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Evaluation of Algae Removal Technologies and Suggestion for Field Application

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Abstract

While various algae removal technologies have been developed, it is still difficult to choose an appropriate method for a given on-site condition, such as the period of the onset and the extent of algal bloom. In Republic of Korea, domestically developed technologies were categorized into physical, chemical, biological, and convergent controls. It was found that 32.2% of the domestic technologies employed physical controls, such as water circulation etc., and 25.0% utilized chemical controls such as coagulants etc. Biological methods, including the use of microbial culture, zooplankton (using grazing systems) and wetland, accounted for 21.4%. Also, most of these algal removal technologies were designed for "Attention" and "Warning" stage, while only 21.4% were deemed applicable to "Mass occurrence" stage. In conclusion, it was found that the frequency of choosing a removal technology was evenly distributed in the early and preventive phase of algal bloom, while chemical removal was the most popular choice in cases of significant algal bloom.

Keywords: Algal bloom; Algae removal technology; Classification; Algae growth

Introduction

In the face of climate change, continuous influx of nutrients into domestic water systems and increased hydraulic retention time due to the construction of river-crossing structures during the 'Four Major Rivers Project (2009-2013)', excessive proliferation of algae in large rivers and lakes has been observed in Republic of Korea [1,2]. It was reported that the year-round algal bloom has significantly damaged the natural habitat for aquatic organisms, due to increased turbidity in water systems, depletion of dissolved oxygen, and formation of [3-6]. Furthermore, odor and toxic substances generated by certain algal species has also compromised the value and quality of water resources [7]. Water temperature, light intensity, nutrients, water velocity, and stratification have often been cited in many previous studies as major factors that affect algal growth [8-11].

Algae removal methods utilizing various techniques have been developed and put into practice both internationally and domestically to improve the quality of water resources and reduce the risks of contamination. However, a complex interplay

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of numerous environmental factors is responsible for algal growth, implying that the likelihood of algal proliferation and severe algal bloom are determined by climate, morphology of basin, waterbody characteristics, and other physical, chemical, and biological factors [2].

To effectively control the algae, we necessitate the implementation of algae removal technologies customized for each site. In Republic of Korea, most domestically developed algae removal technologies, although effective in short-term and small regions, are not sustainable and cases of successful implementation are few especially in main rivers, where seasonal and hydraulic conditions fluctuate significantly [2]. This study aimed to investigate the domestic and international trends in the development of algae removal technologies with effective algae reduction and growth control capabilities that have low environmental risk on aquatic systems, and how such techniques may be employed.

Materials and Methods

This study focuses on 32 technologies that have commercialized for algae removal technologies in Republic of Korea. We have tried to classify the technical status of the algae removal technologies in many respects (characteristic, usability, economy etc.) that is being used in Republic of Korea and to find a technical supplement and review of the algae management policy in the future from a larger perspective. Also, we investigated the algae management technology of overseas and examined whether it could be used for related work.

According to our research method, algae removal methods applied previously and those currently in use domestically and internationally were categorized into four classes, physical, chemical, biological, and convergent controls (controls that make use of two or more independent technologies), depending on their theoretical principles. Examples of physical controls firstly include category of water circulation, filtration, and ultrasound. More specifically, physical controls has water circulation devices (spraying, impeller, ship etc.) and some micro technologies. Chemical control is a technique that uses chemical reactions to interfere with or inhibit algal growth. Chemical techniques comprise coagulants, photo-degradation, plasma, naphthoquinone, and some filtration technologies in this study. Biological techniques may include microbial culture, zooplankton (using grazing systems) and wetland.

In this regard, the classification system of all technologies refer to the “Enforcement rule of the law concerning the preservation of water quality and aquatic ecosystems (No. 543, Ministry of Environment)” article 7 annex 5 in Republic of Korea in this study.

In addition, we considered the stepwise algae bloom period to apply the technologies. The algal bloom period was divided into three phases based on the algae bloom alert system in use domestically. Classification of the algae bloom alert system is important criteria because it is possible to respond to the situation according to the algal bloom. The first phase includes “Attention (blue-green algae cell count over 1,000 cells/mL)” and the second and third phases correspond to “Warning (blue-green algae cell count over 10,000 cells/mL)” status and “Mass occurrence (blue-green algae cell count over 1,000,000 cells/mL)” status respectively. In view of these parts, we reclassified the appropriate technologies at the time of the occurrence of the algae bloom alert system.

Results

Classification of algae removal technologies

In this study, the distribution of the domestic algae removal technologies was as follows: physical controls 32.2%, biological controls 21.4%, chemical controls 25.0%, and convergent controls 21.4% (**FIG. 1**).

Physical controls are roughly divided into four types, water circulation 55.6%, ultrasound 22.2%, micro bubble 11.1%, and filtration 11.1%, and most of the physical controls utilized were water circulation and mechanical mixing. Biological controls method was increasing resource competition. Biological controls are showed by three types, microbial culture 50.0%, wetland 33.3%, and zooplankton 16.7%, respectively. Chemical controls are represented by five types, coagulants 42.9%, photo-degradation 14.3%, plasma 14.3%, naphthoquinone 14.3%, and filtration 14.3%. For convergence controls, the combination of physical and chemical processing methods proved to be the most common. Convergence controls are divided into three types, micro bubble 50.0%, harvesting ship 33.3%, and microbial culture 16.7%. Many of these technologies were being applied to small ponds and lakes, while those applied to river were limited to mechanical mixing, coagulation, and floating artificial wetlands.

According to the results, physical controls showed the highest rate and biological controls showed relatively low rate. In detail, the water circulation of the physical control showed the highest portion, and the micro bubble showed the lowest portion. But, in case of micro bubble also can be seen that it is widely used by convergent control.

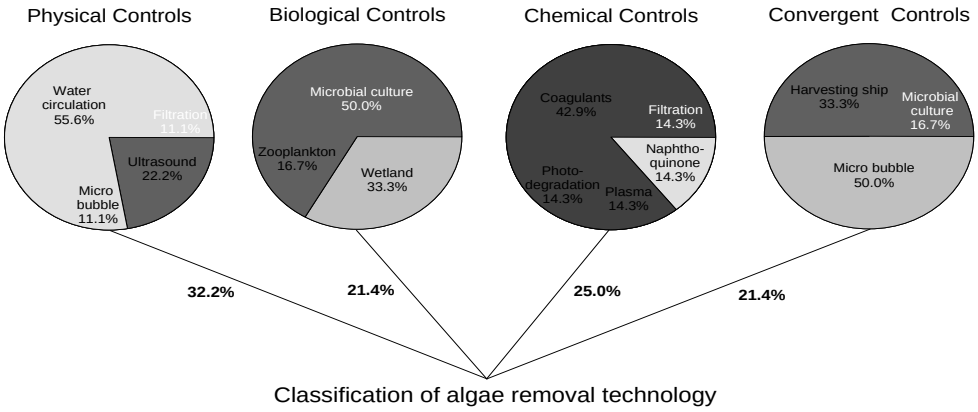

FIG. 1. **Classification of algae removal technologies on Republic of Korea (Byeon et al., 2016).**

Analysis of algae technology for application phase

According to algae bloom alert system, there are three major stages of algal bloom in Republic of Korea. In Republic of Korea, Chl-a was designated as the standard for issuing the algae bloom alert system, but it has been revised to the number of cyanobacterial cells as main parameter since 2016.

In this study, distribution of algae removal technologies according to the stage of the algae bloom alert system represent in **TABLE 1.** In the "Attention" phase have physical and biological controls in high rate (respectively 66.7%, 50.0%). And "Warning" phase have biological and convergent controls in high rate (respectively 50.0%, 50.0%). But, "Mass occurrence" phase have Chemical control in high rate (57.1%), and physical and biological controls had no data.

In other words, during the early stages of the algal bloom, the periods of "Attention" and "Warning" was primarily applied by the physical and biological controls, but, during the last stage of the algal bloom, the period of "Mass occurrence" was primarily applied by the chemical control.

Also, the rate of technologies are developed and concentrated on "Attention" and "Warning" periods in the early stages for algal bloom (respectively 35.7%, 42.9%). But, the rate of technologies in "Mass occurrence" period represented a low value than the early stages of the algal bloom (21.4%). This means that there is a relatively shortage of algae removal technologies that are appropriate for the peak time of algal bloom. Therefore, it can be seen that post-management techniques for last stage

of algal bloom are important in the future.

Therefore, algae removal technologies are important according to the period of onset of algal bloom. If the method is focused on curbing algal growth in early stage rather than direct removal of algae, then it would be suitable to employ the method prior to the onset of algal bloom. In cases where some extent of algal growth has been observed, both algae removal and control must be carried out in cooperation.

Also, in algae bloom alert system, at "Warning" status, or the second phase, in which algae formation and proliferation occur simultaneously, algae removal and growth control must be carried out concurrently. Since effective algae control cannot be achieved simply by water circulation, additional techniques like ultrasound, coagulation, and barley straw must be utilized together. At "Mass occurrence" status, or the third phase, in which the key objective must be centered on algae removal, techniques incorporating coagulation are used conventionally. Furthermore, in this case, additional processes to increase the coagulation efficiency must be conducted in cooperation. Hence, application of algae control and removal methods must be carried out after considering the advantages and disadvantages of each method depending on the stage of algal bloom. Technologies suggested as the ultimate steps measures include dredging and drawdown.

TABLE 2. **Distribution of algae removal technology according to the stage of the algae bloom alert system.**

Description	**Attention**	**Warning**	**Mass occurrence**
Algae bloom alert system	>1,000 cells/mL	>10,000 cells/mL	>1,000,000 cells/mL
Physical control	66.70%	33.30%	N.D.
Biological control	50.00%	50.00%	N.D.
Chemical control	N.D.	42.90%	57.10%
Convergent control	16.70%	50.00%	33.30%
Rate of technologies	35.70%	42.90%	21.40%

Algae removal methods from overseas

To solve the problem described above, there is a need to refer to similar overseas cases to algae removal. In the United States, the main algae control methods targeted at small ponds and lakes included ultrasound and surface skimming techniques. However, a traditional method named "barley straw", which does not scientifically specific proven yet, was being tried in river streams to reduce algal population. In addition, although originally used for securing water resources, a technique named "shade ball" that covers the entire water surface with a ball was also used. On the other hand, main algae control techniques for lakes in Japan included the combination of ultrasound and mechanical mixing using vessels, as well as coagulation using naturally found materials. Also, Chinese authorities utilized dredging engineering, artificial aeration, hydrologic manipulations, mechanical algae removal, and biological control techniques such as constructed wetland, ecological regulation, and biological floating island.

Discussion

In the domestic environment, algal problems are significantly recognized in river streams than in lakes. As such, the algae removal technology chosen must be suitable for domestic river stream environments. While periphyton is usually responsible

for algal blooms in shallow streams, the algal problems in domestic rivers are mostly brought about by blue-green algae of phytoplankton. This means that the occurrence of algal bloom by phytoplankton in river and stream in Republic of Korea is more socially significant.

Local authorities in Republic of Korea have recently claimed that there are plans to carry out hydrologic manipulations for algae control. Given such plans, it may be difficult to implement techniques that require installation of structures in the water bodies, such as mechanical mixing, circulation, and floating artificial wetlands, as they may be damaged once water is released from the upstream dams. But, as hydrologic manipulations are carried out, algae control methods must still be applied to regions near the river mainstream where algal bloom can still present after the release of water. According to a study conducted by the KWRC (2016), high concentrations of algae were observed in the surface of the river at many points, tributaries, and the regions of confluence between mainstream and tributaries.

Based on this opinion, it may be suitable to choose a sustainable algae reduction technique if algal bloom is constantly observed, or short-term techniques if algal bloom occurs on a massive scale. Most sustainable algae removal technologies are based on physical means, such as aeration, mechanical mixing, circulation, and ultrasound, while chemical methods like coagulation and convergence technologies that include coagulation can be utilized as short-term methods.

Likewise, if algae proliferation is deemed out of human control, fundamental algae removal methods must be applied. Light, water temperature, and nutrients are primary factors that affect the growth of algae, while water velocity may also influence algal growth [8-11]. For example, the “shade ball” method is a representative technique that restricts algal growth by preventing the photosynthesis of the algae.

However, the effect of preventing light exposure on other aquatic organisms has not yet been researched, and the application of preventing light exposure would only be deemed applicable on water resources used for potable water. Furthermore, blocking light may not be effective unless the entire waterbody is covered. None of the techniques developed as of now work by directly controlling the water temperature, perhaps apart from hypolimnetic discharging of water from upstream dams. While the discharge of cold water into the streams may be effective in reducing blue-green algae population, subsequent “Cold shock” may have undesirable consequences on other aquatic organisms [12].

Meanwhile, coagulation technique, which works by adsorbing phosphorus, restricts the concentration of nutrients required for algal growth. As a representative example, “phoslock”, a technique that adsorbs phosphorus to remove nutrients for algae, may be considered. However, it is difficult to say that “phoslock” removes phosphorus from the water system, as nutrients are merely adsorbed to the river bottom in this process. Also, adsorption of nutrients other than phosphorus may increase concentrations of NH_4^+ and oxidized Fe ions relatively [13].

Conclusion

In this study, we classified the type of algae removal technology on Republic of Korea and organized them by occurrence period. The distribution of the domestic algae removal technologies was as follows: physical controls 32.2%, biological controls 21.4%, chemical controls 25.0%, and convergent controls 21.4%.

In terms of the application phase, during the early stages of the algal bloom, the periods of “Attention” and “Warning” was primarily applied by the physical and biological controls, but, during the last stage of the algal bloom, the period of “Mass occurrence” was primarily applied by the chemical control.

Content to be suggested through the results of this study are as follows. Most algae control methods utilized both domestically and internationally are based on physical techniques. However, the control method deemed most suitable for

the “Mass occurrence” phase was chemical controls like coagulation, although the method is sometimes cited as environmental problems. Each algae control and removal technologies has its respective advantages and disadvantages, and hence an environmental investigation on target areas must first be carried out to identify relevant information such as the species responsible, period and frequency of occurrence, and characteristics of watershed. Depending on the extent of proliferation, the most effective method among the categories of algae removal technologies can be selected and subsequently employed.

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