JOURNAL OF
EMERGING INVESTIGATORS

Article

Floating aquatic plants form groups faster through current

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SUMMARY

Floating plants are plants that freely live on water without formal roots. Examples include *Lemna minor* and *Lemna gibba* (common name: duckweed). Duckweeds are often kept under conditions with no current to reduce stress; however, this may not always be beneficial. The purpose of this experiment was to determine whether water current, as an exogenous factor, can expedite duckweed integration after a stressor is applied. We hypothesized that duckweeds form a unified colony faster in a current-sustained environment than in motionless water. We found that colonies of duckweeds are formed through successive unifications of groups, mediated by the current. In fact, current flow disrupted and recreated the colony, which benefited the community because it reorganized and therefore enhanced both the diversity and the reproductive capability of the colony. In a current-disintegrating environment, the duckweeds never created a unified colony and rather formed small groups. The experiment demonstrated that floating aquatic organisms form communities faster in current-sustained environments than in environments where no visible current is present. These findings could have future implications in agriculture, conservationism, and artificial intelligence engineering.

INTRODUCTION

Floating aquatic plants are plants that live on water without attachments to the ground. Duckweeds are normally found in silent ponds, marshes, lakes, and streams in North America. They require groups to perform sexual reproduction and to consolidate survival, so the ability to create a unified community could be vital to their efflorescence (1, 2). Duckweeds support the environment they live in by providing a habitat for the wildlife that consumes the plant, slowing the growth of invasive algae, and removing excess nitrates (3). Floating plants are often kept under non-current environments under the assumption that current can be destructive to the duckweeds; however, this may not always be the case.

In this study, we investigated the ability of duckweeds to create colonies under current. We chose to study *Lemna minor* due to its abundance, low cost, reliability, and high sensitivity to inorganic and organic substances (4). We tested the overall ability of duckweeds to create unified communities after being placed under conditions with either current or no current. We hypothesized that floating plants form unified communities faster in current-sustaining environments than in motionless environments. This hypothesis was supported by our results, which showed that the unstable environments were able to create entirely unified communities through current in a short amount of time. The motionless environment, however, tended to create unified colonies in substantially larger amounts of time. Bernoulli's Theorem states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure (5). In this case, the sudden decrease may cause two bodies of duckweeds to unify when a faster current is placed between them. As a result, Bernoulli's Theorem may play a key role in the unification of separate groups of duckweeds. The study demonstrated that current or water agitation brings duckweed together, allowing rapid colony formation. This study could be key in exploring the depths of the biophysical ecology of floating plants, and further studies could investigate colony formation in larger bodies of water with receding shores, like most ponds and lakes.

Floating plants are often kept in nature reserves, parks, zoos, local ponds, and lakes, frequently with other fauna and flora. Efficiently learning to create colonies of duckweeds within minutes may help zoologists, farmers, and botanists to create a stable ecosystem. In the case of zoologists, duckweeds serve as feed for tilapia, koi fish, and grass carp, and colonies of floating plants even serve as habitats for microorganisms (6).

RESULTS

To test our hypothesis, we used a bucket filled with water to simulate a pond. Shaking the bucket at the start simulated stress, creating the current required to emulate the unstable environment. We used this to create the environment with current. We used another medium without shaking the bucket to simulate the motionless environment. Dead duckweed remnants were used to indicate the current in the current-sustaining environment **(Figure 1)**. The unstable duckweeds created a unified community significantly faster than those in the motionless environment (p = 0.0004; **Figure 1**). Under current, the duckweeds created a unified colony through multiple successions of smaller colonies merging. These small groups joined together on average every 2.95 minutes **(Figure 2)**. However, in the group with no current, the duckweeds created unified colonies in a much longer amount of time, 38.56 minutes, also with multiple successions of small colonies merging **(Figure 2)**. We performed the experiment three times to ensure normality in results. In summary, the duckweeds in the group with current formed colonies significantly faster than those in the bucket without current.

DISCUSSION

The experiment shows that current facilitates the unification of the colony of duckweeds faster than without current. This

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DOI: https://doi.org/10.59720/22-222

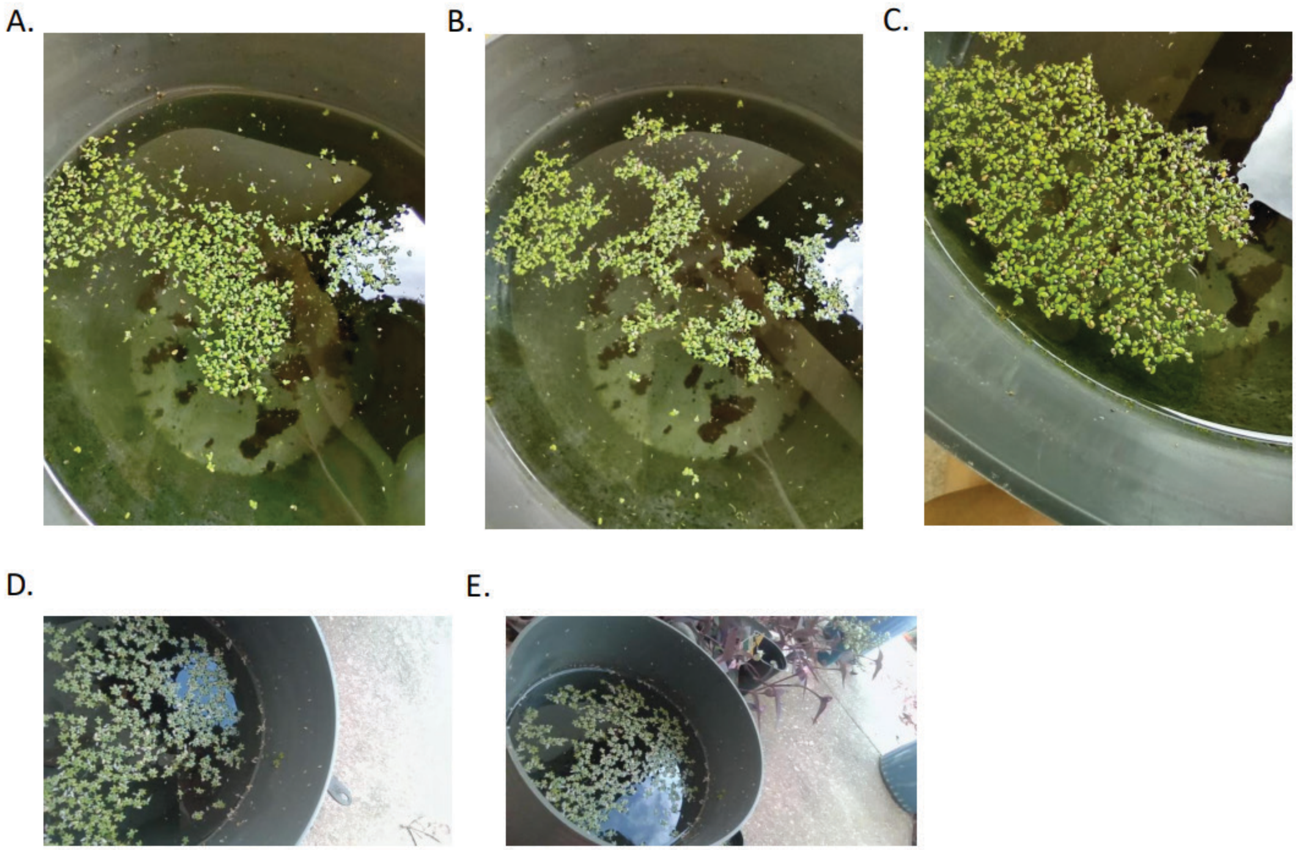

Figure 1: Current facilitates the creation of a unified duckweed colony. Representative pictures of the current-sustained and the motionless duckweed at different timepoints. Current (mean = 2.95, SD = 0.41) and non-current (mean = 38.6, SD = 5.7) showed significantly different colony formation times (p = 0.0004, t-test). A). First second after duckweeds are applied in current-sustaining environment; duckweed colony is disorganized and no connections with other duckweeds are apparent. B) After a minute, the duckweeds begin to form small groups through current. C) Unified duckweed colony after 3 minutes. D) First second after duckweeds are placed into a motionless environment. E) Duckweeds begin to form small groups but fail to create a unified community without current in more than 40 minutes. In this case, a unified colony occurs when more than 80% of the duckweeds are present in one clump. The duckweeds in the motionless environment fail to attach to one another and remain in isolation, ($p < 0.001$, t-test). The experiment used three replicates.

current helps to artificially aggregate the duckweeds into a unified colony over time. However, the bucket used, due to its ovaloid shape and absence of a receding shore or border like a real pond, may have influenced the results. In addition, the motionless environment was not entirely without current because even still water has some degree of motion, and it would be exceedingly difficult to simulate such an environment. This may be the largest bias in our experiment, but it should also be noted that a true "current-free" environment would be unlikely to exist in nature. Similarly, the simulation of current in the unstable environment may be a better representation in lakes and ponds without clearly defined receding borders. The inability to place the duckweeds equally throughout a grid within the bucket may also be a limitation. Because of this, aggregation may have been easier to attain in the experiment.

Future experiments could investigate which compounds, biochemicals, or molecules are involved in the tendency of duckweeds to attach to one another, and if duckweeds are specifically adapted to maximize the effects of current flow per Bernoulli's Theorem. Biochemicals could be released to help solidify the connection between two duckweeds in the creation of a colony. Without the unification of duckweeds by current, they may not be able to perform sexual reproduction, negatively affecting the prosperity of a colony. An experiment could further deduce whether the lack of colonization in duckweeds could affect their ability to reproduce. A future experiment could also assess whether current facilitates the creation of a unified colony of duckweeds in natural bodies of waters, such as lakes or ponds.

As climate change increasingly creates variability in the environment of duckweeds throughout the world, the ability to artificially aggregate through current may help to preserve some communities. In colonies, duckweeds have been shown to reproduce and thrive, and the growth of duckweed in many ecosystems can be beneficial as well. In ponds throughout North America, duckweeds serve as micro ecosystems for invertebrates and are consumed by birds, fish, and other wildlife (3). However, even so, climate change will negatively impact the habitat of duckweeds and their ability to reproduce, as the environments they live in have many variables that may be disrupted by changes in temperature and native species abundance. Temperatures above 35°C can also directly affect the growth of duckweeds (7). In many ways, these changes will also affect duckweeds directly, despite their ability to overcome other obstacles. In nature, the ability to create communities of duckweed in a short amount of time

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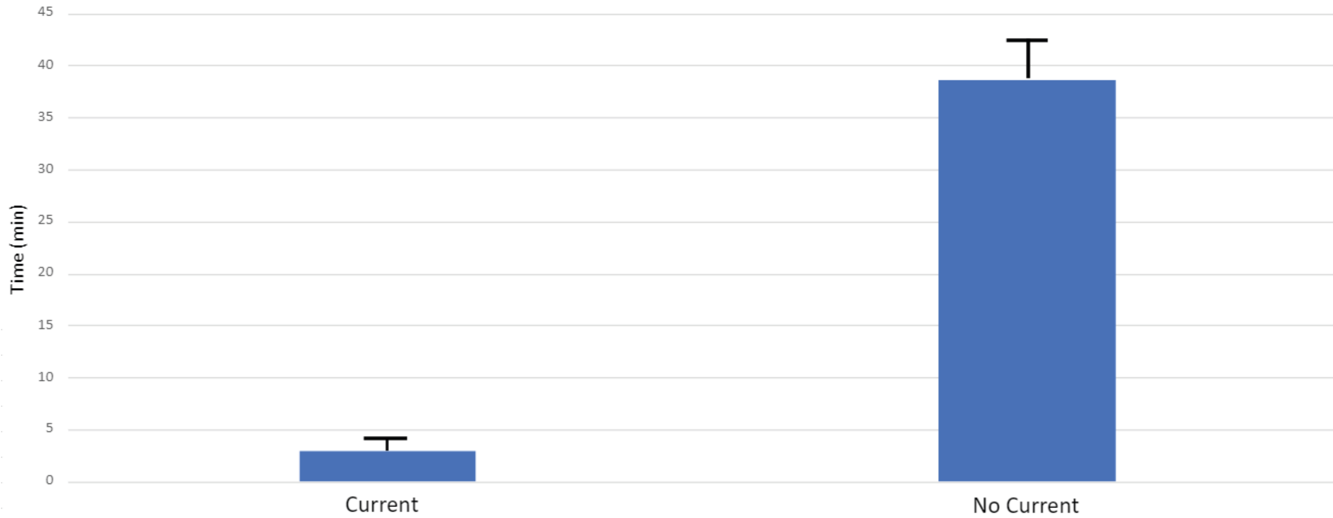

Figure 2: Groups of duckweed with current create groups, or unified colonies, significantly faster than those in motionless environments. In this case, a unified colony occurs when more than 80% of the duckweeds are present in one clump. "Current" denotes the average time to create unified colonies within the currented group of duckweeds; "No current" that of the duckweeds within the motionless environment. The error bars represent the standard deviations. The mean was found using an average of three replicates. There was a significant difference in the time needed to create unified colonies for current (Mean = 2.95, SD = 0.41) and non-current (Mean = 38.55, SD = 5.67) conditions (t-test, p = 0.0004).

through the exogenous factor of current would be essential to its survival, otherwise the duckweeds would not be able to sexually reproduce and propagate as easily (8). This principle may be applied to other floating aquatic plants. Current is often sustained in ponds and lakes where duckweeds and other floating plants can be found. The importance of this phenomenon would be immense in its natural environment because numerous forces and stresses would influence the growth and reproduction of floating aquatic plants. The result of the experiment is statistically significant and may even be practically significant in its implications for horticulture, agriculture, and ecology.

In fact, the tendency to attach to other floating plants, the ability to form large solid bodies of colonies, and their ability to synchronize the colony as a single individual in movement through current enable floating plants to create a unified community. Similarly, Placozoa move synchronously without neural networks or forms of communication and later influenced self-oscillating robots and robots which reach consensus without human interference (9). Like Placozoa, the duckweeds created groups due to an external factor, in this case current. However, further experimentation is needed to support the correlation of the two.

We speculate that the groups of duckweeds unified by Bernoulli's Theorem, which states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure (5). In this case, the sudden decrease may cause two bodies of duckweeds to unify when a faster current is placed between them. As a result, Bernoulli's Theorem may play a key role in the unification of separate groups of duckweeds. Further experimentation must be done to ensure the credibility of this observation.

The study demonstrated that current facilitates, rather than dissipates, the creation of a unified duckweed colony. In Placozoa, colonies form groups using current to coordinate actions and movement as well (9). Further studies involving the application of passive unification through current in AI engineering could have immense potential in this way. The ability to transiently form a unified community without the need of a neural network could be substantial in our quest to create truly conscious AI.

MATERIALS AND METHODS

The duckweeds were purchased from Amazon (Seller: Aquatic Arts) and were in the reproductive stage of their life cycles. Approximately 50 *Lemna minor* duckweeds (3.425 g) were placed in two ovaloid buckets with major axes of 26.8 cm and minor axes of 22.7 cm. The bucket was 16 centimeters tall with 3 quarts of water filling it, and the duckweeds were randomly placed within the bucket. The two buckets were placed outside to simulate the duckweed's natural environment. One bucket was shaken to create current, indicated by dead duckweed remains. The dead duckweed remains simply flowed in the direction of the current without influencing the action of the live duckweeds, and indicated how current influenced the creation of a colony. Colonies were formed when groups of duckweeds attached to one another and moved synchronously, while duckweeds were separately identified because of their gray color. The bucket was shaken back and forth multiple times at the beginning of the experiment for 10 seconds. The current stimulated the current-sustained environment. The remaining second bucket was not shaken and remained in a motionless environment. The amount of time it took for each group of duckweeds to create a unified colony was then recorded. Unified colonies were defined as when more than 80%, an eye estimate, of the duckweeds attached to one another to create one clump. We repeated the experiment three times, and the results were analyzed with a t-test using OpenStat to determine the significance of colony formation in current vs. non-current groups. An alpha level of $p < 0.001$ was considered significant.

DOI: https://doi.org/10.59720/22-222

Received: July 20, 2022
Accepted: April 17, 2023
Published: October 16, 2023

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