Consequences of Lake Deweeding on Periphytic Algae: A Case Study of Dal Lake, Kashmir

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Abstract
Environmental effects of harvesting have been reported in aquatic ecosystems around the globe. An ecological monitoring study was undertaken to ascertain the impacts of this lake management practice on the structure and distribution of Periphyton community of Dal lake ecosystem. Deweeding significantly reduced periphytic diversity and density ($P<0.05$). Upon initiation of deweeding process, maximum number of dominant taxa got removed along with the harvested weeds, which as a result provided an opportunity for few rare taxa to thrive at such sites. Bacillariophyceae was the dominant group in all seasons. Cyanophyceae (*Oscillatoria* sp. and *Anabaena* sp.) registered slight rise after deweeding. The species of *Achnanthidium, Synedra, Chlorella, Navicula, Cymbella and Fragillaria* were observed to be highly prominent at deweeding sites. Due to harvesting operation, species composition and distributional pattern of this very important autotrophic community got altered. The present study concludes that there was a negative impact on periphyton community by deweeding process soon after implementation of this practice. The recovery rate of studied periphytic community was slow. In order to ascertain the full recovery of periphytic community, long term ecological monitoring (>10 years) is mandatory.
Key words: Deweeding, periphyton, lake ecosystem

Introduction

Biological communities have been shown to be useful indicators of general water quality (Belmont and Counties, 2015; Martinez-Haro *et al.*, 2015). Biological monitoring, or biomonitoring, is therefore used as an integrator of various stressors that provides valuable information about the overall integrity of a water body. While chemical monitoring is conducted to support established water quality criteria and some priority pollutants, chemical monitoring alone cannot ensure that all pollutants and interactions among them are meeting water quality goals. Biological organisms serve not only as useful indicators of current conditions, but also of cumulative effects and changes over time (Morin *et al.*, 2015).

Periphyton is an important component of aquatic ecosystems, providing food for invertebrates, and also acts as a bio-indicator (Finlay *et al.*, 2002). Excessive periphyton growth can occur in aquatic systems as a result of nutrient enrichment and entry of effluents from wastewater treatment facilities. Therefore the occurrence and abundance of the group can serve as an indicator of the health of the concerned aquatic system (Cascallar *et al.*, 2003; Giorgi and Malacalza, 2002). The assemblage also plays a very important role in aquatic food webs by providing a readily available energy source for a wide range of aquatic organisms. Periphytic algae reproduce and respond rapidly to environmental change and provide early warning indicators of both pollution increases and habitat restoration success (Stevenson and Pan, 1999).

Periphyton is sensitive to changes in water quality and, in particular, responds rapidly and predictably to nutrient enrichment in lakes and streams (Horner *et al.* 1983; Stevenson *et al.* 1985; Cattaneo, 1987; Biggs, 1988; Lowe, 1996). The short generation times of algae allow them to respond more rapidly to changes in water quality than macrophytes or fauna. Certain structural (i.e. species shifts) and functional i.e. growth rates changes in the Periphyton are symptomatic of nutrient enrichment and provide an early signal of eutrophication. Reference conditions can be determined by characterizing Periphyton in least affected areas.

Lake restorations are usually attempted to improve water quality or to improve aesthetic and recreational needs (Gangstad, 1982). Macrophyte harvest (Deweeding) differs from other restoration approaches in that these techniques involve physical removal of material from the water body. The idea behind deweeding as a restoration technique is that it will reduce the internal productivity of the water body and remove phosphorus that is stored in the plant by removing the plant. Harvesting is also done for social and recreational reasons; most people think of all aquatic vegetation as weeds and do not want the vegetation in their lake. All harvesters are generally based on designs by Wisconsin researchers (Cooke *et al.*, 1986). The units are paddle wheel propelled and have a large frame extending down into the water ahead of the bow (Figure 1). This frame is made up of vertical sickles on the sides and a sickle across the bottom connecting the two sides. A conveyer belt extends up from this frame to the boat and carries the cut macrophytes to the surface where they are collected (Cooke *et al.* 1986). The main advantage of macrophyte harvest is that it is a highly visible technique that provides instant results. The main disadvantage is that the process does not remove a significant amount of phosphorus from the system.

As ecosystem is a delicate web of organisms, the above restoration activity was thought to impact the entire biological community and Periphyton is no exception. In order to have an insight into the impact of deweeding in the Dal Lake on the occurrence, abundance and distribution pattern of the Periphyton community, the present study was undertaken.

Figure 1: Mechanical harvesters (Aquarius systems) in Dal Lake.

Material and Methods

Sampling schedule

For the present study, sampling was carried out on bi-monthly basis for a period of two consecutive years to evaluate the impact of ongoing deweeding on the community structure and distributional pattern of Periphyton of Dal Lake.

Study sites

For the present study, fourteen sites (Figure 2 and Table 1) were taken across the length and breadth of Dal Lake to assess the composition and distribution of Periphyton.

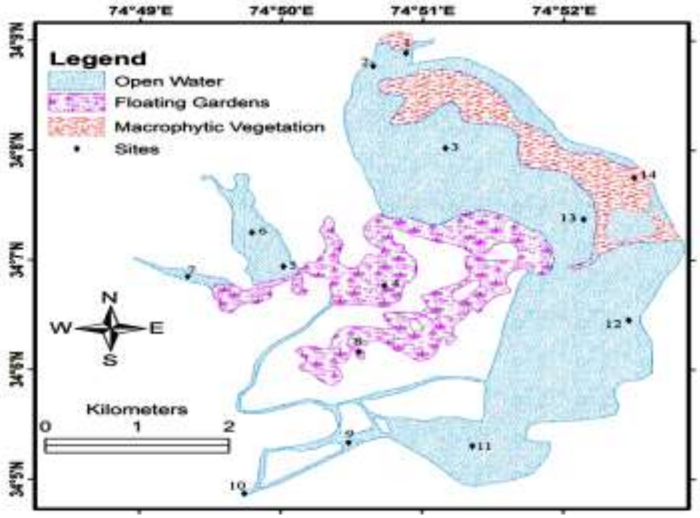

Figure 2: Map showing the Study sites

Table 1: Location of the sampling sites

Site	Name of Site	Location	Site	Name of Site	Location
1	Inflow - I	Telbal Nala	8	Floating Garden –II	Kandmohalla
2	Inflow -II	Boutkul Near Habak STP	9	House Boat -II	Bouleward road near
3	Hazratbal open	Between Hazratbal	10	Dal exit -II	Near Dal lock gate
4	Floating	Near Ashai Bagh	11	Gagribal open	Gagribal Basin
5	House Boat -I	Nigeen Basin	12	Deweeding –I	Between Centure hotel
6	Nigeen open	Nigeen Basin	13	Nishat open	Nishat basin
7	Dal exit -I	Pokhribal (Nigeen Basin)	14	Deweeding –II	Near Dockyard

Sample collection

For the collection of Periphyton, sampling was carried out on bi-monthly basis. The dominant macrophytes (natural substrates) were recorded at each site (Table 2). The aquatic plants collected for Periphyton included *Potamogeton natans, Trapa natans, Nymphoides peltatum, Potamogeton leucens, Ceratophyllum demersum, Myriophyllum spicatum and Hydrilla verticellata.* The plant leaves were packed in polybags and transferred to laboratory for further processing (Cattaneo and Kalff, 1978).

Sample processing

In the laboratory, each macrophyte was placed in a tray. The plant leaves were scraped with a sharp blade and then washed with distilled/deionized water (Cattaneo, 1978). Further, plastic bags were also rinsed with deionized water to procure detached algae. Host plant material if present, was removed from the epiphyte slurry. Epiphytic slurry after raised to a definite volume with distilled water was quantitatively subsampled for abundance and taxonomic composition (Gough and Woelkerling, 1976).

Preservation

Lugol's Iodine (Rice *et al*., 2005) and 4% formaline (Wetzel and Likens, 2004) was used for the preservation of Periphytic samples.

Table 2: Dominant macrophytes collected at each site

Sites	Dominant Macrophytes	Sites	Dominant Macrophytes
1	*Potamogeton leucens, Hydrilla verticellata*	**8**	*Ceratophyllum demersum, Nymphoides peltatum*
2	*Potamogeton crispus, Ceratophyllum demersum,*	**9**	*Ceratophyllum demersum, Hydrilla verticellata.*
3	*Potamogeton natans, Ceratophyllum demersum,Potamogeton crispus.*	**10**	*Hydrilla verticellata, Potamogeton leucens.*
4	*Nymphoides peltatum,Nymphaea mexicana.*	**11**	*Potamogeton leucens, Myriophyllum spicatum.*
5	*Ceratophyllum demersum, Potamogeton leucens,*	**12**	*Potamogeton natans, Potamogeton crispus.*
6	*Ceratophyllum demersum, Nymphoides peltatum*	**13**	*Ceratophyllum demersum, Potamogeton natans, Hydrilla verticellata, Potamogeton leucens.*
7	*Trapa natans,Hydrilla verticellata, Ceratophyllum demersum*	**14**	*Nymphoides peltatum, Potamogeton natans.*

Counting

Enumeration of Periphyton was carried either via strip or field counting by taking one ml of sub-sample in Sedgwick-rafter cell (Rice *et al*., 2005). In case, the material in Sedgwick-Rafter cell was found too dense to count directly, dilution technique was trailed. The morphology of many macrophytes (*C. demersum, M. spicatum, H. verticellata*) is of such a complex nature that determination of average surface area was difficult to determine, so individuals per10mg dry weight of macrophyte was followed in accordance with Zutshi and Ticku (1990).

Identification

For identification, standard works of Edmondson (1959), Prescott (1964), Adoni *et al.* (1985), Cox (1996), Biggs and Kilroy (2000) were followed. Periphytic algae were identified at 400X under Olympus binocular microscope. SEM technique was also employed for the identification and characterization of some of the species.

Sorenson's similarity coefficient (syn. coefficient of community, CC)

Uses presence/absence data:

$\mathbf{S_S}$ = 2a/ (2a + b + c),

Where, S_S = Sorensen similarity coefficient

a = number of species common to both Sites

b = number of species unique to the one site, and

c = number of species unique to the second site

S_S usually is multiplied by 100% and may be represented in terms of dissimilarity (i.e., $D_S = 1.0 - S_S$)

Results and Discussion

Myriophyllum and *Ceratophyllum* supported maximum no. of taxa while the minimum no. was recorded on Trapa. A total of 137 species belonging to 75 genera of periphytic algae were identified. Bacillariophyceae (88) was the dominant group found on all the sites followed by Chlorophyceae (41), Cyanophyceae (08) and Xanthophyceae (01).

Among the Bacillariophyceae, the dominant taxa were *Cymbella*, *Amphora, Navicula, Synedra, Cocconeis, Gomphonema, Fragillaria, Epithemia* and *Stauroneis*. The less dominant taxa included *Meriodon, Achnanthes, Achnanthidium, Nitzschia, Mougeotia, Craticula, Pinnularia, Cyclotella, Diploneis, Neidium, Asterionella, Selanastrum, Staurastrum* and *Tetraedon*. In Chlorophyceae, the dominant taxa include *Cosmarium*, *Microspora*, *Spirogyra*, *Lyngbya* and *Scenedesmus.* Cyanophyceae were represented by *Oscillatoria* and *Anabaena.* Xanthophyceae was represented by *Vaucheria.*

On the basis of their morphological features the following categories of periphyton were distinguished:

i) Filamentous green algae (*Spirogyra, Ulothrix*)
ii) Prostrate or heterotrichous green alage (*stigeoclonium*).
iii) Unicellular algae, mostly diatoms, attached by mucilage (*Cymbella, Amphora*);
iv) Unicellular stalked(regular stalk or gelatinous stalk) algae(*Gomphonema*);
v) Unicellular forms loosely attached with or without mucilage (*Navicula*); and
vi) Small colonial algae loosely or firmly attached (*Scenedesmus*).

The Dal Lake is for most part infested with macrophytes of all the four recognized categories, viz., submerged, rooted free floating leaf, emergent and free floating types. A total of 31 species of macrophytes have been reported from the lake (Qadri and Yousuf, 2008). The submerged macrophytes like *Ceratophylum demersum, Myriophyllum spicatum, Hydrilla verticillata* and *Potamogeton crispus* are the most prominent ones that are removed during mechanical deweeding. These submerged macrophytes with their characteristic finely dissected and densely packed leaves provided an adequate shelter and food source for Periphyton (Bogut *et al.*, 2009).

Generally high number of Periphyton were found attached to *Myriophyllum spicatum and C. demersum* followed by *H. verticillata*, *P. crispus, P. natans* and least for *T. natans and N. peltata*. Periphyton growth on natural substrates was maximum in late autumn (Nov-Dec.) to early spring and minimum in summer. Overall, the highest population density (230×10^3 units/10mg.dw) was recorded at site 3(undisturbed) in late autumn. On the other hand, lowest density (10×10^3 units/10mg.dw) was observed at site 14(deweeding) during harvesting operation in spring.

Majority of predominant Periphyton occurred frequently at all the study sites but a few were site-specific. For instance, *Merismopedia* sp. was confined to deweeding sites. The Bacillariophyceae (diatoms) was much more diverse than Chlorophyceae (green algae) and Cyanophyceae (blue green algae) in the lake and in terms of mean density of individuals the group was also showing maximum occurrence.

Periphyton dynamics at undisturbed sites

Four Sites were selected which were undisturbed ones across the length and breadth of the Dal Lake. Each undisturbed site was selected from each basin of the Lake. These included Site5 (Hazratbal basin), Site9 (Nigeen basin), Site14 (Gagribal basin), and Site16 (Nishat basin). All these undisturbed sites showed a similar trend in terms of population density with increasing trend towards the late autumn and decreasing trends towards spring and summer. Overall high population density of periphyton was observed at Site 3 among various undisturbed sites.

Periphyton dynamics at deweeding sites

The process of deweeding in the Lake ecosystem took place twice every year in spring and autumn. These sites showed comparatively less number of Periphyton species, particularly during the deweeding operation, with slight increase afterwards. Bacillariophyceae was the dominant group in all seasons. Cyanophyceae (*Oscillatoria* sp. and *Anabaena* sp.) registered slight rise after deweeding. The species of *Achnanthidium*, *Synedra, Chlorella, Navicula, Cymbella and Fragillaria* were observed to be highly prominent at deweeding sites. Some of the sensitive species were not found in harvesting period primarily because of the habitat disruption due to deweeding.

During deweeding in summers the harvester prompted vigorous turbulence in the water column, which led to perturbation in the area in terms of suspension of sediments as it was revealed by the decrease in Sechi transparency. Habitat disturbance in the sites due to removal of plant biomass along with large-scale turbulence of water column was found to result in dislodging and removal of Periphytic algae. The removal of Bacillariophyceae from the macrophytes was highest as compared to Chlorophyceae and Cyanophyaceae due to their numerical abundance.

The data revealed that the dominance of some species slightly decreased leading to uniformity of Periphytic algae. The plausible reason might be that prior to deweeding the community was composed of a few dominant and several less common as well as some rare taxa. Once there was deweeding, more number of dominant taxa got removed along with the harvested weeds, while the taxa that were rare before deweeding got better opportunities to increase in their population. The list of the Periphytic species which were exclusively present in Dal Lake is given in Table 3.

Table 3: Distributional pattern of periphytic algae among undisturbed and deweeding sites in the Dal lake ecosystem

Taxa	Undisturbed Sites	Deweeding Sites
Bacillariophyceae		
Achnanthes affinis	+	+
Achnanthes clevei	+	-
Achnanthes pseudoswazi	+	-
Achnanthes rostrata	+	-
Achnanthes hungarica	+	+
Acnanthidium delicatulum	+	-
Achnanthidium lanceolatum	+	-
Achnanthidium minutissima	*A*	*A*
Achnanthidium rosenstockii	+	-
Achnanthidium sp.	+	-
Amphipleura pellucid	+	-
Amphora veneta	+	-
Actinella sp.	+	+
Amphora ovalis	+	+
Amphora sp.	*A*	+
Asterionella sp.	+	-
Audoeinella sp.	+	-
Aulocosiera sp.	+	+
Brachysira serians	+	-
Brachysira sp.	+	+
Caloneis sp.	+	+
Cavinula sp.	+	-
Cocconeis placentula	+	-
Cocconeis sp.	+	+
Coconeis pediculus	+	+
Craticula sp.	+	-
Cyclotella sp.	+	+
Cymbella affinis	+	-
Cymbella aspera	+	-
Cymbella cistula	+	-

Taxa	Undisturbed Sites	Deweeding Sites
Cymbella cymbiformis	+	-
Cymbella microcephala	+	-
Cymbella sp.	*A*	*A*
Cymbella tumida	+	-
Diatoma heimale	+	+
Diploneis sp.	+	-
Encyonema prostratum	+	-
Encyonema sp.	+	+
Entomoneis alata	+	+
Entomoneis sp.	+	-
Epithemia argus	+	-
Epithemia sorex	+	-
Epithemia sp.	+	+
Epithemia turgid	+	+
Eunotia sp.	+	-
Fragillaria capucina	+	-
Fragillaria sp.	*A*	*A*
Fragillariforma virescens	+	-
Fragillariforma sp.	+	-
Frustulia rhomboids	+	-
Frustulia sp.	*R*	+
Gomphoneis sp.	+	*R*
Gomphonema accuminatum	+	-
Gomphonema auger	+	-
Gomphonema olivaceum	+	+
Gomphonema purvulum	+	-
Gomphonema sp.	+	+
Gomphonema truncatum	+	-
Luticola heufleriana	+	-
Melosira sp.	+	-
Mastogloia sp.	+	-
Meriodon circulare	+	-
Meriodon sp.	+	-
Navicula cryptocephala	+	+
Navicula digitoradiata	+	+
Navicula lanceolatum	+	-
Navicula menisculus	+	+
Navicula cincta	+	+
Navicula phyllepta	+	-
Navicula sp.	*D*	*D*
Neidium binodis	+	-

Taxa	Undisturbed Sites	Deweeding Sites
Nitzschia palea	+	+
Nitzschia paleacea	+	-
Nitzschia pusilla	+	-
Nitzschia hantzschiana	+	-
Nitzschia sp.	+	+
Pinnularia sp.	+	+
Pinnularis sp	+	-
Punctastrata sp.	+	-
Stauroneis anceps	+	+
Stauroneis phoenicenteron	+	-
Stauroneis sp.	*A*	-
Synedra acus	+	-
Synedra sp.	+	*A*
Synedra ulna	+	+
Synedra vaucheriae	+	-
Tabellaria sp.	+	*R*
Tryblionella debilis	+	-
Chlorophyceae		
Ankistrodesmus sp.	+	-
Ankistrodesmus falcatus	+	+
Ankistrodesmus spiralis	+	-
Pediastrum boryanum	+	-
Pediastrum biradium	+	-
Chlorella vulgaris	+	*A*
Cladophora sp.	+	-
Closterium acutum	+	-
Closterium sp.	+	-
Closteridium sp.	+	+
Cosmarium granatum	+	-
Cosmarium impressulum	+	-
Cosmarium renifome	+	-
Cosmarium sp.	+	+
Coelestrum sp.	+	+
Crucigenia sp.	+	+
Desmidium sp.	+	-
Kirchneriella sp.	+	+
Microspora sp.	+	+
Mougetia sp.	+	+
Oedogonium sp.	+	-
Pediastrum biradiatum	+	-
Rhizoclonium sp	+	-

Taxa	Undisturbed Sites	Deweeding Sites
Rhopalodia gibba	+	-
Scenedesmus communis	+	-
Scenedesmus armatus	+	+
Scenedesmus dimorphus	+	-
Scenedesmus obliquus	+	+
Scenedesmus quadricauda	+	+
Scenedesmus sp	+	-
Selenastrum westii	+	-
Selenastrum sp.	+	+
Spirogyra sp.	+	-
Stigeoclonium sp.	+	-
Straustrum sp.	+	-
Tetraedron hemisphaericum	+	-
Tetraedon sp.	+	-
Tetrastrum heterocanthum	+	-
Ulothrix sp.	+	-
Volvox sp.	+	-
Cyanophyceae		
Anabaena sp.	+	+
Calothrix braunii	+	-
Gleocapsa sp.	+	-
Lyngbya sp.	+	-
Merismopedia sp.	*R*	+
Microcystis aeroginosa	+	-
Oscillatoria sp.	+	+
Phormidium sp.	+	-
Xanthophyceae		
Vaucheria sp.	+	-

D = Dominant; A=Abundant; + present; R=Rare; - Absent

Sorenson's similarity coefficient

Based on the similarity between Undisturbed and Dredging sites, the value of Sorrensons similarity coefficient came 0.39 (39%), which means these sites differed by 61%.

Student's *t* test was applied between undisturbed and deweeding site. The results show significant difference (t value=17.35, $p<0.05$) between undisturbed and deweeding sites in terms of Periphyton abundance. There was considerably higher population abundance in undisturbed sites. ANNOVA was also applied on the abundance of Periphytic algae of undisturbed sites. There was insignificant ($F_{67,3}$ =0.495, P=0.68) variation among undisturbed sites. ANNOVA ($F_{7, 138}$ = 39.9, P=0.001) was also applied on other sites of the Lake ecosystem.

The Periphyton community recorded from undisturbed sites of the Lake did not show any significant variation; even the sequence of dominant taxa was almost identical. The reason for this structural similarity may be attributed to almost identical physico-chemical environment of these sites. As these sites remained untouched by dredging and deweeding operation, highest density was recorded.

When different natural substrates (macrophytes) of the lake were taken into consideration, significant variation was observed in the population density and dominance pattern of different taxa. This would suggest that the nature of the substrate has an important role to play on the size and composition of the Periphyton population. It has been observed that some of the dominant taxa occurred regularly on various substrates and none was strictly limited to any biotype. This might be due to their better adaptability (McIntire, 1971).

Maximum colonization on macrophytes was observed when the plant species entered the phase of senescence and started decaying towards the end of the growing season (Late Autumn). This may be because of the fact that the old parts of a macrophyte become soft and spongy due to decay and thus make a suitable substratum for the attachment of the Periphytic flora. It may also be due to rapid metabolic leakages from the decaying macrophytes. This is supported by Brix (1994), Wetzel and Allen (1972); Fontaine and Nigh (1983). The decreased populations during summer revealed the less abundance of most of the dominant Periphytic species and increased grazing pressure by zooplankton (Higgins *et al*., 2014).

M. Spicatum followed by *C. demersum* supported rich and varied Periphytic flora both in terms of number of taxa and the population density. This could be because of its greater surface area with highly dissected nature of its leaves. Similar findings were also observed by Harrod and Hall (1962) and Cyr and Downing (1988). According to Cattaneo and Kalff (1979), finely dissected plants like *Myriophyllum* have much greater biomass than coarsely leaved ones as the former have much larger surface area per unit weight than the latter. Some specific macrophytes like *T. natans and N. Peltata* harboured less number of Periphyton species. It may be due to increased release of allelopathically active compounds by this macrophyte that might have hampered the growth of Periphyton (Wium-Andersen *et al*., 1982).

The influence of deweeding on Periphyton was mainly due to habitat disturbance through removal of vegetation. Deweeding on one hand decreased the abundance of Periphytic algae (attached) and on the other increased the numerical abundance of phytoplankton (freely moving). This might be due to vigorous shaking of macrophytes by harvesters, the Periphytic forms got dislodged in the process, remained suspended and added to the overall numerical abundance of plankton group. Periphyton attached to surface of macrophytes competes with these plants for different nutrients (Underwood and Thomas, 1990) thus, harvesting of Periphyton infested macrophytes paves the way for growth of uninfested macrophytes which utilize the resources fully in absence of the Periphyton.

Decline in the number of Periphytic species during deweeding process can be attributed to the fact that the manipulated environment formed due to the removal of weeds does not provide the necessary requirements for the concerned Periphytic algae in appropriate capacity to flourish. This is supported by the fact that the reference site which doesn't undergo any deweeding does not exhibit any significant changes in the Periphytic algae during the same period.

The harvesting operation at some sites was found to favour the growth of invasive macrophyte species (Engel, 1990). The re-growth of macrophytes is possible in two ways. Firstly the underground parts that were left behind during harvesting grew new shoots quickly. Secondly, the viable fragmented portions of stem, stolon or rhizome, cut from the parent plant during deweeding form the nucleus of new population. Besides, the harvester may also spread the propagules (fragment, buds and turion) throughout the lake (Habib and Yousuf, 2014).

Due to harvesting, apical dominance of macrophytes was hampered. This probably promoted the release of cytokinin plant hormone that led to denser and accelerated growth of lateral branches (Cline, 1994), thereby hampering apical dominance. Besides, rapid re-colonization of macrophytes occurred perhaps through vegetative fragments (Vári, 2013) that were dispersed during partial deweeding early in the season (Engel, 1990; Nichols and Lathrop, 1994).

Prior to deweeding, the Periphytic community was observed to be composed of a few dominant and several less common and some rare taxa. But upon initiation of deweeding process, maximum number of dominant taxa got removed along with the harvested weeds, which as a result gave an opportunity for some of the rare taxa to grow. Thus, as a consequence of which species composition and distributional pattern of this very important autotrophic community got altered. The present study therefore concludes that there was a negative impact on periphyton community by deweeding processes as evident by 67.15% loss in the species composition immediately after the initiation of harvesting operation. The recovery rate of studied Periphytic community was also registered to be slow. In order to ascertain the full recovery of Periphytic community, continuous long term assessment (>10 years) is mandatory.

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