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NOTE

A Classic Viewpoint on Fish Removal Biomanipulation in Whole-lake Studies

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호소전체를 대상으로 한 고전적 관점의 생물학적 조절법에 관한 소고: 물고기 제거에 의한 호소 수질 향상. 정상옥 (공주대학교 유해조류대발생예방연구실-국가지정연구실)

수십년 전부터 민물의 부영양화는 수질 관리에 문제를 제기해왔다. 전세계적으로 생물학적 조절론이 아닌 영양염류 저감론에 의한 부영양화 해결 방안이 대세를 이루고 있다. 생물학적 조절법은 호소 생태계에서 최상위 먹이망에 위치한 물고기 생태와 생체량의 중요성에 착안한 수질 향상 이론으로 부영양화 해결을 위한 강력한 도구로 받아들여지고 있다. 그러나 실제적으로 수질 향상을 위한 긍정적 효과를 얻으려면 해당 각 수역 전체의 먹이망에 관한 정확한 이해가 필요하다. 생물학적 조절법으로 얻은 수질 향상 효과를 장기간에 걸쳐서 누리려면 어떻게 해야 최적인가가 현재 제기되는 논의의 중심이다.

Key words : fish removal biomanipulation

INTRODUCTION

The modern problem of eutrophication of lakes (reservoirs) results mainly from man's activities (Odum, 1971). Severe eutrophication generally results in poor water quality due to high algal production associated with low water transparency. Therefore, methods for water quality improvement are focused on the decrease in algal production (i.e., phytoplankton or chlorophyll biomass) and on the increase in water transparency in the pelagic zone of lakes (reservoirs).

In order to achieve these goals, two main trends and the combined hypothesis in modern limnology were introduced, apart from the destratification technique (Reynolds, 1997) :

(1) "bottom-up" (nutrient supply/ resource availability regulates/ producer controlled) links between long-term averages phytoplankton chlorophyll *a* and P (phosphorus) bioavailability (Vollenweider, 1976; Schindler, 1988),

(2) "top-down" (grazing/ predation effects/ consumer controlled) or "cascading trophic interaction" hypothesis, which postulates that changes at the top of the food web are transmitted down to primary producers (Carpenter *et al*., 1985), explains differences in productivity among lakes with food webs unlike nutrient supplies. In other words, enhanced piscivory can decrease planktivore densities, increase grazer densities, and decrease chlorophyll *a*. Prior to this hypothesis, practical "top-down" manipulations were performed in the fish pond (Hrbáček *et al*., 1961) or in the experimental lake (Shapiro *et al*., 1975) and they are lately known as "biomanipulation", and

(3) this combined hypothesis (McQueen *et al*., 1986) which predicts that "top-down" effects are strong at the top but weaker near the bottom of the food web. It stresses on the relative impacts of "bottom-up" and "top-down" forces on the biomass and size structure of five major components of freshwater pelagic systems (piscivores,

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planktivores, zooplankton, phytoplankton, and also total phosphorus availability).

The aim of this presentation is to briefly introduce classically (i.e. *sensu* Shapiro, emphasis on the fish rather than the zooplankton) defined "biomanipulation" (specifically focused on 'whole−lake scale' rather than chemostat, enclosure, or limnocorral), especially "fish removal biomanipulation" among food web manipulation techniques. This short essay is mainly from the author's doctoral dissertation (Chung, 2001).

BIOMANIPULATION

In original concept, biomanipulation is a series of manipulations of the biota of lakes and of their habitats to facilitate certain interactions and results which as lake users consider beneficial (i.e. increased transparency resulting from reduced algal biomass and, in particular, of blue−green species) according to Shapiro (1990, 1995).

The biota indicates "the fish". The fish thus implies diet types "piscivores" or "plankivores" according to originally conceived schema (Fig. 1) in a pelagic ecosystem (Shapiro, 1995).

The manipulation means fish stock regulation from experimental ecosystems by means of methods following;

- piscivore addition,
- piscivore catch restriction,
- piscivore removal,
- planktivore addition,
- planktivore exclusion,
- planktivore removal:
  - selective catch,
  - lake emptying/ refilling,
  - fish poisons/ toxins (e.g. rotenone),
  - disease,
  - winterkill (e.g. higher temperature than normal), and
  - summerkill (e.g. lower temperature than normal),
- habitat enhancement,
- habitat expansion or contraction, and
- 'Mother Nature' (i.e. happens naturally) (Shapiro, 1990).

Due to the very flexible methods described, biomanipulation includes fortuitous experiments *a priori* (Shapiro, 1990). It is considered as a biomanipulation, for example, in case that fish elimination occurred in a lake by accident without changes in nutrient loading, and it led to water clarity improvement resulting from either an increase in zooplankton biomass (Vanni *et al*., 1990) or a dramatic decline in phytoplankton biomass (van Donk *et al*., 1989). Moreover, biomanipulation (a simple lake restoration technique at the beginning) had an opportunity to become a practical ecosystem theory linking with "cascade trophic interactions" (Carpenter *et al*., 1985). This demonstrated that fish has an effect on phytoplankton biomass and productivity by whole−lake experiments. Predator influences were previously observed in fish ponds (Hrbáček *et al*., 1961). In effect, biomanipulation integrated predator effects and becomes a representative for "top−down" theory with experimental evidences. It may be important to emphasize experimental evidences unlike "bottom−up" hypothesis (i.e. to avoid a probable confusion, the latter hypothesis has been used to give a diagnostic for a trophic status rather than to perform an experiment in lakes).

Up to the mid 1990's, biomanipulation was mainly performed in 'shallow' *sensu* Reynolds (1994) (e.g. maximum depth $<$3 m), small (e.g. $<$25 ha), and eutrophic lakes or reservoirs. It generally resulted in successful water quality improvement for at least a short−term (i.e. one or two years) (Gophen, 1990; Gulati *et al*., 1990; Lammens *et al*., 1990; Philips and Moss 1993; Reynolds, 1994; Shapiro, 1995; Pijanowska and Prejs, 1997).

FISH REMOVAL BIOMANIPULATION

There are fewer biomanipulations carried out in deep stratified lakes than in shallow lakes. McQueen (1998) summarized some positive biomanipulation effects on deep and stratified lakes and stressed on the importance of "planktivore removals". Planktivore removals in deep stratified lakes frequently result in initial food web mediated reductions in algal standing stocks. The controversies that have surrounded the interpretation of aquatic food web biomanipulation experiments typify the importance of recognizing the unique physico−chemical characteristics of particular aquatic environments. Three different types of food web biomanipulations that have been reported are planktivore additions, planktivore removals (Meijer *et al*., 1990 reviewed in

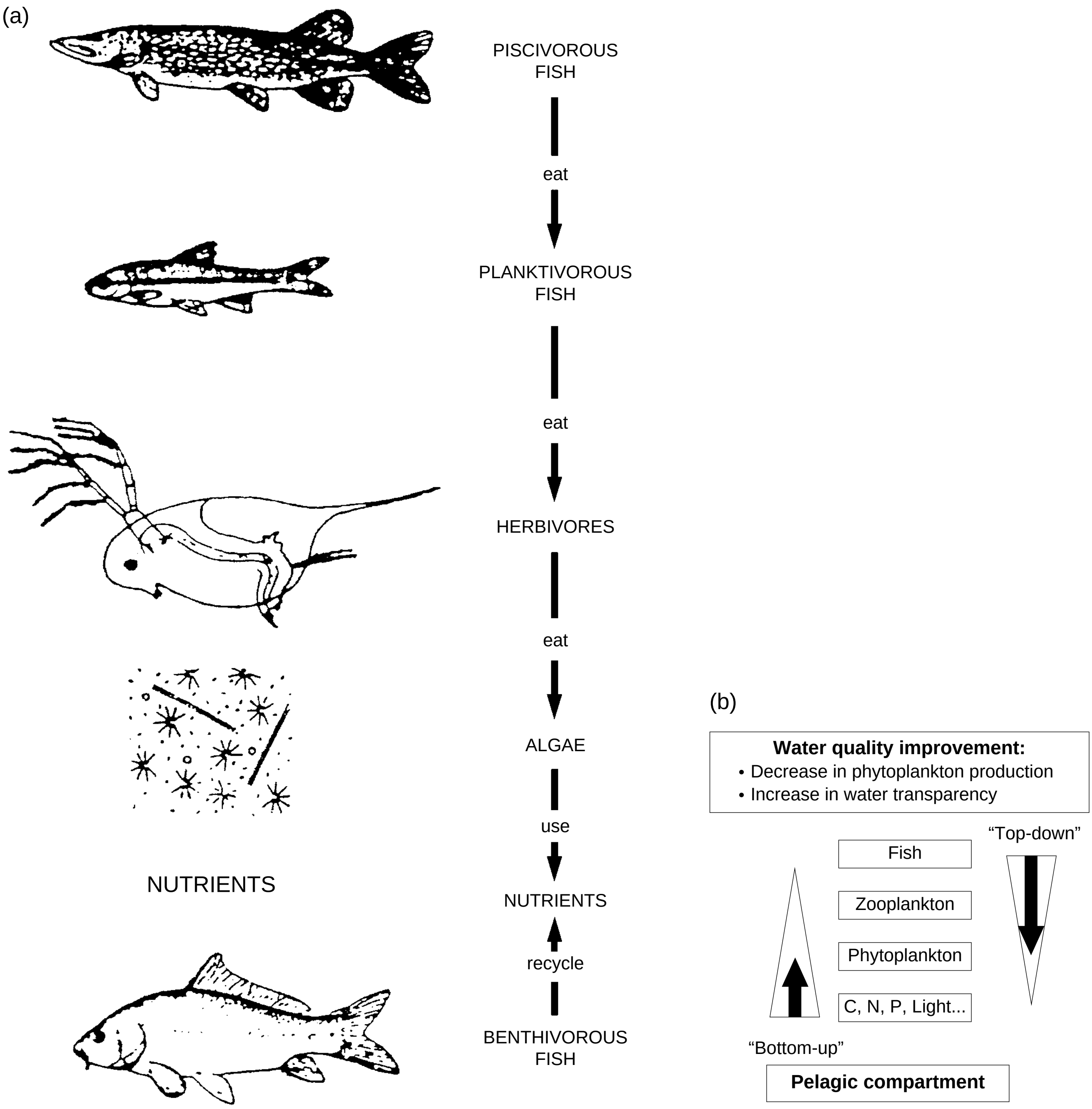

Fig. 1. Originally conceived schema and redrawing by Shapiro (1995) for biomanipulation (a) and simply idealized "bottom–up/top–down" forcing schemas for water quality improvement in a pelagic ecosystem (b).

Gulati *et al.*, 1990; Søndergaard *et al.*, 1990; Jeppesen *et al.*, 1997) and control of planktivorous fish with piscivore stocking.

• Planktivore removals in shallow lakes:

In general, such manipulations are associated with decreased phosphorus concentrations (Meijer *et al.*, 1990; Søndergaard *et al.*, 1990), decreased bioturbation (Breukelaar *et al.*, 1994), increased abundance and size of zooplankton (Meijer *et al.*, 1994; Jeppesen *et al.*, 1997), increased grazing pressure on algae (Meijer *et al.*, 1994; Jeppesen *et al.*, 1996; Jeppesen *et al.*, 1997) and increased growth of macrophytes (van Donk *et al.*, 1990; Meijer and Hosper, 1997). Most planktivore removals have involved pond draining or netting and showed improvements in water quality associated with increased zooplankton biomasses and body sizes, and reductions in chlorophyll *a* (Shapiro *et al*., 1975; Stenson *et al*., 1978; Shapiro and Wright, 1984; Pijanowaska and Prejs, 1997; Prejs *et al*., 1997). However, the authors have suggested that prior to rotenone treatment, stocking YOY (young of the year) piscivores had no effect on zooplankton or water quality but after rotenone was applied, newly stocked YOY seemed able to control *Daphnia* (zooplankton) body size and densities (McQueen, 1998).

• Planktivore removals from deep stratified lakes:

In stratified lakes, complete planktivore removal (Stenson *et al*., 1978; Shapiro and Wright, 1984; Francisco and Tourenq, 1997; Chung, 2001) but long follow−ups are rare (Reinertsen *et al*., 1990). Without exception, these experiments initially resulted in much lower algal biomass and clear water conditions. These studies were rather short−term (2～3 years post− manipulation), and cases of algal species substitutions (Kasprzak *et al*., 1993) or increased invertebrate predation on zooplankton grazers (Benndorf, 1995) are likely based on the results of some long−term piscivore removal manipulations (McQueen, 1998).

Based on the results, it seems likely that biomanipulation success depends upon both treatment (i.e. decrease in nutrient loading and/ or fish manipulation based on 'bottom−up' and 'top−down' hypotheses) and the lake type (i.e. lake depth, trophic status, and time scale). The order of likely success is (McQueen, 1998):

(1) complete planktivore removal from shallow lakes or ponds,

(2) complete fish removal from stratified lakes,

(3) piscivore−induced fish removal from shallow lakes and ponds,

(4) piscivore−induced removal of planktivores from deeper lakes.

The key success in deep lakes is to find ways to promote sustained high levels of zooplankton grazing (McQueen, 1998).

Recently, the complexity of the ecosystem response and the role of "bottom−up" forces and/or nutrient−mediated effects of planktivorous fish on plankton community structure were integrated into biomanipulation research (McQueen *et al*., 1986; Benndorf, 1995; Lathrop *et al*., 1996).

Fish removal biomanipulation (Edmonson, 1994a, Edmonson, 1994b; Hanson and Butler, 1994; Benndorf, 1995; Vighi *et al*., 1995; Francisco and Tourenq, 1997; Goldyn *et al*., 1997; Horppila *et al*., 1998) was successful about 40% (chlorophyll *a* and water transparency improvement after the biomanipulation) according to Drenner and Hambright (1999).

Nowadays positive biomanipulation effects in nutrient dynamics are applied to even in marine ecosystem management (Hjerne, 2002).

PERSPECTIVES

For practical applications of biomanipulation in lake (reservoir) management, further development and understanding of the food web research under the specific lake condition are needed (e.g. sustained low cisco biomass for continued water quality enhancement in Lake Mendota: Johnson and Kitchell, 1996). It might be very important to perceive restrictions and conditions before a manipulation in order to obtain successful results for at least a short−term.

The question is how we can maintain the positive effects resulted from biomanipulation (fortuitous or planned) for a long term in any shallow or deep waterbodies (Shapiro, 1995; McQueen, 1998).

FURTHER READINGS

There are two excellent special issues published, which are dedicated to the past and present biomanipulation research results and trends with ample case studies and hypotheses developed:

(1) Hydrobiologia, 1990. vol. 200/201.

(2) Freshwater Biology, 2002. vol. 47 (12).

ABSTRACT

For some decades eutrophication poses a great problem in water quality management in freshwaters. To solve this problem, studies based on "bottom−up" hypothesis have been mostly carried out worldwidely unlike biomanipulation. This implies that not only fish but also fish stock play

a key role down to other food web components in pelagic ecosystem. It is generally accepted that biomanipulation becomes a potent tool for eutrophication control. For a practical application of this, however, further development and understanding of the food web under the specific lake condition on a whole-lake scale are needed. The question is how can we maintain the positive effects resulted from biomanipulation (fortuitous or planned) for a long period.

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