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Future directions for management and treatment of algal blooms: A case study of filamentous——Cyanobacteria in Dianchi Lake

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Abstract. In March of each year, dormant spores of filamentous cyanobacteria (Aphanizomenon flosaquae) responsible for algal blooms in Dianchi Lake start to revive as the temperature reaches around 14 degrees Celsius. The apparent succession phenomenon between filamentous cyanobacteria and microcystis algae has made it one of the dominant species of eutrophication in Dianchi Lake. So far, China has invested more than 50 billion RMB in the treatment of eutrophication in Dianchi Lake, but the situation remains far from optimistic, with water quality only being classified as Class IV. To achieve sustainable development in Dianchi Lake water quality treatment and restoration, it is important to consider the economic value of the treatment products while implementing the remediation. Filamentous cyanobacteria, one of the main pollutants of eutrophication in water bodies, can be used to extract AFA-phycocyanin, which has been identified as a complex of C-phycocyanin/allophycocyanin, phycobiliproteins (including the chromophore phycoviolobilin), AFA-photosynthetic pigments, and mycosporine-like amino acids (MAA). These extracts can be used in nutritional cosmetics and pharmaceutical compositions for the prevention or treatment of diseases, disorders, or symptoms involving acute or chronic inflammation, oxidative denaturation of cellular or tissue, or uncontrolled cell proliferation. By extracting and processing filamentous cyanobacteria, its economic value can be increased, treatment costs can be reduced, and contributions can be made to the sustainable development of algal bloom pollution control in Dianchi Lake.

Keywords: blue-green algae blooms, filamentous cyanobacteria, water pollution management, phycocyanin.

1. Introduction

Recent theoretical developments have revealed that algae are rich in protein and other amino acids, especially Aphanizomenon flos-aquae which can be used as future cosmetic ingredients. According to the patent (patent No. CN101489527B) published on April 9, 2014, the phycocyanin extract contained in those algae can be used in medicine and cosmetics to treat acute or chronic inflammation and prevent skin aging. At the same time, Dianchi Lake in China has been plagued by water bloom pollution in recent years, this appears as a more straightforward problem. According to the research report in May 2018, Aphanizomenon flos-aquae have become an important factor in water bloom pollution in Dianchi Lake. How to deal with these algae has become a problem to be solved. However, can the pollutant algae become a cosmetic ingredient has rarely been studied directly. In the word ,

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this research aims at finding a solution for this challenging problem of use the extraction technology to convert the pollutant algae into raw materials for cosmetics and drugs, while protecting the environment, let these pollutants obtain economic value. Because economic value will promote enthusiasm for environmental protection.

2. Eutrophication and eutrophic water bodies

Eutrophication of water bodies refers to the phenomenon of water quality pollution caused by excessive amounts of nutrients such as nitrogen and phosphorus in the water. The essence of eutrophication is the imbalance between the input and output of nutrients, which leads to the imbalance of species distribution in the aquatic ecosystem, the excessive growth of certain species, and the disruption of the flow of matter and energy in the system, gradually leading to the demise of the entire aquatic ecosystem.

Eutrophication of water bodies is a gradual process of increasing nutrient levels, and with population growth, economic development, and industrialization, the process of eutrophication may accelerate, causing significant differences in water quality in just a few decades or even years. Internationally, the classification of eutrophic water bodies is generally based on the primary productivity of water bodies and the main nutrient elements that affect it. Different classification systems have different definitions of eutrophic water bodies, but the differences are only in the quantity or degree of attention paid to various nutrients, or in different ecological system indices with multiple parameters.

3. Overview of Dianchi Lake

Dianchi Lake, also known as Kunming Lake, is located in the southwest of Kunming City, Yunnan Province. It is a lake formed by a seismic fault. The lake surface is at an altitude of 1,886 meters, 39 kilometers long from north to south, and 13 kilometers wide from east to west. The length of the lakeshore is 163.2 kilometers, the area is 306.3 square kilometers, and the water capacity is 1.57 billion cubic meters. Being a seismic fault collapse lake, its shape is like a crescent.[1] The physical and chemical environment of the lake is constantly changing with the development of water pollution, which in turn affects the balance of the entire aquatic ecosystem and changes the original form and characteristics of the aquatic ecosystem. Dianchi Lake, with its low latitude, high altitude, constant temperature, and long water exchange cycle, has become a global problem for controlling blue-green algae blooms.

4. Dianchi Lake blue algae pollution status

Currently, there are more than 30 types of blue algae in Dianchi Lake, with the most common being Microcystis, Oscillatoria, and Anabaena. In January of each year, there is a clear succession phenomenon between the water blooms of Oscillatoria and Microcystis in Dianchi Lake. The dormant spores of Oscillatoria begin to revive at around 14°C in March and continue to grow for about a month, occupying a significant population advantage in the absence of competitive pressure. During this period, Microcystis is severely inhibited in revival and growth due to low water temperature stress and its revival process is significantly delayed compared to Oscillatoria, leading to a succession phenomenon between water blooms of Oscillatoria and Microcystis from late April to May.[2]

In recent decades, the water quality of Dianchi Lake has continued to deteriorate, and eutrophication of the water body has become increasingly prominent. Blue-green algae "water blooms" have become a "heart disease" for Kunming residents. Since the 1980s, the discharge of large amounts of industrial wastewater into Dianchi Lake has aggravated its pollution. After entering the 21st century, with the acceleration of industrialization, water bloom pollution has intensified, and Dianchi Lake has faced severe challenges. In the worst-case scenario, Dianchi Lake is covered with an unpleasant green film. Data shows that in 1953, the forest coverage rate along the lake was 59%, and most of the lake shore was covered with green vegetation. By 1982, the forest coverage rate in the entire area was only 16.5%, and only the western part of the lake had green vegetation. With the

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passage of time and the continuous improvement of human socio-economic development level, the ecological environment has been severely damaged. Currently, it has become one of the key areas for national governance. Unfortunately, in the past 20 years, Dianchi Lake pollution has become increasingly severe, and water quality has continued to deteriorate. Human activities have had a serious impact on the coastal ecology of Dianchi Lake.

Regarding natural factors, Dianchi Lake is located in a phosphate deposit area, and surface precipitation can cause a large amount of phosphorus to be lost. As rivers flow into Dianchi Lake, this can exacerbate eutrophication. Additionally, according to the general evolution pattern of lakes, Dianchi Lake is in an aging stage with a shallower basin, severe sedimentation, shrinking surface area, and water storage capacity that is only 2% of its ancient level. Under these circumstances, if water resource exploitation and utilization continue to increase, it will result in further deterioration of water quality and exacerbation of eutrophication in Dianchi Lake.

5. Dianchi Lake's microcystis and oscillatoria blooms

Since the 1990s, algae have begun to proliferate in large quantities in Dianchi Lake. From April to November each year, large areas of blooms appear on the lake's surface. The blooms of Microcystis and Oscillatoria alternate in Dianchi Lake, with the latter having a stronger tolerance to low temperatures and the ability to fix free nitrogen in the air. As a result, the blooms of Oscillatoria, as the dominant bacterial species, usually occur in the winter and spring seasons, before the Microcystis blooms. The outbreak of Oscillatoria blooms in Dianchi Lake seriously endangers the ecological environment, greatly reduces water quality, and imposes a heavy burden on people's daily lives, causing huge losses to local agriculture, fisheries, industry, tourism, and other sectors. During the outbreak of Oscillatoria blooms in Dianchi Lake, there have been reports of mass fish deaths caused by a lack of dissolved oxygen in the water due to the proliferation of algae and their subsequent decomposition, or due to the filamentous algae blocking the fish's gills and inhibiting their respiration. The harm caused by Oscillatoria blooms in Dianchi Lake should not be underestimated.

6. Dianchi Lake eutrophication control

Currently, the main focus of Dianchi Lake water treatment is on strengthening control of key industrial pollution sources, as well as controlling urban life pollution related to Dianchi Lake, rationalizing water resource allocation, and managing outbreaks of harmful algal blooms.

Phase One: From the founding of the People's Republic of China to 1996

During this period, township enterprises developed rapidly, population grew sharply, urban areas expanded, and large amounts of urban sewage and industrial and agricultural wastewater were discharged into Dianchi Lake. As a result, the lake suffered serious pollution. In the 1990s, the water quality of Dianchi Lake deteriorated to the worst Class V, with frequent outbreaks of blue-green algae blooms, making it one of the most severely polluted lakes in China. In 1990, the Dianchi Lake Protection Committee of Kunming City was established, beginning a difficult journey of protection and management.

Phase Two: From 1996 to 2015

During the "Ninth Five-Year Plan" period, the Chinese government included Dianchi Lake in its key "Three Lakes and Three Rivers" control system, and Yunnan Province and Kunming City began to pay attention to Dianchi Lake treatment. During the "Tenth Five-Year Plan" period, Dianchi Lake treatment focused on point source and non-point source pollution control, cleaning up the inflow rivers, renovating the urban drainage network, promoting clean industrial production, implementing Dianchi Lake sediment dredging, blue-green algae removal, mountain greening, and aquatic ecological restoration, among many other projects. In April 2002, the Kunming Dianchi Lake Management Bureau was officially established.

Phase Three: From 2015 to the present

In 2018, breakthroughs were achieved in the pollution control of Dianchi Lake, and the water quality improved from Class V in 2015 to Class IV, two levels higher.

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7. Dianchi algae salvage management

Scientific research and practical experience have shown that to prevent large-scale outbreaks of blue-green algae blooms, it is necessary to control the nutrient substances such as nitrogen and phosphorus that enter the water body, reduce the eutrophication level of the water, and block the nutrient "supply line" that causes blue-green algae blooms. This is the fundamental solution. The remedial solution is to salvage and dispose of blue-green algae to reduce secondary pollution. The interaction and coordination between the fundamental and remedial measures are essential. After the blue-green algae die and decompose, nutrients are released back into the water, causing secondary pollution and providing nutrients for other algae. By salvaging a large amount of blue-green algae that accumulate in local areas, it is not only possible to prevent the hazards of algal blooms but also to slow down excessive proliferation, improve the water landscape, eliminate odors, and enhance the tourism value of Dianchi Lake. Therefore, it is necessary to regard the control and removal of blue-green algae as one of the effective means of controlling and treating pollution in Dianchi Lake for a certain period.

After more than 20 years of persistent protection and management, in 2018, the water quality of the grassy and outer seas of Dianchi Lake improved from the previous Class V to Class IV, and the nutrient status of the water also changed from heavily eutrophic to mildly eutrophic, showing a clear trend of stabilization and improvement.[3] In 2018, the Kunming Municipal Party Committee and Government embarked on a new journey and led the people of the city to launch a "three-year attack on the protection and management of Dianchi Lake," implementing dual control of "water quality" and "pollution load reduction" for all inflows and tributaries of Dianchi River, and doing everything possible to prevent pollutants from entering Dianchi Lake and block the nutrient supply of blue-green algae blooms.

8. Overview of Aphanizomenon Flos-aquae (AFA)

Currently, there is limited research on the formation mechanism of Aphanizomenon flos-aquae blooms both domestically and internationally. Most research has focused on the classification, identification, and molecular systematics of Aphanizomenon species. Aphanizomenon, a filamentous nitrogen-fixing cyanobacterium, exhibits diverse and variable morphologies, and the differences between Aphanizomenon and other cyanobacteria such as Anabaena are not significant, making classification and identification difficult. The classification of the genus Aphanizomenon is still disputed internationally. Recently, some researchers have proposed including eight morphologically distinct species in the genus Aphanizomenon, while others have established a new genus for some species previously classified as Aphanizomenon, such as Cuspidothrix for Aphanizomenon issatschenkoi. According to traditional classification, common freshwater Aphanizomenon species in China can be roughly divided into three categories: Aphanizomenon flos-aquae, Aphanizomenon issatschenkoi, and Aphanizomenon gracile [4].

Commercial value of Aphanizomenon flos-aquae: Aphanizomenon flos-aquae (AFA) is one of the many types of blue-green algae and is found abundantly in Upper Klamath Lake in southern Oregon [5]. AFA is one of the few edible microalgae and is different from other microalgae, such as Spirulina and Chlorella, which grow in ponds. AFA exhibits significant nutritional characteristics, including a wide range of vitamins and organic minerals, proteins, and amino acids, and w3 fatty acids, within its natural habitat range. It is known to contain certain amounts of nutrients with antioxidant properties, such as chlorophyll and carotenoids. Recent studies have shown that the phycocyanin in the blue-green microalgae Spirulina exhibits significant antioxidant and anti-inflammatory properties. After the active components of Aphanizomenon flos-aquae are extracted, they can be used as cosmetic extracts and pharmaceutical raw materials, making them highly valuable commercially.

9. Conclusion

In summary, eutrophication pollution in Dianchi Lake has been a difficult problem for environmental restoration due to both human activities and natural limitations. Aphanizomenon flos-aquae, the dominant species in algal blooms, has exacerbated the problem. China has invested a significant

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amount of manpower and financial resources to address the water pollution in Dianchi Lake, but the situation is still challenging. In order to sustainably develop the water pollution control in Dianchi Lake, economic development.

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