

**Review Article**

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Advantageous and Disadvantageous of Non-Classical Biomanipulation

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In classical biomanipulation, piscivores fish is introduced to a water body which fed on planktivorous fish and causes an increase in the numbers of zooplankton and zooplankton by feeding on phytoplankton roots to reduction in algal blooms. In contrast, during non-classical biomanipulation piscivores fish is removed from the water body and planktivorous fish is introduced which fed on all kinds of plankton and led to improving the water quality parameters by reducing nuisance algae. Here, we examine the management of water quality parameters through non-classical biomanipulation by identifying problems and extract recommendations. Preference is given to non-classical biomanipulation due to certain hindrances with traditional biomanipulation such as planktivorous fish removal, increase in numbers of macrophyte and decrease in phosphorous (external and internal), respectively. In fact, non-classical biomanipulation can also be used to control algal blooms in tropical, highly productive lakes, where reduction in nutrient concentration is almost impossible. In spite of overlapping prey and predator spaces in closed environments, such as in tanks and ponds, similar results of non-classical biomanipulation were also obtained in lake ecosystems as well. Non-classical biomanipulation changed the community composition of phytoplankton at the start of trial in both enclosed water bodies and lakes. In our review of 30 studies, 63% of studies demonstrated successful control of phytoplankton with non-classical biomanipulation. Microcystis blooms were controlled efficiently by two planktivorous fish, bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*Hypophthalmichthys molitrix*), in Lakes Qiandaohu and Donghu, respectively. Eutrophic waters that lack sufficient concentration of macrozooplankton can be effectively managed through planktivorous fishes, such as bighead and silver carp. Non-classical biomanipulation is confirmed as an effective tool for the control of those nuisance algal blooms that cannot be controlled efficiently by large bodied herbivorous zooplankton while ineffective with blooms of nanophytoplankton species.

Keywords: Non-classical biomanipulation, Classical biomanipulation, Bighead Carp, Silver Carp, Algal blooms, Filter feeding fish, Planktivorous.

Efficacy of Control of Blue-Green Blooms through Non-Classical Biomanipulation

Restriction of Classical biomanipulation:

Powerful indirect interactions in ecosystems can easily change the organization of an aquatic ecosystem [1, 2]. Biogeochemical cycles of marine ecosystems depend upon trophic forces [3,4], as demonstrated experimentally by biomanipulation [5]. Classical biomanipulation, used to manage water quality of lakes, involves increasing zooplankton populations, especially *Daphnia* species that usually feed on phytoplankton [6]. Classical biomanipulation can also be achieved through change in community structure by eliminating planktivorous fish (to increase zooplankton

populations) and favoring piscivorous fish. Shift in community structure can be achieved by five different methods that can be used collectively or separately: decrease in water level, fish poisoning, fish winter killing, removal of fish and piscivorous fish stocking [7]. It is evident that zooplankton can control phytoplankton, but results can be variable [7-14], as compared to planktivorous fish [5, 8, 15, 16]. Due to peculiar processes and structures which are highly variable, outcome of biomanipulation is difficult to measure quantitatively. Certain factors should be considered for the successful implementation of classical biomanipulation, such as continued elimination of planktivorous fish and low concentration of phosphorus [17], to decrease phytoplankton amount, and high

numbers of macrophytes to maintain water quality [18,19]. Thus, for long term success, such biomanipulation should be restricted to certain types of lakes [20, 21].

Non-Classical Biomanipulation: Use of Planktivorous Fish

Scientists have discovered other methods to control the eutrophication of lakes containing blooms of cyanobacteria as compared to classical manipulation which utilized planktivorous zooplankton. Different studies also determined that large sized zooplankton are more efficient in elimination of algae than smaller [22]. Many studies also found that increase in eutrophication due to cyanobacterial blooms in summer is caused by decrease in numbers of zooplankton especially *Daphnia* [23, 24]. Zooplankton concentration, composition and growth are also effected by toxic cyanobacteria [25]. In eutrophic lakes where concentration of zooplanktons usually decreases in summer and concentration of algal blooms increase rapidly, we can adopt an alternative approach such as use of planktivorous fish for direct elimination of algal blooms which proved very efficient, respectively [26, 27]. Planktivorous filter feeding fish engulf phytoplankton with large quantities of water and filter them from it in buccal cavity eating more than one prey at a time [27]. Filter feeding silver carp is obligatory planktivorous eating only phytoplankton and small particles [28,29]. Studies showed that filter feeding bighead carp is mainly feed on zooplankton [27,30] but shifted its feeding regime towards phytoplankton during unavailability of zooplankton [27,31].

Use of planktivorous fish as contrast to piscivorous fish for elimination of blue green algae had been done in closed water body and open lake ecosystem as well. Around sixteen studies [31], found the successful elimination of algae blooms with silver carp and some studies observed no or adverse effect [32-34]. Certain studies lead to controversial situation on the use of silver carp for the management of phytoplankton that increase their number instead of ceasing them [35,36]. Gut content analysis of laboratory fed silver carp demonstrated consumption of phytoplankton and zooplankton but not algae [37]. Moreover, silver carp are behaving like omnivorous instead of planktivorous. While, during high concentration of phytoplankton silver carp feed like omnivorous and epibenthic browser at low concentration, respectively [38]. However, the change in dynamics and structure of phytoplankton community by filter feeding planktivorous fish through biogeochemical process, predation and zooplankton grazing is well documented. Biogeochemical recycling by filter feeding fish led to two types of factors [39]. Consumption of nutrient by phytoplankton is interacted with planktivorous fish by recycling of nutrient [40]. Indirect prove of nutrient cycling by planktivorous fish was found in different studies [41]. Conversely, nutrient cycling by zooplankton grazing is determined [42]. Literature confirmed that use of planktivorous fish proved successful for the manipulation of phytoplankton. Although, role of zooplankton can also be never separated in lake ecosystem [43].

Phytoplankton Concentration Dynamics Impacted by Nutrient Fluctuation

Algal blooms were observed in St. George Lake (Maine, United States) through nutrient cycling by planktivorous fish [43]. Planktivorous fish did not affect the concentration of zooplankton directly, but rather increased the availability of nutrients by recycling [43,44]. Small sized algae compete with larger sized algae for nutrients, while better surviving the grazing and absorbing more nutrients which are recycled by fish [45]. These factors caused the shift of algae dynamics towards small algae [41]. However, some researchers believed that insufficiency of phosphorous produced from feces of fish in natural ecosystem to alter algae dynamics as high phosphorous rapidly led to bloom [40]. Similarly, recycling of nutrients by zooplankton is another debate. There is also uncertainty in the response of algae to zooplankton and planktivorous fish recycled nutrients [46]. Planktivorous fish led to reduced biomass of zooplankton in contrast to prior studies [43], while nutrients were recycled primarily by zooplankton. Reduction in zooplankton concentration by planktivorous fish is not determined but higher excretion rate was found in small zooplankton as compared to fish [47]. It is believed that nutrient cycling increased indirectly by planktivorous fish by reducing zooplankton biomass. However, phytoplankton production increased exponentially by nutrient recycled by both zooplankton and planktivorous fish respectively [48]. Therefore, different mechanisms such as zooplankton interaction with fish and fish response to phytoplankton would affect the dynamic of phytoplankton [42]. It has been observed that some algae species such as *Aphanizomenon* and *Microcystis* which are majorly causes of nuisance blooms get their required phosphorus from gut of planktivorous fish [49]. Further, it was confirmed that *Microcystis* covered with mucosa remain protected from digestion in gut of planktivorous fish and consume phosphorous required for their growth [50]. While, planktivorous fish as bio cultivar [51] for this bloom forming algal species and increase their survival and photosynthetic ability [51,52]. Incubation of *Microcystis* into a lake collected from feces of bighead carp, silver carp and tilapia led to eight times increase in colonies cyanobacteria[50]. In contrast to previous studies which were conducted in in-vitro conditions, colonies of *Microcystis* broken down to single cell in gut of planktivorous fish [53]. In vivo circumstances are totally different and feces containing broken colonies of *Microcystis* settle at bottom. Several factors are required to release colonies from faces and planktivorous fish has negative effect on algal blooms.

Higher Trophic Level Suppression through Predation

Zooplankton can be suppressed directly by grazing of planktivorous fish and indirectly by decreasing the amount of biomass of algae [45]. Planktivorous fish always led to shift in the community of zooplankton by increasing the density of small zooplankton, such as *copepods* [54]. The presence of planktivorous fish proved advantageous for the growth of nanophytoplankton and picophytoplankton, as the fish predated on macrozooplankton. This factor ultimately led to an increase in numbers of phytoplankton

by suppressing their predators, zooplankton [55]. Alternative situations were observed in eutrophic lakes of subtropical region where silver carp easily controlled the number of phytoplankton and boosted the density of Nano zooplankton [27]. Planktivorous filter feeding fish caused suppressing of zooplankton which is confirmed by numerous studies [26,27,40]. Eight gram per meter cube ($8\text{g}/\text{m}^3$) is optimum density of silver carp. Below this density, an increase in growth efficiency of phytoplankton causes a harmful effect on the growth of herbivorous zooplankton. Under low water temperatures, the filter feeding efficiency of silver carp remains constant while cyanobacterial blooms are not enough [56]. Reduction in colonial phytoplankton density was observed in the presence of silver carp, despite the presence of crustaceans, due to their selective grazing on small sized phytoplankton [57]. Biomanipulation with silver carp is only efficient at eliminating the algal blooms that cannot be eliminated by herbivorous zooplankton [58]. Isotopic techniques estimate around 45% assimilation rate of *Microcystis aeruginosa* in silver carp [59]. Similarly, silver carp's growth and ingestion were noted while fed with toxic species of *Microcystis* in controlled environment [60]. However, in Taihu Lake fast growth of silver carp was observed with consumption of toxic phytoplankton such as *Microcystis* up to 84.4% of total phytoplankton consumption [61].

Historical background of non-classical biomanipulation with planktivorous filter feeding fish especially bighead and silver carp regarding water quality management is presented. Through small scale and large-scale experimentation for lake recovery by non-classical biomanipulation was estimated. Due to variation in result of different studies, it is needed to study different lakes with different changing parameters such as composition of food web, trophic condition, geochemistry and development of littoral

zone [62]. Spatial and time-based restriction in field experiments led to inappropriate interpretation [63]. These problems can be diminished while studying whole scale community but that is impossible logistically and not quite often. Similarly, same determining factors such as planktivorous fish and nutrients observed in lake experimentation as well [43].

Drawing of theory through small-scale Experiments

Since 1975, almost thirty studies have evaluated the effect of planktivorous fish, such as bighead and silver carp, on the control of phytoplankton. Of those, 63% of studies demonstrated control of phytoplankton with non-classical biomanipulation [27, 37, 54, 57, 62], 9 studies showed no significant change on phytoplankton density [40, 45, 64] and several studies showed no effect on planktivorous [65, 66] (Table 1). The following are the major factors that led to inconsistency in non-classical biomanipulation: temperature [67], stocking density of planktivorous fish [68], composition of phytoplankton community and initial composition of zooplankton [48,67]. Thirty experiments (Table 1) varying in fish stocking density from 0.74 to $480\text{ g}/\text{m}^3$ showed no significant relationship of increasing density with reduction of algal blooms. Due to overlapping of planktivorous fish and nutrients, neither of those variables are considered to be a determining factor for the control of phytoplankton [27]. Initial density and composition of phytoplankton and planktivorous fish behavior should be considered for successful management. Diversity in food selection was noted by silver carp [56], which depends solely and strongly on the type of food available in the environment including zooplankton and phytoplankton [69,70]. Silver carp led to reduction in chlorophyll if net phytoplankton dominated the macro phytoplankton density and gain in chlorophyll noted when phytoplankton density is occupied by nanophytoplankton.

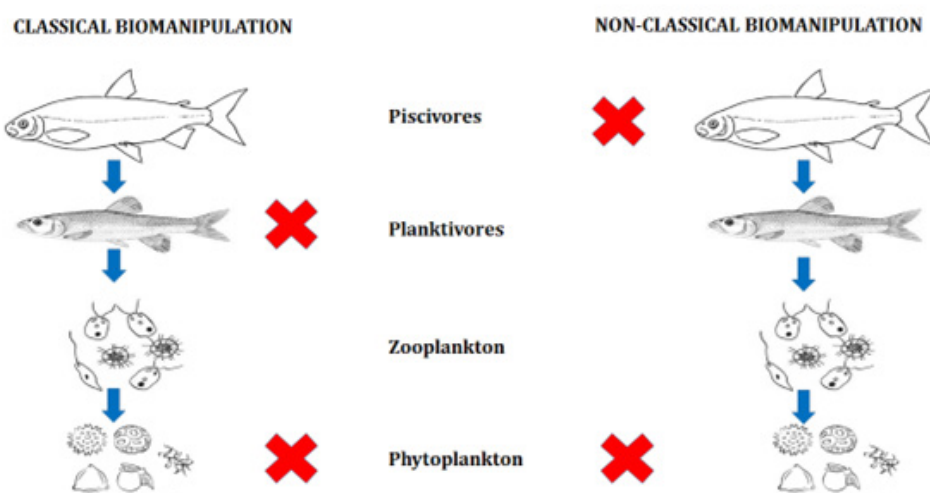


Figure 1: Systematic diagram of classical and non-classical biomanipulation.

Table 1: Effect of planktivorous fish on zooplankton and phytoplankton density and total phosphate in small scale and large-scale experiments

Species	Reference	System	Stocking density (g per m ³)	Carps Effects		
				Plankton Density	Zooplankton Density	Total Phosphate
Silver Carp	(45, 75)	Tanks	100g/m ³	Reduced	Reduced	Not evaluated
	(27, 76)	Pound	32.4g/m ³	Reduced	Weekly affected	Reduced
		Enclosures	21-33	Reduced	Not evaluated	Not evaluated
	(77)	Enclosures	<27	Reduced	Enhanced	No effect
	(66)	Enclosures (summer)	10	Reduced	Reduced	Reduced
	(78)	Enclosures	480	Reduced	Not evaluated	No effect
	(79)	Tanks (Fiberglass)	41	Reduced	No effect	No effect
	(80)	Enclosures	30-90	Reduced	Reduced	Not evaluated
	(81)	Enclosures	5.5-9	Reduced	Reduced	Enhanced
	(82)	Ponds	1.56	Reduced	Not evaluated	Not evaluated
	(83)	Enclosures	46.5-126	Reduced	Reduced	No effect
	(84)	Enclosures	9.1-78	Reduced	Not evaluated	Not evaluated
	(85)	Aquarium	30	Reduced	Reduced	Reduced
	(86)	Enclosures	75	Reduced	Enhanced	Reduced
	(87)	Enclosures	55	Reduced	Reduced	No effect
	(74)	Enclosures	10	Enhanced	Reduced	Enhanced
	(68)	Mesocosms	8	Enhanced	Reduced	Not evaluated
	(88)	Ponds	0.7	Enhanced	Reduced	Not evaluated
	(89)	Ponds	16.2-29	Enhanced	Reduced	Not evaluated
	(90)	Enclosures	>76	Enhanced	Not evaluated	Not evaluated
	(91)	Ponds	4.6	Enhanced	Not evaluated	Not evaluated
	(66)	Enclosures	3-15	No effect	No effect	Enhanced
	(65)	Ponds	0.6-2.1	No effect	Not evaluated	Not evaluated
Bighead Carp	(76)	Enclosures (1989)	365	Reduced	Reduced	Not evaluated
		Enclosures (1992)	69-75	Reduced	Reduced	Not evaluated
	(78)	Enclosures	432	Reduced	Not evaluated	No effect
	(92)	Ponds	60-97	Reduced	Reduced	Not evaluated
	(27, 93)	Ponds	32.4g/m ³	Reduced	Weakly affect	Reduced
	(85)	Aquarium	30	Enhanced	Reduced	Reduced
	(76)	Donghu lake	46-50	Reduced	Reduced	Not evaluated
	(94)	Qiandaohu lake	1.5-7.4	Reduced	Not evaluated	Reduced
	(95)	Taihu lake	40	Reduced	Reduced	No effect
	(96)	Natofa Reservoir	0.05-0.6	Reduced	Reduced	Not evaluated
	(97)	Yuehu lake	<9.8	Reduced	Not evaluated	Enhanced
	(29)	Kinnerat lake	11×10 ⁶	Enhanced	Reduced	Not evaluated
	(98)causes, consequences</title><secondary-title>Hydrobiologia</secondary-title></titles><periodical><-full-title>Hydrobiologia</full-title></periodical><pages>185-192</pages><volume>504</volume><number>1</number><dates><-year>2003</year></dates><isbn>1573-5117</isbn><urls></urls></record></Cite></EndNote>	Saidenbach Reservoir	300kg/ha	Enhanced	Reduced	Not evaluated

Classical biomanipulation was more successful in shallow water bodies as compared to deep water bodies [71, 72] while this factor's impact upon non-classical traditional biomanipulation is not confirmed. However, shallow water bodies lead to overlapping of space which causes increased predator-prey encounters [73]. One non-classical biomanipulation study was conducted in deep water bodies where decreased zooplankton density and increased phytoplankton was noted [74]. Previous studies confirmed that phytoplankton density determined success of non-classical biomanipulation, not the depth of water system [74]. However, for the successful implementation of biomanipulation, phytoplankton composition and density should be noted critically. Non-classical biomanipulation technique can be used for successful maintenance of lakes with high temperature having high density of blue-green algae. Another important concept is that small scale experiments can be helpful in estimation of points, but it should not be applied to large scale experiments [62].

Efficiency of Large-Scale Experiment

Bighead and silver carps are native to eastern Asia and introduced worldwide for culturing purposes and commonly poly-cultured with other fishes [99]. In spite of non-classical biomanipulation for the control of algal blooms, other ecological impacts of bighead and silver carps are not known. Since 1970, bighead and silver carp have been used for control of algal blooms and maintaining water quality in lakes, sewage lagoons and ponds, respectively. Due to the high bone ratio in silver carp and low market demand of these two fish (bighead head and silver carp), people only fish them when other options are not available. Due to the introduction of these fish from Asia, most countries treated them as pest species [65]. Introduced species proved very vulnerable to indigenous species because of no natural predators [100], and introduction proved feasible in community lacking fish species. Invasive species led to changes in ecosystem from mild to very severe viz., hybridization and alteration of habitat and trophic system [101]. In USA, for the protection, welfare and maintenance of indigenous species, the silver and bighead carp are listed in harmful species by Fish and Wildlife Service of the United States, 2007. We describe invasive species as introduced or non-native to ecosystem and cause environmental and economic losses as well as to human health. Just because of high survival and reproductive rate can easily dispersed to wide area. With the establishment of bighead and silver carp in riverine system, it is likely that they can move to lakes as well. Therefore, the stocking of fish should be taken place in proper and effective manner. However, the population of silver and bighead could be kept in check because carps required floating water for the proper development of eggs. If further stocking is stopped, this will lead to gradual decline in fish population respectively. Therefore, silver and bighead carp can be used for maintenance of water quality in eutrophic lakes, respectively.

Inefficient and inappropriate non-classical biomanipulation results of long-term large-scale experiment in lake were determined [29,98] and around five experiments produced efficient and successful results [76, 94-97], as given in (Table 1). Enhancing

numbers of indigenous (perch & roach) and exotic (silver carp) planktivorous fish led to decrease in numbers of zooplankton (*Daphnia*) and increases the density of nanophytoplankton in Ziebach Reservoir of Germany [45]. In lake Pyhajjarvi, change in zooplankton composition led to increase in density of phytoplankton [31,102]. These couple of studies found that a stronger interacting force exists between zooplankton and phytoplankton as compared to phytoplankton and planktivorous fish. Planktivorous fish cause a decrease in density of zooplankton which ultimately boosts the density of small sized phytoplankton which further cause turbidity in water. Similar results were also noted in lake Kinneret of Israel where introduction of fingerlings of silver carp led increase in density of nanophytoplankton by reduction in numbers of zooplankton, respectively [45].

However, successful non-classical manipulation was observed in five different studies in which lakes and reservoirs were bothered by blue green algae and *Pyridinium*. Cyanobacterial blooms in lake Donghu were successfully eliminated by silver and bighead carp for almost twenty years by gradually increasing the fish density (0.09-0.11 per m²) to eliminate *Microcystis* as well as irritating algae, respectively [50]. Nutrients from feces of planktivorous fish are not easily available and optimum for phytoplankton production. So, it proved that nutrients from waste are not important for fish growth [103]. If planktivorous fish feed on zooplankton, then there is a low amount of phosphorous in their bodies and if they fed in littoral zone then high amount of phosphorous available to phytoplankton [104]. The quantitative measurement of nutrient recycling by fish is possible in control or laboratory condition and impossible to measure in natural environment due to dynamic interaction between different food webs.

Experiment in lake Qiandaohu, researcher observed total elimination of algal blooms due to reintroduction of bighead and silver carp. However, decrease in density of planktivorous fish led to cyanobacterial blooms [105]. Similarly, successful biomanipulation with these two carps are also confirmed in lake Taihu at the start of twenty first century [106] and these fish are commonly used in China for biomanipulation, respectively. During summer, a trial was conducted to evaluate the effect of increased stocking density of fish on *Microcystis* which proved successful. Very slight pathological changes by *Microcystis* in spite of high blooms were noted in liver of silver carp during study lake Taihu [107]. Fast recovery in liver and kidney tissue of silver confirmed the resistance of silver carp to the toxic cyanobacterial blooms [61,108,109]. That's why, its universal truth that silver carp can be efficiently used for the elimination of *Microcystis* blooms and recorded up to 93%, respectively [58]. Change of feeding habitat of organism in lake ecosystem by planktivorous fish make very difficult to made sound prediction of manipulation [110]. Detailed study on food web interaction is required for sound interpretation. Every natural and anthropogenic change in ecosystem has its uniqueness because two lakes can never be same [111]. Because inconsistency in results of large scale experiments regarding water turbidity and fish on phytoplankton, small scale trials are necessary for analyze the management and complexity of food web which set a tool for enhancing water quality through non-classical biomanipulation effectively.

Conclusion

As we know, two different water bodies have their own unique characteristic ecosystem. Although, effectiveness of non-classical manipulation was observed in small scale trials and not as such in large scale. It is because of the complexity of the ecosystem and involvement of different factors such as different interaction in food web. We inference from present review of literature that eutrophic lakes containing blue green algae can easily be maintained by non-classical manipulation except water bodies having nanophytoplankton.

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Conflict of Interest

Author declares no conflict of interests.

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