277–284. In: *Aquatic weeds in south east Asia*. (Eds Varshney CK and Rzoska J.) Dr. W. Junk B.V., The Hague.

Pandey DK. 1994. Inhibition of salvinia (*Salvinia molesta* Mitchell) by parthenium (*Parthenium hysterophorus* L.) I. Effect of leaf residue and allelochemicals. *J. C hem.Ecol.* 20, 3111-3122.

Pandey DK.1996a. Phytotoxicity of sesquiterpene lactone parthenin on aquatic weeds. *J. Chem. Ecol.* 22 (1), 151-160.

Pandey DK.1996b. Relative toxicity of allelochemicals to aquatic weeds. *Allelopathay Journal, 3,* 229-234.

Pandey DK, Kauraw LP and Bhan VM 1993. Inhibitory effect of parthenium (*Parthenium hysterophorus* L.) residue on growth of water hyacinth (*Eichhornia crassipes* Mart Solms) .I. effect of leaf residue. *J. Chem. Ecol.* 19(11): 2651-2662.

Patnaik S. 1976. Control of some aquatic vegetation in fish ponds at Cuttack. *J. Inland Fish. Soc. India*, 8 : 221–26.

Patnaik S. 1980. Toxicity of organic copper compound (Cutrine) on some algae and *fish. J. Inland Fish.Soc.India, 12* (1) 136–137.

Patnaik S and Ramachandran V. 1976. Control of blue-green algae blooms with Simazine in fish ponds. 285–292. In: *Aquatic weeds in south east Asia*, (Eds. Varshney CK and Rzoska J) Dr. W. Junk B.V., The Hague.

Philipose MT. 1963. Making fish ponds weed free. *Indian Livestock*, 1(2) : 20 –21, 34–36.

Philipose MT. 1968. Present trends in the control of weeds in fish cultural waters of Asia and the Far East. In: *FAO Fish. Rep.* 44. Vol.5 pp. 26–52.

Phogat BS. 1996. Classification and distribution of aquatic weeds in India. 1-5. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Pimentel D, McLaughlin L. Zepp B. Kakitan, Kraus T. Kleinman P, Vancini F. Roach WJ, Graap E, Keeton WS and Selig G. 1993. Environmental and economic effects of reducing pesticide use in agriculture. *Agricu. Ecosys.Environ.* 46(1-4): 273-288.

Praveena R and Naseema A. 2004. Fungi occurring on water hyacinth in Kerala. *J. Trop. Agri.,* 42(1/2): 21-23.

Praveena R, Naseema A and George T. 2006. Bioherbicidal potential of a phytotoxin produced by *Fusarium pallidoroseum*, a potent biocontrol agent of water hyacinth. *Indian Phytopathol.* 59(4): 518-520.

Praveena R, Naseema A and George S. 2007; Effect of herbicides on *Fusarium pallidoroseum* - a potential biocontrol agent of water hyacinth . *J. Tropi. Agricul.* 45(1/2): 55-57.

Praveena R and Naseema A. 2008a. Liquid substrates for mass production of potent biocontrol agents of water hyacinth. *Indian Phytopathol.* 61(1): 108-110.

Praveena R, Naseema A. 2008b. Bioefficacy and shelf life of formulations of *Fusarium pallidoroseum*, for biological control of water hyacinth. *Green Farm.* 2(1): 22-24.

Radhakrishnan S and Bhuyan BR. 1977. Aquatic weeds of ponds in Assam, India. 295-300 In: *Proc. 6th Asian-Pac. Weed Sci. Soc. Conf.*.

Raju RA and Reddy MN. 1988. Control of water hyacinth through herbicides. *Indian Farm.*, **38**(3): 19-21.

Ramachandran V. and T. Ramaprabhu, 1968. Investigations on aquatic weed control with special reference to the use of chemicals. *FAO Fish. Rep. 44, Vol. 5 pp. 92–108*

Ramachandran V, Ramaprabhu T and Reddy PVGK. 1973. A standard field technique of clearance of water hyacinth infestations by chemical treatment. *J. Inland. Fish. Soc. India*, 5: 154–161.

Ray Puja, Pandey AK and Sushilkumar 2008a. *Alternaria alternata:* a potential biocontrol agent of water hyacinth. *J. Basic Appl. Mycol.*, 7: 43-45.

Ray Puja, Sushilkumar and Pandey AK .2008b. Survey and selection of potential pathogen for biological control of waterhyacinth. *Indian J. Weed Sci.*, 40: 75-78.

Ray Puja, Sushilkumar and Pandey AK 2008c. Efficacy of pathogens of water hyacinth *(Eichhornia crassipes),* singly and in combinations for its biological control. *J. Biolo. Control,* 22 (1): 173-177.

Ray Puja, Sushilkumar and Pandey AK. 2009. Impact evaluation of *Neochetina* spp. on different growth stages of waterhyacinth. *J.Plant Prote. Res.*, 49(1): 7-13.

Ray Puja,Sushilkumar and Pandey AK. 2008d. Deleterious effect of herbicides on waterhyacinth biocontrol agents *Neochetina bruchi* and *Alternaria alternata*. *Biocontrol Sci. and Technol.,* 18 (5): 523-533.

Richard J. Hobbs and Humphries Stella E 1995. An integrated approach to the ecology and management of plant invasions. *Conservation Biology*, 9(4): 761–770.

Rojas M and Aguero R. 1996. Biological control of *Hydrilla verticillata* by utilization of the grass carp (*Ctenopharyngodon idella Vía*). *Agronomia Mesoamericana* 7 (2) : 1-12.

Salim AM and Naseema A.2005. Interaction of two potent biological control agents on water hyacinth. *Plant Disease Research* Ludhiana 20(2): 208-209.

Sharma MK and Chandi JS. 1996. Eradication of water hyacinth (*Eichornia crassipes*) in irrigation drains and ponds of Punjab. 65-70. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Sharma LL and Solomon II J. 2005. Weed menace in Udaipur lakes and options for control: a limnological perspective. 1-13. In : Aquatic weeds: problems, control and management. (Eds. Mathur SM, Mathur A N, Trivedy RK, Bhatt YC and Mohnot P). Himanshu Publication, Udaipur.

Sharma RC, Gupta DK and Sharma VP. 1989. Control of water hyacinth in the ponds of Kheda district, Gujarat, A cost:benefit analysis. *Indian J. Weed Sci.,* **21**(3&4): 19-24.

Singh EJ and Okram ID. 2006. Ecological aspects of *Eichhornia crassipes* in the Waithou lake, Manipur, North-Eastern India. *Journal of Phytological Research*: 19(2): 299-304

Singh M, Kumar SP, Gnansambandhan S and Chandurkar PS. 2006. Eco friendly management of water hyacinth with a mycoherbicide. *Plant Prote. Bulletin* (Faridabad), 58(1/2): 33-35.

Singh RKS, Chakravorty SK, Kumar Vinay and Bhattacharjee B. 1996. Environmental and ecological impacts of aquatic weeds in Loktak Lake. 169-174. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Singh SB. 1962. Control of some emergent and floating weeds with Taficide-80. *Proceed. of Indian Sci. Congress.* 49(3), Abstr.107.

Singh SP. 1989. *Biological suppression of weeds*. Technical Buletin No.1. Biological Control Centre. National Centre for Integrated Pest Management , Bangalore: 27p.

Singh. SP 2004. *Some success stories in classical biological control in India Asian and Pacific Coconut Community*, APCC.

Singh SP, Pahuja SS and Moolani, MK. 1976. Cultural control of *Typha angustata* at different stages of growth. 245-247. In: *Aquatic Weeds in South East Asia.* Varshney CK and Rzoska J (Ed.) Dr. W. Junk B.V. The Hague.

Singh T. 1987. A Mechanical under-water weed cutter for submerged weeds in irrigation channels. *Proceedings of the Workshop on Management of Aquatic Wee*ds, Amritsar, Punjab, India. 21st November, 1987.

Sondhia Shobha. 2008. Evaluation of potential risk of herbicides bioaccumulations in fishes. 149-151. In: *Proceedings of Tall 2007: the 12th World Lake* Conference (Eds. Sengupta M and Dalwani R).

Sondhia Shobha. 2010. *Annual Progress Report.* Directorate of Weed Science Research, Jabalpur, India.

Srinivasan, R and Chacko, P.I. 1952. The control of aquatic vegetation with 2,4-D. *J. Bombay Nat. Hist. Soc.*, 51(1): 164–169.

Sriramkumar P. Rabindra RJ and Ellison CA. 2008. Expanding classical biological control of weeds with pathogens in India: the way forward 165-172. In: *Proceedings of the XII International Symposium on Biological Control of Weeds.* La Grande Motte,France,22-27 April, 2007.

Sushilkumar.1993. Biological control of forests and waste land weeds in India. *Ann. Entomol.,* 11(2):131-153

Sushilkumar. 2006. Economic benefits in biological control of Parthenium by Mexican beetle, *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) in India. *Ann. Entomol.*, 24(1&2): 75-78.

Sushilkumar. 2008 Annual Report. National Research Centre for Weed Science, Jabalpur.

Sushilkumar. 2011. Biological based chemical integration for early control of water hyacinth. *Indian J. Weed Sci.* 43(3&4) : 211-214.

Sushilkumar, Sondhia Shobha and Vishwakarma K. 2003. *Role of insects in suppression of problematic alligator weed (Altemanthera philoxeroides)* and testing of herbicides for its integrated management. Final Report of ICAR Adhoc Project (1.9.2000 to 31.8 2003): 39 p.

Sushilkumar, Sondhia Shobha and Vishwakarma K. 2008a Evaluation of herbicides in context to regrowth against terrestrial form of alligatorweed *Indian J.Weed Sci.,* 40 (3&4) : 180-187.

Sushilkumar, Shobha Sondhia and Vishwakarma K. 2008. Evaluation of herbicide persistence in sediment to control alligator weed. *Indian J. Weed Sci.* 40 (1&2) : 46-49.

Sushilkumar, Shobha Sondhia, Kamlesh Vishwakarma 2009. Occurrence of alien alligator weed in India with special reference to its infestation in some districts of Madhya Pradesh *Indian J. Weed Sci.* 41(3&4) : 185-187,

Sushilkumar, Vishwakarma K and Yaduraju NT. 2005. Chemical control of lotus (*Nelumbo nucifera* Gaertn) in fish culture pond and its impact on water quality. *Indian J. Weed Sci.* 37 (3&4): 293-295.

Sushilkumar and Varsheny, Jay G. 2007. Successful biological control of water hyacinth *(Eichhornia crassipes)* through weevil *Neochetina* spp. in ponds of Jabalpur, Madhya Pradesh, India - a case study. Abstract published in the *Proceedings of 12th World Lake Conference*, Jiapur, 28 October to 2 November 2007,

Sushilkumar, Kamlesh Vishwakarma and Ray P. 2008. Non-target effect of herbicides on *Neochetina* spp, a biological control agent of waterhyacinth. *Indian Journal of Weed Science* 40 (3&4) : 200 - 202,

Sutton DL and VandiverJr. VV. 1995. *Grass carp: a fish for biological management of Hydrilla and other aquatic weeds in Florida*. Agricultural Experiment Station,

Suresh RV. 2000. Floating islands: a unique fish aggregating method. *Naga, The ICLARM Quaterly*, 23(1):11-13

Thirunavukkarsu S and Kayarkanni T. 1996. Environmental impacts of aquatic weeds. 16-20. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

Teague ML and Brorsen BW. 1995. Pesticide productivity: what are the trends? *J.Agricul. Appl. Ecol*. 27: 276-282.

Tyagi AC and Gireesha O. 1996. Successful management of submerged weeds in the power canal and Hampi Foreway pf the Tungabhadra Board. 185-190. In: *Proceedings of Workshop on "Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ) held at Bangalore (Karnataka), 5-7 June 1996.

VanZon JCT. 1984. Econmic weed control with grass carp (*Ctenopharygon idella* Val. ) 249-260. In *Proceedings of Vth Symposium on biological control of weeds*. Brisbane , Australia.

Varshney Jay G, Sushilkumar and Mishra J.S. 2008..Current status of aquatic weeds and their management in India. *Proceedings of Tal:* (Eds. Sengupta M. and Dalwani R.) The 12th World Lake Conference, Jiapur, 28 October - 2 November 2007: 1039-1045.

Varshney CK and Rzoska (Eds.) 1976. *Aquatic Weeds in South East Asia* .W. Junk, The Hague, Netherland.

Visalakshy, PNG. 1992. Effect of commonly used weedicides and mosquito larvicides on exotic water hyacinth mite, *Orthogalumna terebrantis* Wallwork (Acarina: Galumnidae)', *J. Biolo. Control*,6, 37-37.

Visalakshi, GPN and Sushilkumar. 2008. Biological control of terrestrial and aquatic weeds in India. pp. 57-62. In the *Proceedings of ISWS Biennial Conference on "Weed Management in Modern Agriculture : Emerging Challenges and Opportunities*" February 27-28, 2008 held at Bihar Veterinary College, Patna (RAU, Pusa, Bihar.

Wattendorf B. 2001. What's this about weed-eating fish? *Fish and Game Finder Magzine.*

World Bank Report. 2010. The World Bank Agriculture & Rural Development Data - data.worldbank.org/topic/agriculture-and-rural-development.