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Deweeding as a Lake Management Intervention– A Critical Analysis

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ABSTRACT

Eutrophication of freshwater ecosystems, particularly lakes have manifested in numerous problems and one such unavoidable outcome is the excessive weed growth, which has drastically altered the structure and overall functioning of the lake ecosystems around the globe. Deweeding has come up as an important management tool to eradicate aquatic weeds along with removal of huge nutrient loads from lake ecosystems. Deweeding has both beneficial and deleterious impacts on the overall lake ecology that needed to be ascertained through the available literature. This huge plethora of literature has been systematically arranged into various sections and sub-sections. In this comprehensive review, we have tried to evaluate the efficiency and success rates of the deweeding intervention as a lake management tool and to provide an overall picture of its impacts in light of noteworthy literature throughout the globe to come up with some general understanding, mechanism and science behind the deweeding process.

Key words: *Deweeding, Lake harvesting, Lake management, Weed growth, Eutrophication*

INTRODUCTION

Lakes are subjected to both natural and cultural eutrophication throughout the globe (Pal, 2020; Hass *et al.,* 2019). Natural causes include increased runoff (Tang *et al.,* 2020), sedimentation (Dalu *et al.,* 2019), input of plant material (Hong, 2020), geological characteristics (Liu *et al.,* 2019) which enhance the production levels of lake ecosystems (Schindler, 2006) and the process is often very slow (Calisto *et al.,* 2014). In addition, lake ecosystems have been influenced by a number of human induced factors, which includes nutrient influx from altered catchments (Rather *et al.,* 2016; Khanday *et al.,* 2017; Rashid and Aneaus, 2020), municipal inputs (Li-Kun *et al.,* 2017) and industries (Finnegan *et al.,* 2018).

The visual manifestation of eutrophication in the lake ecosystems are the algal blooms and/or the abundant aquatic weed growth. As a result, several problems arise in the lake ecosystems that have ramifications on the ecology, fishing, navigation, recreation and aesthetics (Charudattan, 2001). Alien invasive species cause more damage to the native flora and fauna causing irreversible changes to aquatic habitats (Villamagna and Murphy, 2010; Stiers *et al.,* 2011; Hussner, 2014). There are numerous management initiatives to control this nuisance from the lakes. These include chemical treatment (Netherland, 2014), shading effect (Caffrey *et al.,* 2010) or water level drawdown (De Winton *et al.,* 2013). However, these controlling methods still act as sources of internal nutrient loading as aquatic weeds die and sink to the bottom of the lake and continue to pose a threat to the ecosystem (Patel, 2012). So, in order to have better lake management, it becomes necessary to physically extract these unwanted aquatic weeds through the deweeding process (Brummer *et al.,* 2017).

METHODOLOGY

In order to come up with a comprehensive review article on lake deweeding, a lot of literature survey was needed. We used Google scholar to gather data from various journals, book chapters, e-books, conference papers by searching key words like "*Deweeding, Lake harvesting, Lake management, Weed-growth, Lake Maintenance, Aquatic weeds* and *Nuisance aquatic macrophytes*". Only those research papers which had significant findings and opinions on aquatic deweeding particularly in lake ecosystems were selected. Our review was hugely enriched through the content analysis of these voluminous research articles. In this review, we have tried to highlight important aspects of weed harvesting and associated problems and to provide a management overview illustrating the relationships between the state of the ecosystem, efficacy, the management goals, and outcomes. We categorized our review in four broad sections and numerous sub-sections to make it more reader friendly.

LAKE DEWEEDING - AN OVERVIEW

The Deweeding method involves physical removal of the plant material from the water body either mechanically (harvesters) or manually (Gulati *et al.,* 2013; Habib and Yousuf, 2016). Consequently, the procedure can achieve numerous objectives like elimination of harmful/toxic pollutants, take out dense weeds, capturing phosphorus, and for navigational purposes (Cooke *et al.,* 1986). Deweeding is most frequently used to reduce the aquatic weed nuisance around the globe and is most suitable for plant or macrophytes species that are soft enough to cut, grow in locations that are accessible to the harvester, and/or float on the water surface (Cooke *et al.,* 2016; Brummer *et al.,* 2017). This management tool can be effective when the recovery of nuisance species is very slow or delayed and when the replacement community is of less nuisance than the existing one. Regarding the aquatic plant management through deweeding, certain factors should be taken into consideration like the rate of re-growth, harvesting efficiency, change in community structure, and techniques used (Cook *et al.,* 2016). Keeping this in mind, we have divided the review into various sections:

1. *Efficiency:* In this section, important factors which significantly influence the efficiency of deweeding process have been discussed.
2. *Re-growth:* This section deals with the re-growth patterns of aquatic weeds and how can re-growth after deweeding be minimized.
3. *Harvesting and Nutrient removal:* How much deweeding is effective in the nutrient removal has been discussed in this section.
4. *Environmental effects:* Finally, some broad impacts of deweeding have been extensively noted down in this section. It has

been further divided into sub-sections namely; Physical and Chemical effects, Biotic effects and Ecosystem effects.

1. Efficiency

The duration, as well as efficiency of deweeding is determined by the initial plant biomass, re-growth patterns, type of reproduction, cutting depth, regularity, completeness, seasonal timing of cuts; and ecosystem factors like the productivity patterns of the area that is being harvested (Cook *et al.,* 2016). There is an agreement among various lake scientists (Nichols, 1974; Wile, 1978; Mikol, 1984; Cooke *et al.,* 1990, 1993; Engel, 1990) that numerous harvests are needed to control the re-growth of a variety of plants in aquatic ecosystems in the growing season.

For example to control the growth of *Nymphaea odorata* in Mill Lake, British Columbia with harvesting operation, only four-week success was achieved (Cooke *et al.,* 1993). There was no difference in biomass of Eurasian watermilfoil between harvested and un-harvested region in Lake Wingra, Wisconsin, six weeks after the harvesting (Kimbel and Carpenter, 1981). In Saratoga Lake (New York), the biomass levels of Eurasian watermilfoil returned to its pre-harvesting condition only one month after harvesting (Mikol, 1984). Similar results were also observed in LaDue Reservoir, Ohio after 23 days (Cooke *et al.,* 1990).

The macrophyte biomass in harvested areas of Lake Minnetonka, Minnesota reached un-harvested areas in six weeks (Crowell *et al.,* 1994). Similar findings were found by Engel (1990) in Halverson Lake, Wisconsin. Sometimes biomass of harvested zone increased in the post-harvesting period, as reported by Serafy *et al*., 1994. Despite complete harvesting, some portion of macrophytes remains in the aquatic ecosystems as was reported by Engel (1990) who observed about 30% of the total standing crop of macrophytes still in the lake ecosystem after the harvesting operations. The reason being the harvester has limited scope in case of plants that grow too shallow or too deep. There is also sediment disturbance due to Paddlewheels creating turbidity that hid plants below the water surface.

The deweeding was efficient in reducing the dry weight (3,600 kg) and phosphorus content (53%) of the Casey Lake. This venture was relatively cheaper than watershed management but costlier than in-lake alum treatment (Bartodziej *et al*., 2017).

One important factor that reduces the efficiency of deweeding is its non-specificity. The harvester cuts randomly submerged aquatic plants without efficient eradication of invasive alien species (Hussner *et al.,* 2017). In this process, some of the indigenous and beneficial aquatic plant species are also eradicated (Cook *et al.,* 2016).

It has been advocated that selective deweeding rather than random deweeding is the better option to get better and efficient results (Chaudhary *et al.,* 2019). Furthermore, lake managers should adopt a combination of manual and mechanical harvesting depending upon the feasibility and the objectives to be attained.

2. Re-growth

Re-growth of macrophytes depends on the timing of the first harvest and more than one harvest is needed for effective management (Kimbel and Carpenter, 1981; Engel, 1990). Aquatic weed cutting only in summer (June and July) were not effective in stopping the re-growth rate and plant density in the lakes. Multiple harvests per season were most useful in reducing stem number and height (Cooke *et al.,* 1986).

Re-growth depends also on the habitat factors and the type of cut. Howard-Williams *et al.* (1996) found noticeably different re-growth patterns in Lake Ohakuri and Lake Aratiatia, New Zealand, as the latter had high water flow as vital factor. Due to this, re-growth was patchy and highly variable in Lake Aratiatia. Engel (1990) while working on Lake Halverson observed that macrophytes quickly re-grew; reaching pre-deweeding biomass within few weeks and even became much denser after deweeding despite removing 75% of the total standing crop of macrophytes.

Re-growth is very slow in very deep waters or where harvester removed the macrophytes close to the lake bottom (Nichols and Cottam, 1972; Cooke *et al.,* 1986, 1990). Similar results were observed in East Twin Lake and LaDue Reservoir, Ohio when milfoil was cut close to the bottom sediments (Conyers and Cooke, 1982; Cooke *et al.,* 1990). To control *Chara* from Paul Lake, British Columbia, unique sediment harvesting was used in which the blade was replaced with the horizontal cutter bar assembly at the bottom of the front conveyor (Cooke *et al.*, 1993). Consequently, the knowledge of meristematic tissue in the target plant species is very important in the effective management of aquatic weeds (Hussner *et al.,* 2017)

Continuous harvesting operations for more than two years can reduce macrophyte biomass in following years (Kimbel and Carpenter, 1981; Painter and Waltho, 1985; Cooke *et al.,* 1986). However, results are not always positive. Only 20 gm^{-2} reduction in biomass was observed in areas (Lake Wingra) previously harvested as compared to un-harvested areas (Kimbel and Carpenter, 1981). In some situations, it is difficult to say whether the biomass reduction was due to deweeding or any other mechanism played the role (Wile *et al.,* 1979; Smith and Barko, 1992). Aquatic macrophytes became more profusely dense subsequent to intensive harvesting in Lake Sallie, Minnesota (Neel *et al.,* 1973). Time of the year and harvest frequency was studied by Painter and Waltho (1985) about Eurasian watermilfoil in Buckhorn Lake, Ontario. They reported that double cuts viz, June/August, or June/September was a suitable management alternative and that milfoil biomass considerably reduced in next season following October cut. Cooke *et al.,* 1986 conducted various experiments on the efficiency of weed harvesting and concluded 2 to 3 cuts including late harvest to be very effective in curtailing the plant re-growth and stem density.

The most probable explanation for reduced growth after continuous harvesting is the reduction in energy reserves (TNC-total nonstructural carbohydrates) (Kimbel and Carpenter, 1981). Deweeding has the greatest impact when storage organs have low TNC levels or transportation of TNC to storage organs is being carried out for next year's growth. Kimbel and Carpenter (1981) concluded that TNC levels decreased after harvesting in Lake Wingra, Wisconsin, but found low TNC had little influence on the control of milfoil. Perkins and Systma (1987) reported that fall deweeding was able to lower carbohydrate levels in milfoil but the reserve stores were replenished in the winter season and growth was unaffected in the following year. In regions experiencing extreme winter delayed season harvesting may prove to be effective.

3. Harvesting and Nutrient removal

Harvesting is as one of the efficient technique of nutrient removal from the lake ecosystem (Carpenter and Adams, 1978). It is highly efficient when the nutrient loading is very low and removal is high. Harvesting may not yield immediate results in eutrophic lakes despite nutrient input is controlled. It will take numerous years to have any impact on the nutrient budget of the lake (Carpenter and Adams, 1977; Burton *et al.,* 1979). There are various examples (Shagawa Lake, Minnesota; Wile *et al*., 1979; Larsen *et al.,* 1979) where harvesting failed miserably because internal loading was not taken into consideration. Sometimes, internal loading is more than external loading in eutrophic lakes, so reducing the internal load of the lakes; macrophyte harvesting may prove highly beneficial. Macrophytic growth in Delevan Lake, Wisconsin accounted for about 1200 kg of Phosphorus (P) to the nutrient budget (Barko and James, 1998). According to Carpenter (1983), the decay of macrophytes in Lake Wingra contributed about half the internal P loading. According to Asaeda *et al.* (2000), it was possible to reduce the level of Phosphorus released by decaying *Potamogeton pectinatus* through above-ground biomass harvesting during the late growing season.

Macrophyte harvesting changes the water chemistry, reduces the sedimentation of plant biomass, and permanently extracts the nutrients that would have otherwise recycled in the water column (Cook *et al.,* 2016). By removing deep-rooted plants, harvesting can also extract nitrogen and phosphorous from the sediments (Carpenter and Adams, 1977). By delaying (late August) the harvesting of Eurasian watermilfoil, maximum phosphorus was removed (Carpenter and Adams, 1978).

As per the model predictions, harvesting has an important role to play in the nutrient budget of a lake ecosystem but only a few studies convey its role in minimizing the nutrients in the water body. Most of the studies advocate no change. But there are also some studies which reported slight increase in the level of phosphorus and algal community due to harvesting. Increased phosphorus was observed during deweeding operations in Long Lake (Welch *et al*. 1994). As per Cooke *et al.* (1990), a high concentration of Phosphorus, chlorophyll, cyanobacteria and seston were associated with deweeding.

As a result of harvesting operation, there is a change in nutrient pathways which trigger the response from other communities. One such example was evident in Lake Sallie. On one hand, harvesting reduced the growth of macrophytes but on the other hand, increased the productivity of phytoplankton (Brakke, 1974).

Harvesting can also have meager changes to the lake ecosystem. According to Engel (1990), no impact was on phytoplankton in Halverson Lake. Similarly, there was no change in phytoplankton and nutrient concentrations in Chemung Lake (Wile *et al*., 1979) and sediment P and N in Buckhorn Lake (Painter and Waltho, 1985). According to Cooke *et al.* (2016), the possible reason might be the reduction of buffering capacity of littoral zones by harvesters that previously checked the input of nutrients into the pelagic zone of a water body or due to short-term harvesting initiatives.

From the above literature, it is evident that harvesting alone cannot solve the nutrient surplus problem of the lake ecosystem. There has to be an integrated lake management plan which will include a reduction in the allochthonous nutrient input, sequestering the in-lake nutrient sources, and permanent nutrient removal. Harvesting should, therefore, be used as a nutrient removal technique in addition to being the solution to aquatic weed nuisance.

4. Environmental Effects:

Harvesting is usually confined to littoral areas in the lake, so impacts should be localized but the impact will be profound in small shallow lakes with dense macrophytic vegetation. The environmental issues associated with deweeding are manifold and will have impacts on physico-chemical aspects of lakes, (2) impacts on biota, and (3) impacts on ecosystem dynamics.

4.1. Physical and Chemical Effects

Some of the prominent physico-chemical alterations due to harvesting include changes in dissolved oxygen levels (Kundanger *et al.,* 2003; Zushi and Ticku, 1991), sediment re-suspension (Kohzu *et al.,* 2019) and Phosphorus release (Morris *et al.,* 2003) due to sediment disturbance or from the leakage of cut stems. Carpenter and Gasith (1978) observed the effect on water chemistry due to harvesting in the littoral zone of Lake Wingra. There was no change in conductivity, temperature, seston, organic carbon, or dissolved reactive phosphorus. There was an insignificant change in the community photosynthesis. They believed that harvesting had very little impact on the lake environment. Madsen *et al*. (1988) reported that deweeding macrophytic beds reduced the variations in diel DO without any rise in the average oxygen concentration.

There have been speculations regarding the impact of harvesting on the nutrient balance between sediments and water column, decrease in photosynthesis, or change in DO levels (Cooke *et al.,* 2016). These results cannot be considered universal as long-term monitoring data is lacking. Many lakes have suffered erosion in littoral areas which were subjected to plant removal due to harvesting (James and Barko, 1994; Howard-Williams *et al.,* 1996). According to Welch *et al*. (1994), there was an increase in total phosphorus levels after macrophyte harvesting. The possible explanation might be sediment re-suspension due to wind-driven currents. Mechanical harvesting increases the particulate and dissolved materials in the water column and reduces their sedimentation rates. One of the prominent studies on the impact of deweeding on the eutrophic lake was conducted by Galanti *et al.* (1990). They observed a significant decrease in the portion of the external annual loading which had its origin from precipitation and run-off.

The immediate effects of mechanical harvesting of submerged macrophytes are suspension of sediments and periphyton and exudation from damaged tissues which potentially change the water chemistry (Carpenter and Gasith, 1978). There are noticeable changes in conductivity, dissolved oxygen, total phosphorus, and nitrates immediately after deweeding as reported by Zutshi and Ticku (1990) while working on the impact of deweeding on the Dal lake ecosystem. Deweeding is not always effective for some macrophytes like *Hydrilla*; however, if areas are highly infested, harvesting can become an effective tool in integrated weed control (McGhee, 1979). While working on the efficiency of deweeding on the ecology of *Myriophullum spicatum;* Painter (1988) observed an appreciable reduction in density, shoot weight, and biomass.

Deweeding in lakes can be used for removal of heavy metals by removing *Potamogeton lucens*, *Salvinia herzogii,* and *Eichhornia crassipes* which are biosorbents for Cr(III), Ni(II), Cu(II), Zn(II), Cd(II), and Pb(II) (Ivoandre *et al.,* 1999). Kundangar *et al.* (2003) reported a decrease in conductivity, dissolved oxygen, total phosphorus, and iron while the increase in transparency and nitrate- nitrogen after macrophyte removal in Dal Lake. James *et al.* (2004) while studying the consequences of deweeding in the lake ecosystem observed changes in invertebrate densities and species richness due to alterations in sediment characteristics and nutrient cycling.

Harvesting may sometimes remove above-ground biomass without achange in nutrient level, but the fragmentation rate seems high (David *et al*., 2006). According to the study of Spencer *et al.*(2006), deweeding had limited success to manage water hyacinth. While on another hand, Edwards and Comas (2009) concluded harvesting to be a better option than bio and chemical techniques. Bal and Meire (2009) reported that an integrated approach along with harvesting is necessary to deal with the nuisance macrophyte biomass.

4.2. Biotic Effects

The direct biotic effects of harvesting are on macrophyte density (Olsen *et al.,* 1998), phytoplankton concentration (Akhurst *et al.,* 2017), and fish stocks (Ban *et al.,* 2019). The removal or impact on non-target plant species is the major consequence of lake harvesting (Lishawa *et al.,* 2017).

Deweeding directly removes fish (Zutshi and Ticku, 1990; Moss, 1990), phytophilous invertebrates (Monahan and Caffrey, 1996; Habib *et al.,* 2014), zoobenthos (Spencer *et al.,* 1998; Mushtaq *et al.,* 2013), periphytic algae (Dixon, 1989; Rather *et al.,* 2015), and microbial community that live in or on aquatic macrophytes (Pandhal *et al.,* 2018). The number of aquatic organisms removed is huge, but the impact varies from lake to lake. Almost 11% to 22% macroinvertebrates and 50,000 fish were removed from 4 ha Halverson Lake during two years of deweeding operation (Engel, 1990). Deweeding removed 60–85% Macro-invertebrates and about one million were removed with a ton of *Ranunculus* sp. (Monahan and Caffrey, 1996). About 2,220 to 7,410/ha fish were removed with weed cutting in Saratoga Lake (Mikol (1984) and 85 kg/ha of fish by *Hydrilla* removal (Haller *et al.,* 1980). Unmuth *et al.* (1998) observed that harvesting removed 2,254 fish/ha and Cook *et al.,*(1993); while working on Okanagan Lakes, reported about 50 to 100 fish with each load of aquatic weeds.

Fishes usually removed by harvesting are very small (2–4 cm long) and slow-moving (Booms, 1999). The only exception is the study of Engel (1990) who reported the removal of large-mouth bass (*Micropterus salmoides*). Mikol (1984) reported removal of 2.4–2.6% of the standing fish crop in Saratoga Lake; while as Haller *et al.* (1980) reported 18% of the fish biomass and 32% of the fish numbers were removed by harvesting. According to Wile (1978), there was no significant impact on the fish fauna in Chemung Lake. Macrophytes act as essential substrates for colonization of various organisms and through their decay and extracellular secretion as a food source (Carpenter and Adams, 1977). Deweeding by removing aquatic plants from the water body denies most organisms habitat and food source. There are large numbers of organisms including mammals, waterfowl, invertebrates which obtain their food directly from the macrophytes. Some of them even inhabit the macrophytic shoots and graze periphytic algae and detritus from the macrophyte surface. So, these consumers are at high risk due to harvesting. Due to harvesting, the feeding habits of Macroinvertebrates get changed (Linden and Lehtiniemi, 2005).

Macrophyte removal has direct negative consequences on the aquatic food chain. Garner *et al.,* 1996 studied the relationships between zooplankton, the growth of roach *(Rutilus rutilus)* and macrophyte cover during deweeding. They observed that macrophyte dominated area was abundant with fish and zooplankton concentration as the former provided food and protection from the high flow. There was a considerable decline of the Cladoceran population due to washout, starvation, and fish predation. The growth rates of roach declined as less number of periphyton were available as a food source.

Harvesting sometimes has positive aspects with reference to the fish ecology. Lakes that have abundant macrophytic growth are associated with stunted fish growth. So, removal of these stunted fish with aquatic weeds from the water body can benefit smaller fish by making limited food available to them (Unmuth and Hanson, 1999). Due to macrophyte removal in Wisconsin lakes, some largemouth bass and bluegills showed positive growth response (Olson *et al.,* 1998). While working on the impact of deweeding on fish population, Bettoli *et al.* (1993) observed no significant changein the abundance or structure except phytophilic *Lepomis* spp. which decreased drastically. Removal of fish means survival of larger zooplankton, which are very essential for biomanipulation efforts.

One aspect of harvesting that has not been studied is the impact on spawning fish. This is important as some species spawn in macrophyte beds and also provides them cover. Mitigating the impacts of harvesting is essential and recovery rates of biota should also be taken into consideration. As per the findings of Monahan and Caffrey (1996), it took ten months for the macroinvertebrate population to return to pre-deweeding levels. Harvesting small patches or leaving one side of the water body un-harvested is the appropriate alternative (Garner *et al.,* 1996) and Aldridge (2000). Modifications to conventional harvesting like close cutting can significantly reduce the fish removal rates. One such study was done by Unmuth *et al.,* 1998 who reported a reduction in fish removal from 2,254 fish/ha to 36 fish/ha.

The relationship between fish and macrophyte cover is a parabolic one so that fish growth and foraging is optimized at intermediate macrophyte density (Trebitz, 1995; Olson *et al.,* 1998). According to Bettoli *et al.,* 1993, large-scale harvesting, on one hand, impacts the fish associated with plants but on the other hand, is beneficial to few species. Harvesting with an intermediate level of plant density is the best option available.

One of the major secondary impacts of harvesting is the propagation of aquatic nuisances to other areas through plant fragments and pieces (Sabol, 1987). *Hydrilla* is found to re-grow from a single node (Langeland and Sutton, 1980). Almost 70% of the biomass, 42% N, and 70% P lost in the water column within 14 days after harvesting indicating substantial nutrient mobilization through decomposition and autolysis (James, 2002). Harvesters usually lose some smaller fragments in the water column; even modified harvesters lose around 15% of the plant fragments (Engel, 1985). Agent’s like boat traffic, water current, and wind can spread plant fragments to less infested zones of the lake creating a nuisance. According to Kimbel (1982), natural watermilfoil fragments can survive more in the winter than the fragments generated by harvesters, so they are less problematic with reference to aquatic plant management.

While comparing harvesting zones in Lake Wingra with un-harvested one, Nichols and Lathrop (1994), reported high species diversity and richness in later. Helsel *et al*. (1999) found an insignificant impact on the number of native aquatic plant species due to harvesting operations on watermilfoil. There are various studies that found little or no impact of harvesting on plant biomass (Welch *et al*., 1994; Cooke *et al.*, 1993). On the contrary, there was an increase in plant growth rates (biomass) after harvesting projects in some studies (Crowell *et al*., 1994; Engel, 1990; Serafy *et al.,* 1994).

It is usually very difficult to manage a plant community selectively as harvesters cut all species in its vicinity but by altering the depth and cut season and by having harvesting and non-harvesting zones, selective harvesting can be achieved to some extent (Nichols and Mori, 1971; Unmuth *et al*., 1998). The impact of harvesting on community structure can be manifold. That is, the resulting community can be (1) dominated by species which was not present before deweeding, (2) dominant species remains the same, or (3) dominated by species which were earlier not prominent (Wade, 1990).

Harvesting *Potamogeton* spp. in Halverson Lake pave way for *Zosterella dubia* to become a dominant plant community (Engel, 1990). Engel (1987) observed *Vallisneria americana* to become dominant after harvesting *Myriophyllum sibiricum.* Similarly in Lake Ohakuri, New Zealand, *Potamogeton crispus* became more dominant (Howard-Williams *et al.,* 1996). Mushtaq *et al.* (2013) observed that mechanical deweeding significantly decreased the number and diversity of the macrozoobenthic community of Dal Lake. Working on phytophilous macroinvertebrates in the same lake; Habib and Yousuf (2014) reported a massive impact on Mollusca and Arthropoda followed by Annelida.

There was an insignificant change in plant community after deweeding (Nichols and Cottam, 1972; Johnson and Bagwell, 1979 and Welch *et al.,* 1994). In Chatauqua Lake, *Potamogeton* spp. were replaced by Eurasian watermilfoil after harvesting (Nicholson, 1981). Harvesting makes it difficult for those species to re-grow which reproduce sexually but on the other hand, species that grow vegetatively can grow and reproduce better and may become dominant after deweeding. This is due to large scale generation of plant fragments through the cutting activity of harvesters and their easy dispersal and establishment of fresh stands of vegetation in the new areas (Hussner *et al.,* 2017)

4.3. Ecosystem Effects

The broad array of impacts due to harvesting on lake ecosystem processes are usually not immediate but take some time and consequences could be simple to complex. Therefore, it is very difficult to predict the impacts with complete authority. Engel (1990) has given an extensive review of short and long-term ecosystem impacts.

Harvesting might shift the stability pattern of shallow lakes from macrophyte-dominated to algae-dominated (Scheffer *et al.,* 1993; Moss *et al.,* 1998). It is very difficult to predict the level of shifts due to the disturbance (van Nes *et al.,* 2002) and very difficult to reverse this shift (Scheffer, 1998). Jacoby *et al.* (2001) studied the shifting pattern in Long Lake. They observed low macrophyte, low transparency, high phosphorus, and high algae associated with harvesting at one time and macrophyte dominated condition with low phosphorus/algae with high transparency during un-harvested condition.

Harvesting aquatic macrophytes can have multiple impacts on the lake ecosystem ranging from the reduction of amenity of the lake and habitat disturbance (Bickel and Closs, 2009) to the spread of invasive plants and impacts due to plant fragments (Dorahy *et al.,* 2009). Moreover, the release of sediment nutrients especially phosphorus as well as diminished uptake of nutrients by macrophytes might lead the lake ecosystem to the condition of hyper-eutrophication (Quilliam *et al.,* 2015). There is a strong competition between phytoplankton and macrophytes for light and nutrients. Sometimes aquatic plants release allelochemicals for competitive advantage (Mulderij *et al*., 2009). Consequently, harvesting macrophytes in the eutrophic lake could trigger the dominance of phytoplankton (Sayer *et al.,* 2010). There is currently no accord regarding the coverage of macrophytes in a lake ecosystem for maximum nutrient uptake and removal by aquatic plants but some of the authors have recommended 5% and 20% to be optimum (Portielje and Van der Molen, 1999; Dai *et al.,* 2012).

CONCLUDING REMARKS AND A WAY FORWARD

Aquatic plant nuisances are mostly caused by invasive, exotic species. An aquatic plant management plan based on comprehensive knowledge and monitoring can pay dividends in the long run for lakes with no existing aquatic weed problems. Early detection and subsequent eradication will save a lot of time and money for the lake managers.

It would be better to go for deweeding in the autumn season, so that the nutrients stored in the aquatic plants are completely eliminated from the lake ecosystem or else these nutrients will again find their way in to the system after senescence. Aquatic plant harvest appears be an efficient tool for nutrient reduction in the lakes worldwide but it will have limited role in controlling the eutrophication unless we stop the huge input of nutrients in the ecosystem.

A management plan removing large scale aquatic plants from the system is bound to have environmental impacts. These impacts can either be beneficial or deleterious to the aquatic ecosystem. Deweeding is predominantly non-selective and it can remove useful aquatic plants from the system along-with small fish and invertebrates and at the same time can remove huge nutrients and organic matter from the system as well. Moreover, several impacts can be everlasting that they are neither evaluated nor measurable in a reasonable management timeframe. Deweeding done only once will not solve the weed problem and re-infestation is likely to occur again once it is stopped. If the level of weed infestation has spread massively, then comprehensive management intervention is needed.

As far as the management of the aquatic weeds is concerned, it needs to be continuous and long-term and several options can be used (like biomanipulation, sediment covering, biological controls, aquatic plant community rehabilitation, chemical controls, and sediment removal). Besides these options, new innovative uses of aquatic biomass should be encouraged. Utilization of aquatic weeds as cattle fodder as well as raw material for biogas production is a promising and sustainable venture. Deweeding can be an effective nutrient management intervention for lake ecosystems but it can't alone control the problem of eutrophication. Management of aquatic weeds should utilize a range of control methods besides deweeding, either alone or in combination, to achieve a successful outcome for the overall lake management.

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