HYDROBIOL. BULL. 24(2), 125-131 (1991)

PERSPECTIVES FOR SUBMERGED MACROPHYTES IN SHALLOW LAKE RESTORATION PROJECTS IN THE NETHERLANDS

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KEYWORDS: Submerged macrophytes; shallow lake restoration; biomanipulation; light climate; (wind-induced) resuspension.

ABSTRACT

Some well-documented studies on restoring eutrophic lake systems in The Netherlands by fish stock management have been evaluated with the emphasis on the role of macrophytes. Furthermore, the factors determining the light climate for submerged macrophytes in a large shallow eutrophic lake (Lake Veluwe) have been assessed and the potential success of biomanipulation in large scale projects is discussed. Today relatively little attention has been paid to macrophyte management although the importance of macrophytes in lake restoration has been recognized regularly. The biomanipulation strategy was successful in small scale projects. In a large scale project, however, wind-induced resuspension may largely determine the underwater light climate through attenuation by the water column and periphytic layer. Therefore, restoration of relatively large waterbodies by fish stock management only is expected not to lead to any noteworthy improvement of the light climate for submerged macrophytes. Additional measures aimed at reducing wind-induced resuspension of sediment particles and reestablishing of the macrophyte stands are required for successful biomanipulation strategies. Water quality managers should pay more attention to macrophyte stands in biomanipulation projects because macrophytes enhance a more stable and diverse ecosystem. Restoration objectives and the methods of their achievement must be carefully planned since an abundant submerged macrophyte vegetation may have undesirable effects as well.

INTRODUCTION

It is widely recognized that eutrophication threatens many macrophyte-dominated aquatic ecosystems over the whole world. Increase in algal biomass, concurrent water turbidity and a marked decline in the abundance of submerged vegetation has been recorded in many northern temperate aquatic systems over the last decades as a result of severe eutrophication (*e.g.* DE NIE, 1987). Generally, there are two main strategies to control eutrophication in fresh waters. Firstly, a reduction of external and internal load of nutrients (BJÖRK, 1985), and, secondly, control of the internal ecogical processes by fish stock management (McQUEEN *et al.*, 1986, BENNDORF, 1988). Reducing the nutrient loading may provide acceptable long-term solutions but it can take a long time before a eutrophic ecosystem is completely recovered (GONS *et al.*, 1986; HOSPER and MEIJER, 1986). This delay in recovery has been explained by disturbance of the food chain due to eutrophication.

The decline in submerged vegetation is accompanied by an alteration of the habitats and food conditions for fish. The food chain of severely eutrophicated waters is generally characterized by a lack of predatory fish (*e.g.* northern pike, *Esox lucius* L.), large biomass of planktivorous and benthivorous fish (mainly bream, *Abramis brama* L.) (LAMMENS, 1986; GRIMM, 1989), low abundance of herbivores (*e.g. Daphnia*), and relatively high phytoplankton densities causing low transparency of the water column (HOSPER, 1989). Furthermore, bream, in search of benthic food, enhance resuspension of sediments and concurrently promote nutrient recycling (TEN WINKEL and MEULEMANS, 1984; LAMMENS, 1986). Because of these negative effects of bream on water quality, it has been attempted to restore the food chain by reducing the bream stock and enlarging the predatory fish stock. An abundant predatory fish stock controls the cyprinids and hence enhances the grazing pressure on phytoplankton. This 'biomanipulation' has shown promising results in various studies with respect to improved water quality in terms of reduction in algal biomass and turbidity (*e.g.* SHAPIRO and WRIGHT, 1984; CARPENTER *et al.*, 1985; BENNDORF *et al.*, 1988; MEYER *et al.*, 1989; VAN DONK *et al.*, 1990-a).

The importance of macrophytes as stabilizing structures in these restored aquatic ecosystems has been recognized in some of these studies (OZIMEK *et al.*, 1990). However, restoration programmes by biomanipulation are mainly concentrating on fish stock management, and relatively little attention has been paid to macrophyte management until now.

The present paper gives an overview of the role of macrophytes in some well-documented restoration projects in The Netherlands and expectations for large scale restoration projects. The potential role of submerged macrophytes in restoration programmes before and after biomanipulation is evaluated.

CASE STUDIES

Lake Zwemlust

The hypertrophic Lake Zwemlust (area 1.5 ha, Zm 1.5 m) was characterized by algal blooms in summer, reducing the Secchi disk transparency to less than 0.3 m. The lake has been object of an extensive limnological study since the removal of planktivorous fish (bream) and the replacement of the water in March, 1987 (VAN DONK *et al.*, 1990-a). The Secchi depth increased to the lake bottom (2.5 m) in the subsequent summer of 1987, and concurrently, submerged macrophytes responded rapidly to the improved light conditions. Six species of submerged macrophytes were present besides the introduced *Chara globularis*. The macrophytes colonized 10% of the lake area. Other species did not appear in 1988 and 1989, but the area covered by macrophytes increased by seven and ten times, respectively. *Elodea nuttallii* was the dominant species. It contributed about 70% and 82% to the total macrophyte

sing N-limitation of phytoplanton growth resulting i
a persistent clear water phase (OZIMEK *et al.*, 1990).

Undesirable features of the increase in macro phytes were, firstly, direct nuisance to swimmer and, secondly, large scale development of snails especially *Lymnaea peregra*, which may harbour th parasite *Trichobilharzia ocellata*; the cercariae of thi trematod cause schistosome dermatitis (swimmer's itch) (VAN DONK *et al.*, 1989; 1990-a)

Lake Bleiswijk

The hypertrophic Lake Bleiswijk, a narrow shallow lake (lenght 2 km, area 14.4 ha, Z_m 1.1 m) was characterized by high algal densities, a Secch disk transparency of about 0.2 m, and absence o submerged macrophytes during the summers o 1980-1986. The lake was divided in two compartments. In one compartment most of the plantivorous and benthivorous fish was removed and predatory fish was introduced in April, 1987. This biomanipulation resulted in an increase in Secchi disk transparency to 1.1 m within two months. Concurrently, Characeae (*Chara vulgaris var. longibracteata*) became abundant and other macrophytes (*Potamogeton pectinatus, P. crispus*, and *Ceratophyllum demersum*) developed during the subsequent summer. High zooplankton densities caused low algal densities until July. Then, the zooplankton densities decreased, but the algal density remained low. This phenomenon was explained by nutrient limitation as a result of high abundance of submerged vegetation or by inhibition of algal growth through allelopathic substances secreted by the macrophytes, or by both mechanisms (MEIJER *et al.*, 1989). The non-treated compartment of the lake remained turbid and no submerged vegetation was present (MEIJER *et al.*, 1989).

Lake Breukeleveen

Lake Breukeleveen (area 180 ha, Zm 1.45 m) is a compartment of the eutrophic Lake Loosdrecht. Earlier investigations (LEENTVAAR and MÖRZER BRUIJNS, 1962) indicated that the macrophytic vegetation changed markedly since 1942, when almost the entire bottom of the lake was covered with Characeae. By 1961 the Characeae had disappeared and only a few submerged macrophyte species, mostly possessing floating leaves (*Nuphar lutea, Nymphaea alba*) were recorded. Lake Breukeleveen was selected to study the effects of whole-lake food-web manipulation on a large scale. The external P-load has been reduced from 1.2 to 0.5 g P m^{-2} y^{-1} by measures *ca.* 0.3 m), however, did not improve. Also the reduction of the planktivorous population from 150 to 57 kg.ha^{-1} in March, 1989, did not result in an increase in water transparency. The dominance of cyanobacteria, rotifers and planktivorous fish had not changed in favour of submerged macrophytes and piscivorous fish. Apparently, the underwater light climate was still unfavourable for macrophyte growth due to resuspension of bottom material and relatively high concentrations of cyanobacteria filaments inhibiting the filtering mechanisms of largebodied zooplankton (VAN DONK *et al.* 1990-b).

Lake Veluwe

Lake Veluwe (area 3,240 ha, Z_m 1.20 m) is since 1957 one of the shore lakes, situated between the dikes of the reclaimed Flevoland polders and the former coastline of the 'old land'. Another shore lake (Lake Nuldernauw) will be subject to biomanipulation within due time. Lake Veluwe was characterized by a high transparency of the water column and a dense submerged vegetation in its early years (LEENTVAAR, 1961). It gradually changed into a turbid, eutrophic lake with relatively low macrophyte biomass in the 1980s (HOSPER and MEIJER, 1986) due to cultural eutrophication starting in the early sixties.

Investigations of the light climate for submerged macrophytes in Lake Veluwe during May-September in 1986 and 1987 revealed that the availability of Photosynthetically Active Radiation (PAR) for submerged macrophytes was largely determined by wind-induced resuspension of sediment particles. The vertical attenuation coefficient of the water column varied between 1.56 and 6.74 m^{-1}. Depletion of irradiance was largely attributed to tripton (detrital and inorganic matter) whereas phytoplankton had only additional effects. The contribution of water and gilvin (dissolved yellow substances) to the beam attenuation coefficient was even negligible (Table 1). The tripton concentration was positively correlated with wind velocity (BRINKMAN and VAN RAAPHORST, 1986; VAN DIJK and ACHTERBERG, 1990). Attenuation by periphyton upon artificial substrate ranged up to more than 90% of the incident PAR. This diminution of PAR was largely ascribed to the backscatter properties of resuspended clay and sand particles settled from the water column into the periphytic layer (VAN DIJK, 1990).

Resuspended sediment particles not only affected the quantity but, to a large extent, also the spectral distribution of PAR available for the submerged macrophytes. Resuspended detritus in the water column was a strong absorber of the blue regions of the spectrum and also the settled sand and clay particles in the periphytic layer performed a selective attenuation for the blue regions. Consequently, the spectral distribution of PAR was progessively compressed with depth into the region between 550 and 700 nm (VAN DIJK and ACHTERBERG, 1990; VAN DIJK, 1990), which may be unfavourable for optimal plant growth (*e.g.* KIRK, 1983).

DISCUSSION

The main objective of biomanipulation in restoring lake systems is to improve the underwater light climate with zooplankton reducing the phytoplankton while nutrient levels stay high. Biomanipulation should create conditions to enchance growth of

Table 1. Mean, minimum and maximum relative contribution of water, gilvin, phytoplankton and tripton to the absorption coefficient (a), scattering coefficient (b), and beam attenuation coefficient (c) during the end of June until the end of September, 1986 (n=8) and the end of April until the beginning of September, 1987 (n=9) in Lake Veluwe, measured fortnightly (VAN DIJK and ACHTERBERG, 1990).

	a(m^{-1})			b(m^{-1})			c(m^{-1})		
Component	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1986									
Water	18	6	24	*ca.* 0	*ca.* 0	*ca.* 0	3	1	5
Gilvin	29	11	40	*ca.* 0	*ca.* 0	*ca.* 0	4	1	8
Phytoplankton	11	6	19	8-16	3- 7	16-33	8-15	4- 6	17-31
Tripton	42	27	68	84-92	67-84	93-97	79-85	61-75	89-91
1987									
Water	10	5	16	*ca.* 0	*ca.* 0	*ca.* 0	2	1	2

submerged macrophytes since light climate is generally recognized as a key factor regulating growth and distribution of submerged macrophytes in eutrophic waters.

The biomanipulation strategy was successful in relatively small scale projects (Lake Zwemlust and Lake Bleiswijk). The water transparency was high and an abundant macrophyte stand had developed within two years after the biomanipulation in these lakes. The restored vegetation increased the stability of the macrophyte dominance by preventing phytoplankton blooms through nitrogen limitation in Lake Zwemlust and likely through allelopathic substances secreted by *Chara* sp. in Lake Bleiswijk (MEIJER *et al.*, 1989).

Biomanipulation, however, did not improve the underwater light climate in a relatively large scale project (Lake Breukeleveen) and the submerged vegetation did not develop. The current light climate for submerged macrophytes in Lake Breukeleveen was probably largely determined by resuspended sediment particles as has been demonstrated for Lake Veluwe. Here, wind-induced resuspension of sediment particles had a major negative impact on the quantity and spectral distribution of PAR available for the submerged vegetation through attenuation by resuspended particles in the water column and settled resuspended particles in the periphytic layer. Lake Breukeleveen and Lake Veluwe are similar with regard to factors favouring wind-induced resuspension through the position of the SW-diagonal (the square Lake Breukeleveen) or the length axis (the rectangular Lake Veluwe), in the prevailing SW wind,

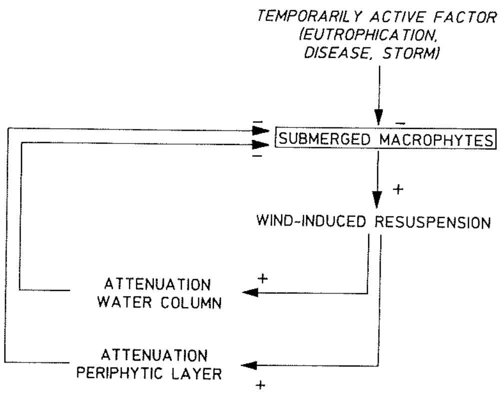

Fig. 1. Scheme of the hypothetical interactions among macrophytes and their light climate in a shallow lake sensitive to wind-induced resuspension of sediment particles. A temporarily active factor reducing the submerged macrophyte biomass leads to increased

the absence of islands giving maximal fetch, their shallowness and easily resuspending uppermost layer of the bottom consisting of fine matter (BRINKMAN and VAN RAAPHORST, 1986; GONS, 1987).

Lake Zwemlust and Lake Bleiswijk are less sensitive to wind-induced resuspension in spite of their shallowness and easily resuspending uppermost layer of the bottom (Lake Zwemlust: mainly silt; data not presented; Lake Bleiswijk: mainly clay, (MEIJER *et al.*, 1989), because these small lakes have a relatively short fetch and are sheltered from the wind by trees along the shore or in the surroundings.

Dense submerged macrophyte stands occurred in Lake Veluwe and Lake Breukeleveen in the 1940s and 1950s. Apparently, at that time, these stands flourished in a favourable light climate by which wind-induced resuspension was limited. Rooted submerged macrophytes reduce stirring up of sediments by stabilizing the sediment and dissipating wave energy (CARPENTER and LODGE, 1986; SCHRÖDER, 1988).

From these observations we hypothesize that shallow macrophyte-dominated lakes sensitive to wind-induced resuspension of sediment particles, may switch irreversibly into a turbid state with low macrophyte density if any at all, when the macrophytes considerably decline due to a temporarily active factor (*e.g.* eutrophication, disease, storm). Afterwards, regeneration of the macrophyte stands may be prevented by unfavourable light conditions through wind-induced resuspension of sediment particles (Fig. 1). Such a phenomenon was observed in Australia, where reestablishment of the submerged vegetation was prevented by wind-induced resuspension after a tropical storm had swept away the entire submerged vegetation (GERBEAUX and WARD, 1988). Wind-induced resuspension of sediment particles may explain the limited improvement of water quality, *i.c.* water transparency, after biomanipulation in Lake Breukeleveen although fish control was successful in terms of standing crops of planktivorous and benthivorous fish populations.

The effectiveness of biomanipulation in large shallow eutrophic lakes which are more frequently subject to wind-induced resuspension of sediment particles than small lakes may be limited when only fish stock management is applied. Fig. 2 (left part) illustrates that biomanipulation through fish stock management leads to a restored food chain (more zooplankton, less algae, higher irradiance penetration, more macrophytes, more predatory fish, less planktivorous fish, more zooplankton, *etc.*) in lakes in

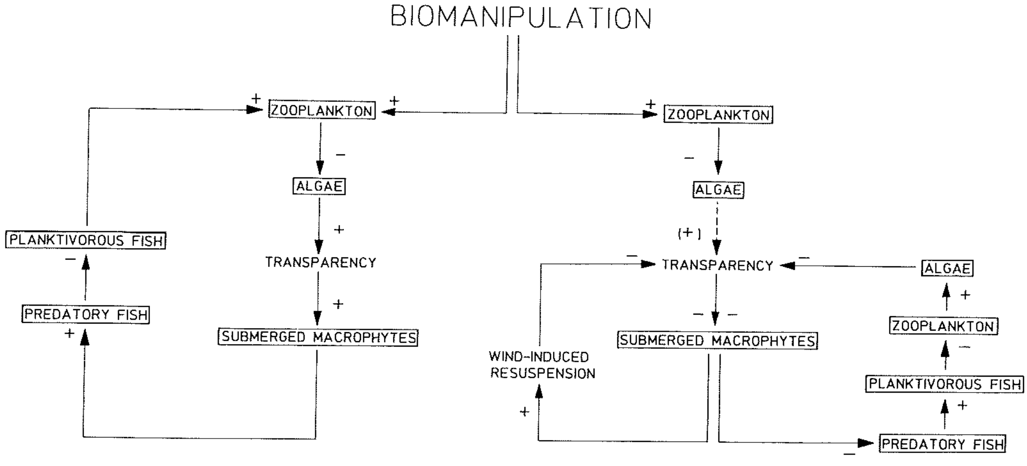

Fig. 2: Scheme of hypothetical interactions among the biota and their environment in shallow, eutrophic Dutch lakes in which wind-induced resuspension of sediment particles plays no role (left, after HOSPER, 1989) or in which it does play a role (right) after biomanipulation (removal of planktivorous fish and introducing predatory fish). Arrows indicated with a + sign represent an increase; with a – sign a decrease in rate or quantity, respectively.

control of algae by zooplankton will hardly improve the underwater light climate and concurrent growth of macrophytes when wind-induced resuspension predominates; a positive impact of biomanipulation on transparency will be prevented by high attenuation due to the resuspended sediment particles (Fig. 2, right part). Consequently, the macrophyte biomass will remain low and the food chain is likely to change again to low predatory fish, high planktivorous fish, low zooplankton, high algae, *etc.*, shortly after the biomanipulation.

Additional measures besides fish stock management are required to get a clear water phase and an abundant submerged vegetation in lakes sensitive to wind-induced resuspension of sediment particles. Firstly, the underwater light climate must be improved before plants can colonize and morphometric measures are required to reduce the wind-induced resuspension (*e.g.* creation of sheltered areas by temporarily windshields; shortening of the fetch by islands or dikes; dredging). The importance of morphometric characteristics on wind-induced resuspension has been recognized by others as well (DUARTE and KALFF, 1988) although it received little attention up to now. Secondly, there must be plants to take advantage of the improved light conditions (MOSS, 1990). Active management in order to stimulate a submerged vegetation may be necessary to accelerate the process (*e.g.* introduction of vegeta-

floating leaves and thus increase sedimentation and trap drifting material (*e.g.* dead leaves) because of the reduced water movements in and around their stands (BROCK, 1985). Inoculation of *Chara vulgaris* showed to be effective in stabilizing the sediments against wind-induced resuspension because of its rhizoidal growth within the substrate leading to clear water conditions (CRAWFORD, 1979).

The buffering mechanisms (stabilization of sediment, dissipation of wave energy, nutrient uptake, secretion of allelopathic substances) which stabilize the plant community are reinstated by restoring the submerged vegetation. Furthermore, submerged macrophytes may indirectly improve their own light climate by creating refuges for zooplankton and for the spawning of pike (GRIMM, 1981, 1983; HAKKARI and BAGGE, 1985; RAAT, 1988). Macrophytes not only stabilize the underwater light climate, but also enhance the diversity of species by offering substratum to periphytic organisms and food to herbivores, periphyton grazers (like molluscs and chironomids), organisms associated with the detritus food chain, and water fowl (*e.g.* Bewick's swan foraging on *P. pectinatus* tubers).

Macrophytes may also have undesirable effects on water quality. Nutrients may increase in systems with a high internal nutrient load as a result of the presence of macrophytes (MALTHUS *et al.*, 1990). Consequently, the increased transparency may be of causing swimmers itch (schistosome dermatitis); an additional undesirable effect, in waters intensively used for recreational purposes (VAN DONK, 1990).

In conclusion, more research on the impact of macrophytes on the functioning of shallow aquatic ecosystems is required. Water quality managers should pay more attention to management of a submerged vegetation considering its buffering mechanisms in stabilizing the dominance of macrophytes and its positive impact on species diversity. But the restoration objectives and the methods o their achievement must also be carefully plannei because an abundant submerged macrophyte vege tation may have undesirable effects as well.

ACKNOWLEDGEMENTS

We like to thank an anonymous referee fo her/his valuable comments on the manuscript.

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