II-215 Biomanipulation in shallow, eutrophic lakes: A numerical model

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1.0. Introduction:

Lake restoration has long been considered to be primarily a matter of chemistry and engineering. Clearly, in-lake techniques to lower nutrient concentrations or to remove sediments or rooted plants can be effective in improving lake trophic state following diversion of silt and nutrients. These approaches, however, usually ignore the biological interactions of the lake ecosystem which cause low water transparency and high internal nutrient release etc. Shapiro *et al.* (1975) and Shapiro (1978) suggested the term *biomanipulation* to include lake improvement methods that alter the food web to favor grazing on algae by zooplankton, or that eliminate fish species which recycle nutrients.

Eutrophication of shallow lakes has led to an abundance in algal biomass, disappearance of most of the macrophytes and disturbance of the food chain. As eutrophication increases, piscivorous fish density falls sharply whereas planktivorous and benthivorous fish densities grow rapidly causing more resuspension of nutrients. This causes the eutrophication becomes intense. Eutrophication problems are, therefore, necessary to be combated in order to restore the water quality. This can be done with the reduction of nutrient levels. But it seems that the reduction of nutrient level does not merely solve the problem due to the present structure of the food chain. Hence, the manipulation of food chain is of paramount importance in combating the eutrophication problems. In other words, reduction of planktivorous and benthivorous fish such as roach *(Rutilus rutilus)*, rudd *(Scardinius erythrophythalmus)*, bream *(Abrama brama)*, carp *(Cyprinus carpio)* and introduction of piscivorous fish such as perch *(Percafluviatilis)*, pike *(Esox lucius)*, pike perch *(Stizostedion lucioperca)*, eel *(Anguilla anguilla)*, cat fish *(Silurus glanis)* are considered to be prerequisites for the restoration of water quality by the method of biomanipulation.

2.0 State equations:

The following governing equations are considered in the model. In this model state variables are phytoplankton comprising of fourteen separate types, zooplankton, detritus, planktivorous and benthivorous fish (Bream) and finally piscivorous fish (Pike perch).

$$\frac{dPy_i}{dt} = (Pg_i - M_i - R_i - G_i)Py_i \tag{1}$$

$$\frac{dZ}{dt} = (G_Z - R_Z - M_Z)Z \tag{2}$$

$$\frac{dD}{dt} = \sum (q.a_i.M_i.Py_i) - u.D - s.D \tag{3}$$

$$\frac{dB}{dt} = ib + G_B.B - cb.B^2 - Pr_{max}.Fr.Pi \tag{4}$$

$$\frac{dPi}{dt} = ip + G_{Pi}.Pi - mp.Pi - cp.Pi^2 \tag{5}$$

where Py is the phytoplankton concentration (mg/m^3); Pg is the gross growth rate of phytoplankton (per day); M is the natural mortality except grazing by zooplankton (per day), R is the respiration of phytoplankton (per day); G is the grazing rate by zooplankton (per day); i represents each phytoplankton type; Z is the zooplankton concentration (mg/m^2); G_Z is the growth rate of zooplankton (per day); R_Z is the respiration rate (per day); M_Z is the natural mortality including grazing by planktivorous and benthivorous fish (per day); D is the detritus concentration due to dead phytoplankton cells (mg P/m^3); q is the nutrient fraction which becomes detritus when a phytoplankter dies; a_i is the fraction of nutrient per unit of phytoplankton type; u is the mineralization rate constant of detritus (per day); s is the sedimentation rate constant (per day); B is the bream density (g/m^2); ib is the immigration rate of bream (g/m^2.day); G_B is the growth rate of bream (per day); cb is the intraspecific competition constant for bream (per m^2 g day); pr_{max} is the maximum predation rate of pike perch (per day); Fr is the functional response of pike perch; Pi is the pike perch density (g/m^2); ip is the immigration rate of pike perch (g/m^2 day); G_{Pi} is the growth rate of pike perch (per day); mp is the natural mortality rate of pike perch (per day); cp is the intraspecific competition constant for pike perch (per m^2 g day).

3.0 Results and discussion:

The temporal variations of phytoplankton biomass as chlorophyll-a and transparency as secchi depths were compared in the Lake Bleiswijkse Zoom, The Netherlands, both in control and treated areas with a comprehensive biological model.(Fig. 1 & 2) The biological model enumerated the species compositions at a given time taking biological, physical and meteorological processes in to account. Reduction of almost all planktivorous fish and 85% of benthivorous fish resulted in increase in transparency, decrease in algal biomass and decrease in resuspended inorganic matters leading to an environmental sound lake ecosystem. This model also provides useful insights in to positive and negative interrelationships among biota in the ecosystem. In other words, from the biomanipulation point of view, poor understanding of interactions among biota and hence, uncertainties of their accurate predictions may lead to controversial evidences.

Fourth order Runge Kutta method was used in this model in order to solve simultaneous differential equations representing state equations. A time step of one day was adopted for the entire computational period and the computational period started from mid April to end of November, 1987.

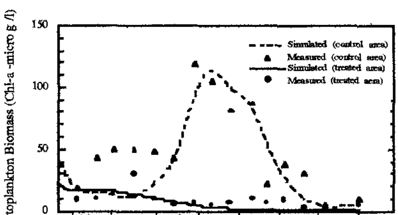

Fig. 1

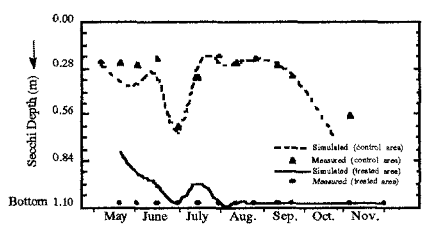

Fig. 2

With these results it can be concluded that the biomanipulation process can be modeled to a certain accuracy. No precise simulation is possible unless the uncertainties of interrelationships among biota of the lake ecosystem are clearly understood. The poor understanding of accurate seasonal variations among some species (For e.g. pike perch, bream etc.) also causes lesser accuracy in the predicted results.

4.0. References:

(1) Hosper, S. H, 1989. Biomanipulation, new perspectives for restoration of shallow eutrophic lakes in The Netherlands. Hydrobiol. Bull. 23:5-10.

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(4) Shapiro, J, 1978. The need for more biology in lake restoration, In lake restoration, EPA-440/5-79-001,161-167.