Algal Sweeper: A Bio-Mechanical Sweeper System for Sustainable Mitigation of Algal Blooms in Waterbodies

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Abstract

Harmful algal blooms (HABs pose significant threats to aquatic ecosystems, public health, and local economies, while existing mitigation strategies often rely on reactive chemical treatments that can produce long-term ecological impacts. This study presents the design, development, and laboratory evaluation of a scalable bio-mechanical Sweeper system for proactive surface-water algal remediation. The system consists of a semi-hexagonal, perforated Sweeper structure fabricated from recycled plastic and integrated with sustainable barley straw filtration media, mounted on an underwater remotely operated vehicle (ROV) for controlled deployment. Hydrodynamic optimization of the Sweeper geometry reduced drag force by approximately 86% relative to an initial flat-plate design, improving structural durability and filtration efficiency. Laboratory testing conducted in a pond simulator demonstrated effective mechanical removal of surface algae and suppression of algal growth over a 3-day period, attributed to low concentrations of hydrogen peroxide released during barley straw decomposition. The ROV-mounted Sweeper enabled continuous surface filtration and remote monitoring via onboard imaging. Results indicate that the proposed system provides an environmentally responsible alternative to chemical algaecides and has strong potential for scalable field deployment. This bio-mechanical approach offers a proactive strategy for HAB mitigation, supporting long-term water quality management and ecosystem protection.

Introduction

Algae are a diverse group of photosynthetic microorganisms that are a beneficial part of the aquatic food web, as they form the energy base. However, when certain toxin-producing suites of microalgae grow excessively, Harmful Algal Blooms (HABs) are produced (1). Harmful algal bloom (HAB) events have been increasing rapidly worldwide, posing serious threats to water quality, marine organisms, and public health. HABs cause billions of dollars in economic losses, particularly in regions dependent on recreation and seafood harvesting (2). Along Florida's coast, unpleasant bloom episodes occur annually, altering water chemistry and disrupting marine food webs. According to the Centers for Disease Control and Prevention, algal bloom cleanup costs approximately $65 million per affected community, while associated human digestive and respiratory illnesses can cost up to $14,600 per case (3).

Traditional monitoring and remediation methods for HABs typically involve field water sampling followed by laboratory-based algal density estimation using microscopy. Based on established algal thresholds, chemical algaecides such as copper compounds or hydrogen peroxide (H_2O_2) are often applied. However, repeated chemical applications can adversely affect aquatic ecosystems over time.

Consequently, there is a growing need for sustainable bio-mechanical alternatives capable of removing biological contaminants from surface waters while minimizing ecological harm.

Methods

A remediating system, referred to as the Sweeper, was designed for proactive algal cleanup. Several prototypes were developed during its evolution. The first prototype consisted of a flat plate with no perforations. This configuration exhibited the highest hydrodynamic drag because all incoming water flowed around the plate rather than through it. Drag force was calculated using

$$F_{(Drag)} = (1/2) \cdot D \cdot \rho \cdot A \cdot v^2,$$

where $F_{(Drag)}$ is the drag force (gm·cm/sec²), D is the drag coefficient, ρ is the density of water (gm/cc), A is the reference area (cm²), and v is velocity (cm/sec). Due to excessive drag and minimal algal removal, this design was deemed ineffective.

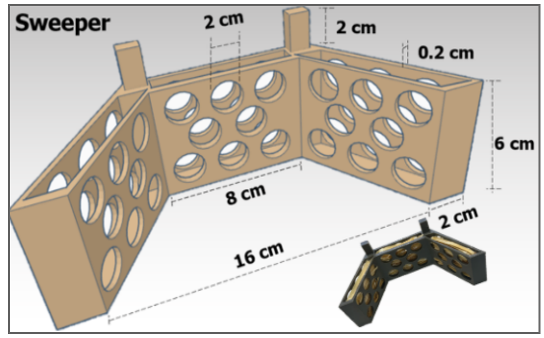

Figure 1: Algal Sweeper Schematic


Figure 2: Barley straw filters inserted in Algal Sweeper

The second prototype was subsequently developed as a semi-hexagonal plate containing square perforations and a central opening to house filtration material. This configuration reduced the drag force by approximately 60% compared to the flat plate, as 38% of the water passed through the Sweeper rather than around it. However, stress concentrations at the square-hole corners induced wake formation and eddies, leading to premature structural failure.

Finally, the third prototype (Figure 1) consisted of a semi-hexagonal plate with circular perforations. This geometry reduced the drag force by approximately 86% relative to the flat plate, with 52% of the water passing through the structure. The circular holes promoted smoother water flow, balanced pressure distribution, and increased filter longevity. This Sweeper (Figure 1) was designed in CAD as a semi-hexagonal structure with 2 cm diameter holes distributed across its surface for filtration. It measured 6 cm in height and 20 cm in length, with 8 cm sides. The structure also included a 2 cm internal gap for barley straw, a sustainable material for filtration (Figure 2). The framework was 3D-printed using recycled plastic.

The Sweeper was firmly mounted to the bow side of an underwater ROV (Figure 3). This carrier ROV was constructed from high-density, durable flotation material measuring 25 cm × 15 cm × 3 cm. It was propelled by four 3V motors and had omnidirectional traversing capabilities. Two motors were positioned at the stern to provide forward thrust. The port and starboard sides each had one motor to assist with turning. A 3D-printed rudder provided the ROV with ride stability.

All circuitry was housed in a custom 3D-printed electronic enclosure that included a Wi-Fi microcontroller powered by a 5V battery. The completed omnidirectional ROV and Algal Sweeper (Figure 4) was programmed to be controlled from a mobile device at a remote location.

Lab Analysis Testing

During experimentation, the engineered Sweeper was tested in a pond simulator. Sufficient quantities of barley straw were inserted into the Sweeper, and the device was manually oscillated in the pond simulator to simulate its behavior during transit in a water body. Over a 24-hour period, algae were observed to settle at the bottom, suggesting that H_2O_2 produced by the barley straw aided in suppressing algal growth (Figure 5). Additionally, the photo intensity in the pond simulator increased over time, suggesting that water clarity improved following algal suppression by barley straw (Figure 6).

Furthermore, the Sweeper effectively removed surface-water algae through mechanical sweeping.

Figure 5: Algal Suppression in pond simulator using barley straws

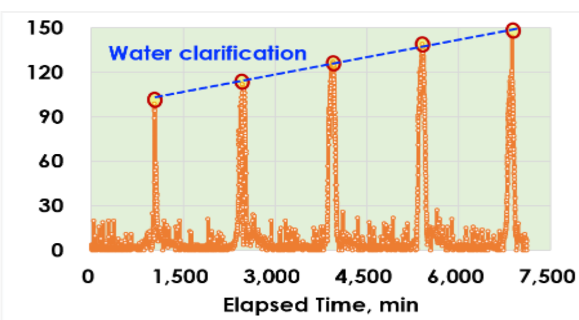

Figure 6: Improvement in Photo intensity index demonstrating water clarification following algal suppression

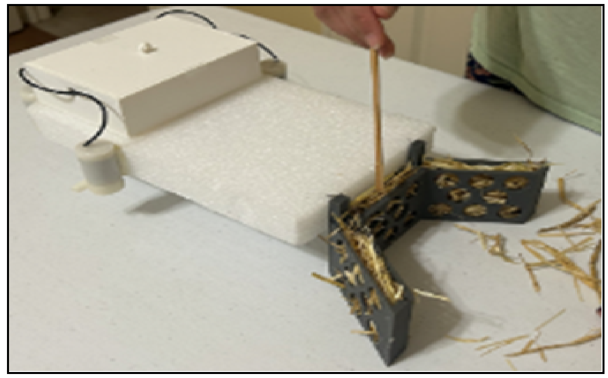

Figure 3: Algal Sweeper mounted on the bow of ROV

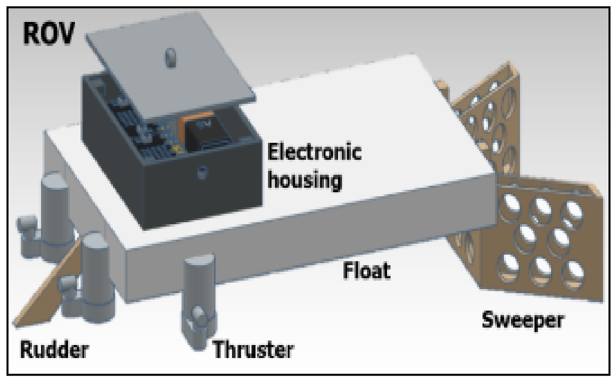

Figure 4: Schematic of completed ROV prototype with Algal Sweeper

Results

Algal abatement was achieved using the Sweeper with barley straw filters. The underwater ROV, which served as the Sweeper carrier, was successfully controlled via a mobile device and remediated algae from surface waters, thereby continuously filtering the water body. Cleanup efforts were monitored using a remote camera. A scaled-up version of this laboratory prototype could be deployed in field applications to sweep surface algal biomass from water bodies.

Discussions

An understanding of algal chemistry is essential for engineers seeking to suppress HABs. Although algal particles naturally settle at the end of their life cycle, this process is slow and often insufficient for effective bloom control. As a result, external stressors are introduced to accelerate algal suppression and settling. In this study, H_2O_2, a weakly acidic compound, was investigated as a means of inhibiting algal growth.

H_2O_2 is a strong oxidizing agent that suppresses algae without leaving harmful residuals in the water. When H_2O_2 decomposes, it generates reactive oxygen species that damage algal cell membranes and denature cellular proteins, ultimately leading to algal mortality (4). Rather than directly applying chemical H_2O_2 to the water body, this study employed a sustainable and non-toxic alternative, barley straw (4). Previous research has shown that decomposing barley straw releases low concentrations of H_2O_2 that inhibit algal growth. This mechanism was observed in the present study, demonstrating that barley straw can suppress algae by serving as a natural source of H_2O_2 while avoiding the risks associated with direct chemical dosing.

Conclusions

Reactive mitigation of harmful algal blooms has cost Florida millions of dollars, highlighting the need for a proactive and sustainable solution. Current mitigation techniques alone remain insufficient for effective HAB control, emphasizing the need for improved elimination strategies. In this research, a semi-hexagonal Sweeper structure equipped with sustainable filtration media, specifically barley straw, was engineered and deployed, with assistance from an underwater remotely operated vehicle, for algal abatement. Laboratory testing using H_2O_2 demonstrated effective suppression of *Chlorella vulgaris* growth within a pond simulator. Overall, the proposed system is scalable and offers marine engineers a proactive, sustainable approach to HAB mitigation, thereby supporting the preservation of water quality and the protection of local economies.

References

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