Efficiency of Diver-Assisted Suction Harvesting (DASH) of Invasive Milfoil in New Hampshire Waterbodies

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An Undergraduate Thesis
Submitted in Partial Fulfillment for the Requirements of

Bachelor of Arts
In
Environmental Science: Water and Life

Carthage College
Kenosha, WI

March 10, 2017

Efficiency of Diver Assisted Suction Harvesting (DASH) Removal of Invasive Variable Milfoil in Northeastern Waterbodies

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May 15, 2017

Abstract

Management of aquatic invasive species is necessary to conserve affected freshwater ecosystems and to protect the integrity of recreational activities. *Myriophyllum heterophyllum* (variable milfoil) is an aquatic invasive species that has invaded many waterbodies in the United States and has been actively dispersing throughout New England. It is crucial to employ milfoil management methods in affected areas that productively remove milfoil without causing further harm to existing ecosystems. Diver assisted-suction harvesting (DASH) is a variable milfoil management technique that has continually demonstrated efficient aquatic invasive species removal. In this study, two different sites located in New Hampshire were examined to assess the efficiency of hand-pulling and DASH to determine whether DASH assists divers in harvesting greater amounts of variable milfoil than hand-pulling and to evaluate if a correlation exists between the gallons of milfoil removed and the number of hours worked. Linear regressions and t-tests were utilized in data analysis. It was found that greater amounts of milfoil were removed using DASH than hand-pulling and there exists a correlation between the number of hours worked and gallons of milfoil removed. Efficient removal of aquatic invasive species is integral in preserving the health of waterbodies.

Introduction

Variable milfoil is a submerged, rooted plant native to the Southeast, but there is no record of this species being native to other regions of the United States. Since the initial introduction of variable milfoil in Connecticut in 1932, variable milfoil has been spreading rapidly within New England and continues to interfere with the growth and management of native aquatic organisms (University of Maine). Due to its ability to reproduce via fragmentation, capacity to adapt to varying environmental conditions, and lack of natural predators, variable milfoil has the potential to alter the integrity of healthy ecosystems.

New Hampshire waterbodies are currently being severely threatened by variable milfoil infestations. From 2007 to 2015, the number of infected waterbodies in the state has increased from 38 to over 73 (Weed Diver Course for Divers and Tenders 2016). New Hampshire is home to more than 400 native aquatic plant species, but their livelihood continues to be compromised by unintentional introductions of aquatic invasive species. Rapid dispersal of variable milfoil can induce irreversible harm to ecosystems if appropriate action is not taken, but the management of exotic species can present environmental and economic challenges.

Although milfoil has been dispersing at an alarming rate, there are several ways in which ecologists can combat the challenges that milfoil infestations have proliferated. Variable milfoil has been controlled through tested methods such as hand-pulling, chemical treatments, benthic barriers, dredging, biological control mechanisms, and diver-assisted suction harvesting (DASH). Integrated Pest Management (IPM) practices are commonly employed to determine which combination of removal methods best suit specific bodies of water.

Of all the methods used to remove milfoil from affected waterbodies, diver-assisted suction harvesting (DASH) may be the most efficient method of protecting the success of native organisms. Using DASH, large quantities of milfoil can be removed from affected areas in short periods of time without compromising the quality of the ecosystem. This study aims to assess the efficiency of DASH of variable milfoil in 2 different New Hampshire waterbodies. It is hypothesized that DASH allows for greater quantities of milfoil to be removed than traditional hand-pulling methods. A second hypothesis states that the gallons of milfoil removed per day by each method is correlated with the amount of crew hours worked.

Literature Review

Invasive Species

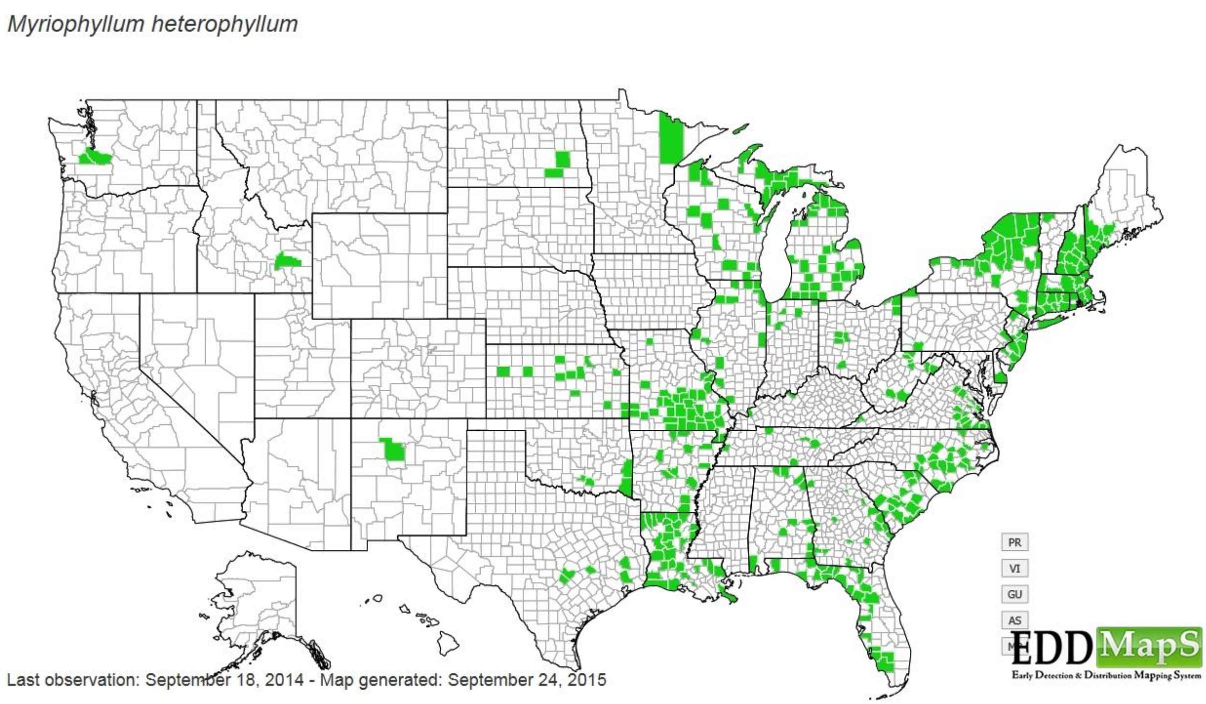
Invasive species, also referred to as pests, weeds, alien species, exotic species, or introduced species, pose a major threat to the biodiversity of ecosystems around the world, regardless of how they are termed in the scientific community (Clout 2009). The health of native species populations can be greatly influenced by the presence of non-native species, and this is an international cause for concern. In fact, more than 40% of threatened and endangered species are at risk due to invasive species infestations (Wisconsin DNR). Invasive species include animals, plants, or any other organisms that threaten the livelihood of a species fulfilling a niche in a distinguished ecosystem (USDA). The dispersal of species between habitats can be a result of natural occurrences or, more commonly, intentional or accidental human interferences. No ecosystem is immune from a potential invasive species intrusion (The Nature Conservancy).

When non-native organisms are introduced into an ecosystem outside of their historical range, organisms have the potential to strive due to advantageous circumstances (Wisconsin DNR). Alien species may directly impact new environments by eating native species, out-competing native species, introducing new diseases, or preventing native species from reproducing (National Wildlife Federation). Many newly-introduced species live and reproduce freely without the threat of established predators. The ecology of healthy ecosystems may become unstable due to changes in resource distribution and nutrient cycling. Food webs can shift from their original state and in turn, the biodiversity of affected habitats may be negatively impacted. Introduced pests such as rats or mosquitos are known to compromise human health under certain circumstances and the control of these species takes a toll on the national economy. In the United States, more than $120 billion is spent annually to repair damages associated with invasive species infestations (U.S. Fish and Wildlife Service).

Aquatic Invasive Species (AIS)

Aquatic invasive species, which include both plants and animals, are organisms that live either in, on, or next to water (USDA). Plant species can be free-floating, attached and emerged, or submerged (Clout 2009). Often, these organisms can be transported within and between ecosystems relatively easily by various recreational means, such as boating or swimming. Plants like milfoil that reproduce via fragmentation pose increased transmission risks because of their ability to re-root themselves entirely. Full plants and fragments collect on boat motors, hulls, bilges, trailers, and anywhere that may come into direct or indirect contact with marine life. For example, zebra mussels can be transported unintentionally when ballast water is exchanged between ships (U.S. Fish and Wildlife Service). Aquatic invasive plant species may spread within a body of water to previously unaffected regions, or they can be completely relocated to other nearby or distant bodies of water. Once a non-native weed is introduced into a body of water, it may prompt resource complications. Due to some aquatic invasive species being completely submerged in water, the discovery of these species introductions may be hindered for months, or even years. Dense, undiscovered patches of recently-introduced aquatic species may overcome the reproductive aptitude of local organisms. Management of aquatic pests is not uniform due to the variability in life histories, ecological impacts, and reproductive habits (Clout 2009).

Presence of Milfoil in New Hampshire



(Center for Invasive Species and Ecosystem Health)

Figure 1. Myriophyllum Heterophyllum Presence in the United States

Milfoil was first discovered in New England in 1932, but its source is unknown. It is likely that the plant was brought to the area by boating equipment or fishing equipment. Milfoil plants are sometimes used as aquarium plants, so a dumped home aquarium is also a possible source (NH DES). Aquatic invasive plant species were first discovered in New Hampshire in

1965 in Lake Winnipesaukee (Weed Control Course for Divers and Tenders 2016). More than 70 waterbodies are currently infected with variable milfoil. Since the discovery of variable milfoil can be difficult, it is possible that more waterbodies are infected than have been discovered. Boater registrations in New Hampshire increased by 20% between 1997 and 2006, which could have proliferated milfoil dispersal within the state (Weed Control Course for Divers and Tenders 2016). The state continues to monitor native and invasive organisms and regularly updates dispersal laws to reflect conservation efforts. It is illegal to transport, collect, sell, transplant, and propagate invasive species in New Hampshire (NH Department of Agriculture, Markets, and Food). Although the transportation of invasive species in illegal, the law is often overlooked and unenforced.

The Weed Watching Program sponsored by New Hampshire Department of Environmental Services provides training to local communities about identifying milfoil. Lake Hosting programs throughout the state monitor boat ramps in busy locations to ensure that no fragments or other invasive organisms are being transported. Volunteers and paid workers inspect boats, trailers, motors, and ramps for plant material. Inspection of boats is voluntary and boat owners have the right to refuse a boat examination.

Life History

Variable milfoil is a submerged aquatic plant that is native to the Southeastern and Midwestern United States. The number leaves in a whorl, leaf arrangement, and number of leaflets may vary between plants, thus presenting challenges in identification (Weed Control Course for Divers and Tenders 2016). This non-native species experiences maximal growth locations where sunlight can easily reach the bottom of a body of water. Since variable milfoil is dependent on sunlight to grow, plants usually do not grow past 15 feet below the surface. Milfoil is generally tolerant of varying chemical conditions, which enables it to adapt and spread quickly within and to other waterbodies and under optimal conditions, variable milfoil may grow up to 1 inch per day (NH DES).

Reproduction

Variable milfoil reproduces through seed production, fragmentation, rhizome division, and arching between root crowns (Weed Diver Couse for Diver and Tenders 2016). Out of all forms of reproduction, fragmentation proves to be the most common method in which milfoil spreads throughout an ecosystem.

Fragmentation occurs as a result of natural forces and human influences. Oftentimes milfoil gets caught on boat motors, thus producing fragments of varying sizes that float on the surface of the water. These fragments are carried by wind, other organisms, water currents, and an array of other natural and human-influenced means. Fragments as small as 2 inches can potentially re-root themselves if presented the opportunity under favorable conditions. Seed and rhizome reproduction are contributors to the dispersal of the plant, but do not pose as great of a risk as fragmentation distribution. If not all plant fragments are removed and collected properly during management, milfoil may still flourish from rooted segments or fragments that have been produced during removal. Each fragment that is let loose into the ecosystem has the potential to grow into an entirely new plant.

Anthropogenic Dispersal

Humans play a significant role in both the spread and management of aquatic invasive species. As mentioned previously, recreational activities play a contributing role in the introduction of nuisance species. Fragmented milfoil is transported on boat hulls, bilges, motors, anchors, and trailers. Motors that run in shallow regions shred rooted milfoil plants into fragmented pieces that may infests other areas nearby or downstream. Boaters often unknowingly carry invasive plants on their boats, fishing equipment, and recreation gear. Milfoil's ability to fragment and collect on portable objects prompts unintentional dispersal of variable milfoil within lakes. Boaters that move their vessels to various bodies of water each season can transport milfoil fragments to previously unaffected waterbodies.

Dense mats of weeds block vital passageways, intrude designated swimming areas, and interfere with fishing activities. Non-native infestations even lower property values in certain areas. Not only can aquatic aliens cause of economic and recreational difficulties, but they can introduce hazardous circumstances for humans. Swimmers may become entangled in dense plant mats and boaters may become stranded if motor blades are overcome by plant fragments. The dangers that aquatic nuisance species have introduced and the unknown possibilities of proliferation require global, national, and regional management efforts.

Preventative measures can be taken to limit the dispersal of milfoil and other AIS from habitat to habitat. Fishing, boating, diving, and swimming equipment could be washed before and after entering a waterbody. Any fragments that are found should be disposed properly. The NH DES should be contacted if any suspicious plant material is found so that action can be taken against possible AIS infestations.

Milfoil Removal Techniques

There are many ways in which milfoil infestations can be managed. Milfoil can be removed by hand-pulling, diver-assisted assisted harvesting, chemical treatments, barrier mats, and biological controls. Removal techniques are continually being tried, tested, and improved. Many organization employ Integrated Pest Management (IPM) techniques to reduce environmental impacts, but all methods of removal may present additional environmental consequences.

Chemical Treatment

Treatment with chemicals including selective and non-selective herbicides such as 2,4-D, diquat, fluoridone, Triclopyr, Renovate, and copper sulfate are commonly used to exterminate aquatic invasive plant species (Weed Control Course for Divers and Tenders 2016). Selective herbicides applied to bodies of water at low concentrations can effectively target milfoil without affecting native species, but chemical resistance may arise. Non-selective herbicides have the oftentimes kill native species and harm the livelihood of other organisms. New Hampshire law requires that chemical herbicides only be applied by licensed applicators. Multiple follow-up treatments may be necessary year to year.

Bottom (Benthic) Barriers

Bottom barriers are utilized to halt the growth of milfoil in densely populated areas. Mats intend to compress aquatic plant life and block sunlight from reaching bottom sediments to prohibit all aquatic plant growth from succeeding, which includes invasive milfoil and other native plants that may be present. They are made of different materials such as plastic, burlap, synthetics, or other woven fabrics and typically run from $0.22 to $1.25 per square foot (Washington State Department of Ecology). Installation is favorable when minimal plant life is present in the intended barrier location. While barrier mats are often effective in prohibiting the growth of milfoil, they do require persistent maintenance to ensure effective obstruction of plant life. Boats motors, anchors, fishing hooks, and wildlife may unintentionally damage barrier fabrics, thus reducing effectiveness and increasing safety hazards.

Biological Control

The only form of biological control known for invasive milfoil is the milfoil weevil, *Euhrychiopsis lecontei.* The milfoil weevil is an aquatic beetle species native to North America whose presence has been associated with declining milfoil populations. This beetle feeds and reproduces on milfoil plants throughout the duration of its lifetime (Illinois EPA). During the larval stage, milfoil weevils feed upon the tips of plants and stem tissues, which damages a plants' ability to deliver nutrients (Illinois EPA). Milfoil plants often die as a result of weevil intrusions. Various studies have indicated that introducing 1.5 to 2 milfoil weevils per milfoil stem is adequate in controlling invasive milfoil plants (State of Washington Department of Ecology). Biological control using milfoil weevils is preferable in comparison to other forms of biological control, as they are native to the United States. Although minimally intrusive to North American ecosystems, milfoil weevils are typically not successful in eliminating milfoil infestations, and additional milfoil removal techniques are often employed concurrently. Further research is necessary to assess their impact and effectiveness.

Hand-pulling

Hand-pulling is an effective technique to utilize if milfoil is lightly scattered in small patches. Target areas are usually surveyed from the surface and individual plants or patches are often marked with buoys prior to hand removal. Grid-system approaches are sometimes utilized to keep track of target removal zones to ensure complete and efficient coverage (Lake Ellwood Association).

Once a target patch has been identified, individuals dive to the bottom of the waterbody and use their hands or a tool to penetrate the bottom of a body of water to eradicate entire root crowns (State of Washington Department of Ecology). Plants that are pulled out are placed into a collection container or a suction device to be transported to the surface (State of Washington Department of Ecology). Collection containers such as bags are brought up to the surface and emptied once full. Entire plants must be placed into bags with caution to avoid fragmentation. Balling, stuffing, sweeping, and lemming are all acceptable bagging techniques and plants should be bagged into, not against the current (Weed Control Course for Divers and Tenders 2016). When bottom sediments are thick or rocky, it is much harder for divers to uproot milfoil crowns. Areas with loose bottom sediments are ideal for hand-pulling. Root crowns that are not completely eradicated have the potential to regrow, further compromising the health of an ecosystem (Personal Communication, Ted Aldrich 2016). While underwater, divers must maintain proper buoyancy to ensure that bottom sediments and rooted plants are not disturbed by equipment or appendages. If bottom sediments are disturbed, it could lead to decreased visibility, resulting in slower hand-pulling, misidentification, and the failure to remove target populations.

Certain conditions must be met to responsibly, safely, and legally manage milfoil through diver removal. Hand-pulling and DASH activities employed in New Hampshire require a Weed Control Diver specialty certification to assure that individuals are able to correctly identify and pull aquatic without harming the environment. Without this certification, perpetrators can be charged up to $2,000 per diving violation and if an invasive species removal permit is not acquired through the Wetlands Bureau, felony charges may be indicted (Weed Control Course for Divers and Tenders 2016). Permits should be acquired through the New Hampshire Department of Environmental Services Exotic Species Program. Documentation of removal activities is integral to the proper management of aquatic invasive species.

Hand-pulling is not possible without surface support. Tenders monitor current weather and water conditions, watch for boats, collect floating fragments, and most importantly, track the movements of underwater divers. Milfoil that is collected must be properly contained until disposal and should be handled in a manner that prevents further spread. This may include moving milfoil masses away from open water and covering exposed plants to evade dispersal by natural elements such as wind or wildlife. Boats, dive equipment, and any instruments used during the removal process should be washed appropriately at the end of each dive.

In comparison to other techniques, hand-pulling is minimally intrusive and typically does not harm the livelihood of an ecosystem. Direct removal of individual plants can be achieved through careful planning and execution. No new organisms or chemicals are added to the system, no wastes are produced, and native organisms are typically not harmed during this process. Although hand-pulling is negligibly destructive to ecosystems, it may contribute to continued dispersal. Milfoil fragments that develop through hand-pulling can re-root, leading to the growth of new plants. Also, if root crowns are not fully uprooted, plants can regenerate (Weed Diver Course for Divers and Tenders 2016). Hand-pulling is not always effective in areas with compact sedimentation because it compromises a diver's ability to penetrate milfoil root crowns. Proper and careful technique is necessary to prevent further habitat damage.

Many organizations contract certified divers through private milfoil removal companies, while other groups fund interns or seek volunteers to reduce hand-pulling management costs. The cost of a Weed Diver Control certification is around $150 and the cost for an organization to contract a hand-pulling dive team is highly variable, depending on the amount of milfoil to be removed, the size of the dive team, and the amount of crew hours that will be required to complete the given task. Hand-pulling can only be employed as the weather permits which usually limits harvesting periods to warmer, summer months. Milfoil removal by hand-pulling is a long-term commitment that calls for many years of continued investment and application.

Diver-Assisted Suction Harvesting (DASH)

Hand-pulling removal can be paired with a suction device to eradicate greater quantities of milfoil per dive. DASH is especially effective in areas of high milfoil density. The intention of

DASH is not to directly harvest milfoil from the soil, but to provide a means of efficient transportation for removed plants from collection zones to the surface (Weed Control Course for Divers and Tenders 2016). The basic removal technique is the similar to hand-pulling, but DASH replaces milfoil collection bags with portable suction hoses. Hose nozzles often feature handles for divers to hold to ease underwater navigation. Once a hose is carefully navigated to a milfoil patch, divers hold the nozzle steady and slowly input milfoil plants and fragments into the suction hose. Divers shake root crowns away from the suction nozzle to minimize debris and sediments that may collect in above-water holding tanks (Lake Ellwood Association). If a root crown is shaken, divers must be sure locate and collect any fragments that may have resulted from hand-pulling. Using this approach, hoses can be moved underwater from one spot to another with ease and diminish the likelihood of hose entanglement. The hose can also be utilized to suction debris that may be compromising visibility.

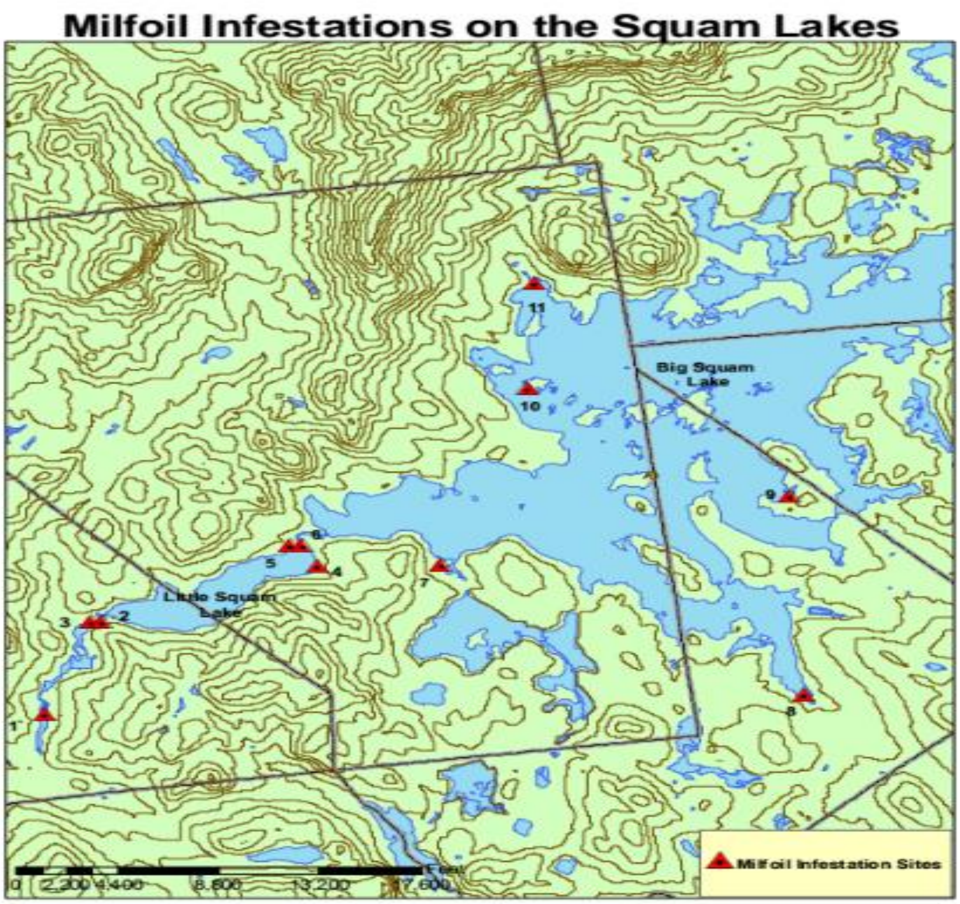
Vacuums are typically around 6 inches in diameter and carry the milfoil that is pulled underwater up to the surface, either to a stationary boat or a landmass where the plants are collected, sorted, and stored appropriately. The methods associated with filtering and separating plant material above the surface may vary greatly, along with individual DASH system set-ups. There is no uniform construction of DASH mechanisms, but many systems generally share basic components. The DASH system works like a vacuum system in which pumps, motors, hydraulics, and various filtering devices work simultaneously to provide an efficient plant transportation process.

DASH is efficient, but may disturb native organisms. Vacuum harvesting does not only collect plants that are directly placed into it, but it also collects anything that meets the nozzle. This can include native plants, small aquatic organisms, and bottom sediments. Drawing up large amounts of sediments such as small rocks or mud can clog filters and reduce suction capabilities. Small organisms may be drawn into the hose and relocated from their natural habitat. Sound and vibration disruptions produced by DASH place stress on organisms above and below the surface. Systems are costly to build and the manual labor, fuel, and upkeep costs prevent some organizations from employing this method of removal. DASH, along with hand-pulling typically require years of continued use to significantly diminish milfoil infestations. Despite a few drawbacks, these devices improve visibility and transport plants quicker than hand-pulling and bagging.

Methods

Two different bodies of water located in New Hampshire were assessed to determine the efficiency of DASH. Squam Lake (Carroll County, Grafton County, and Belknap County) and Lake Winnipesaukee (Belknap County and Carroll County) are featured in this study. Data were provided by the Squam Lakes Association and NH Department of Environmental Services.

Squam Lake

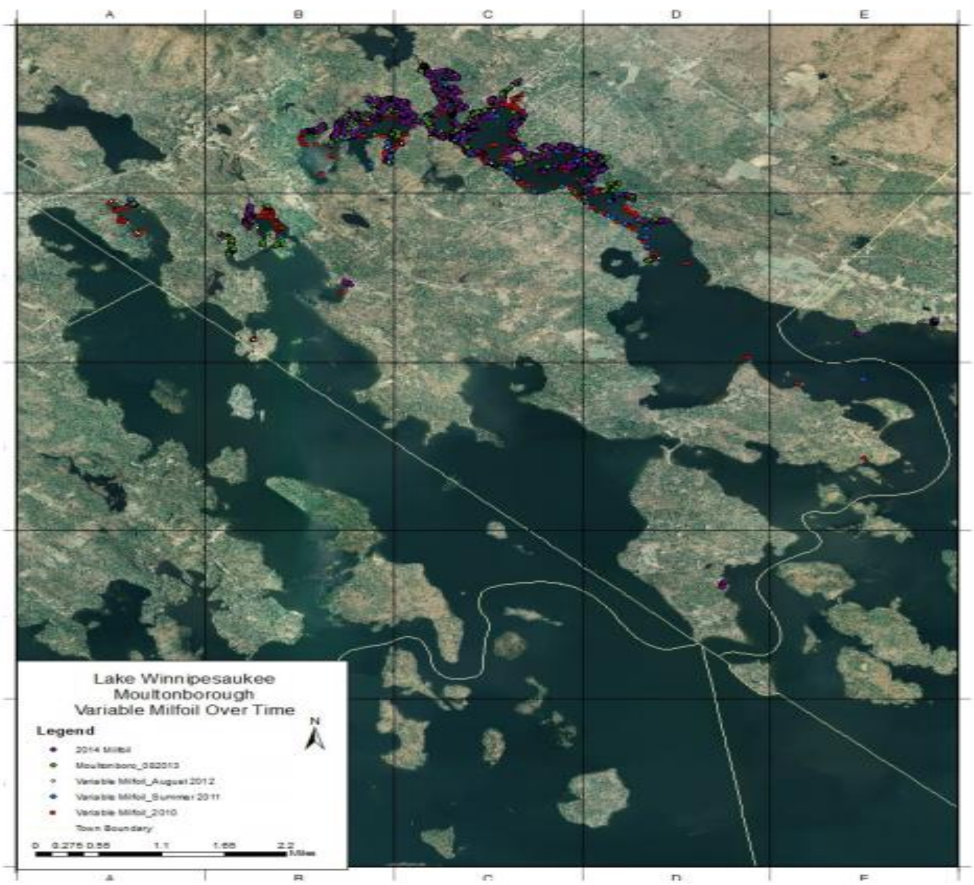


(Squam Lakes Association)

Figure 2. Milfoil Infestations on Squam Lakes

Squam Lake has a surface area of 6,765 acres with 60.5 miles of shoreline (Squam Lakes Association). The Squam Lakes Watershed includes ten major bodies of water including Big Squam, Little Squam, and the Squam River. Milfoil was first discovered in this waterbody in 2000 and aquatic invasive management is mainly accomplished through hand-pulling, benthic barriers, and DASH (Squam Lakes Association). Squam Lakes contains a number of public boat ramps and designated swimming areas, which make it a susceptible to further milfoil dispersal. Data were provided by the Squam Lakes Association (2008-2015).

Lake Winnipesaukee



(Winnipesaukee Gateway)

Figure 3. Lake Winnipesaukee Milfoil Infestations

Lake Winnipesaukee has a surface area of 44,586 acres and includes 240 miles of shoreline (Winnipesaukee Gateway) Since the initial introduction to Lake Winnipesaukee in the

1960s, milfoil has been spreading throughout most areas of this body of water (NH DES). For the past 10 years, the water quality of the lake has shown a negative trend (Winnipesaukee Gateway). Moultonborough Bay, an area of the lake heavily infested by milfoil, challenges the integrity of economic activities and overall health of the waterbody. Data were prepared by NH Department of Environmental Services (2014).

Data Analysis

Squam Lakes

Table 1. Summary of Squam Lakes Milfoil Removal and Efficiency

Year	2013			2014			2015		
Method	Gallons Removed	Crew Hours	Gallons/Hour	Gallons Removed	Crew Hours	Gallons/Hour	Gallons Removed	Crew Hours	Gallons/Hour
DASH	2139.5	392.1	5.5	2755	443.8	6.2	1237	343	3.6
Hand-pull	165	252.6	0.7	130	458.3	0.3	221.95	602	0.4
DASH and Hand-pull	674	248	2.7	1440	339	4.2	536	292.6	1.8
Other	1	36.5	0.0	0	37	0.0	0	16	0.0
Total	2979.5	929.2		4325	1278.05		1994.95	1253.55	

The summary table shows the total gallons removed, crew hours, and the rate of removal for each method during each year. The DASH and hand-pull removal category account for days in which both methods were used, but the hours spent utilizing each method are unknown. During all 3 years, DASH accounts for greater gallons removed and gallons removed/hour than hand-pulling.

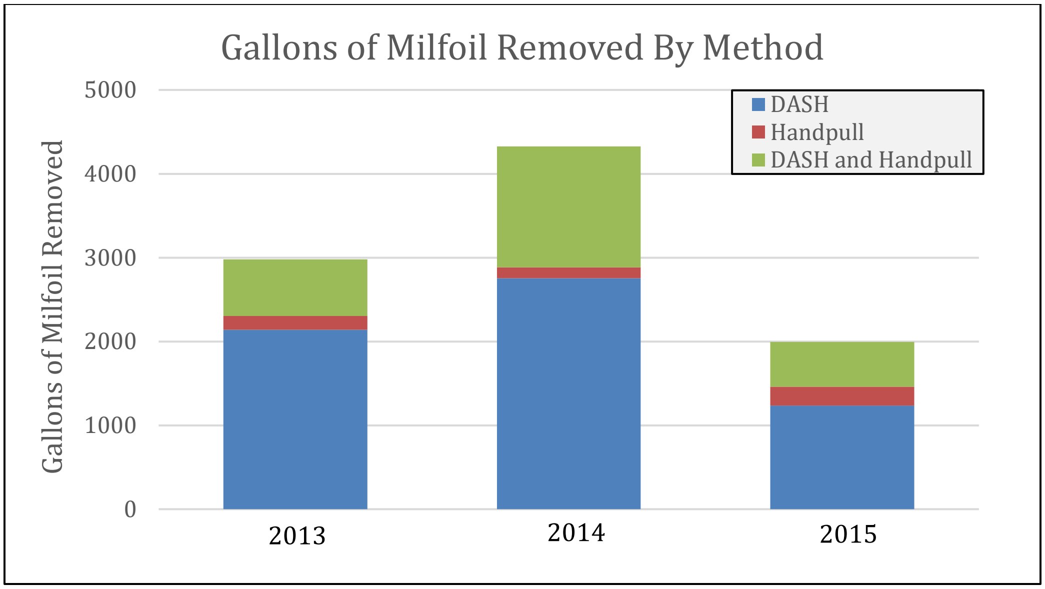


Figure 4. Gallons of Milfoil Removed Per Year by Hand-pull and DASH

The total gallons of milfoil removed at Squam Lakes by each method per year from 2013-2015 are displayed. Quantities displayed for the category DASH and and-pull (shown in green) represent the total gallons removed on work days in which both methods were employed. Almost 3,000 gallons of milfoil were removed by DASH in 2014. Hand-pulling total gallons for each year are much lower than DASH and combined DASH and hand-pull totals.

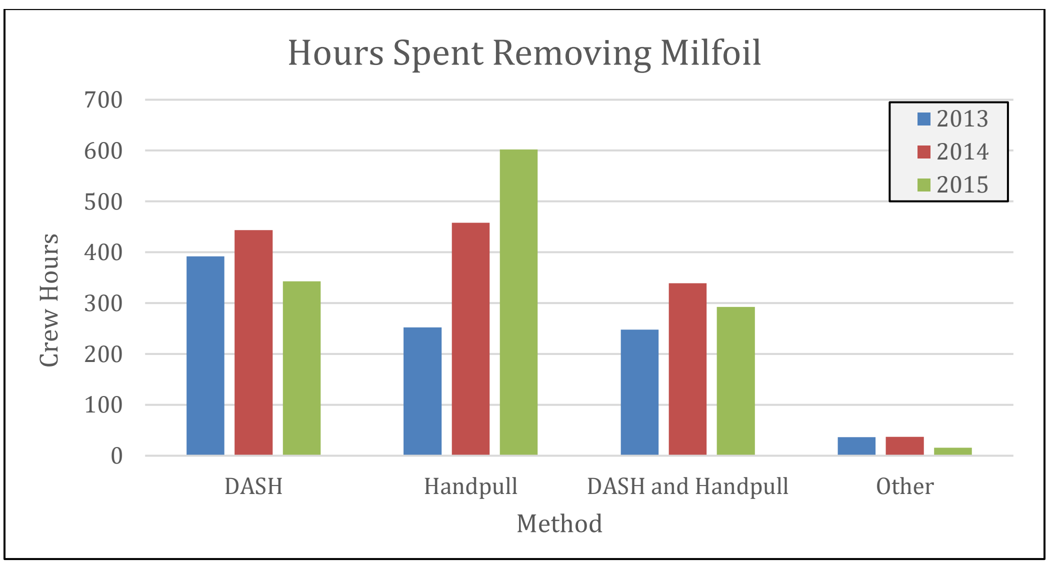


Figure 5. Hand-pull and DASH Milfoil Crew Hours

Displayed are the crew hours that were put in to each method of removal from 2013 to 2014. The Other category may include surveys or other important removal activities. Around 600 crew hours were devoted to hand-pulling in 2015. DASH crew hours range from around 340 to 440. Hand-pulling was most used in 2015 with a total of around 600 crew hours.

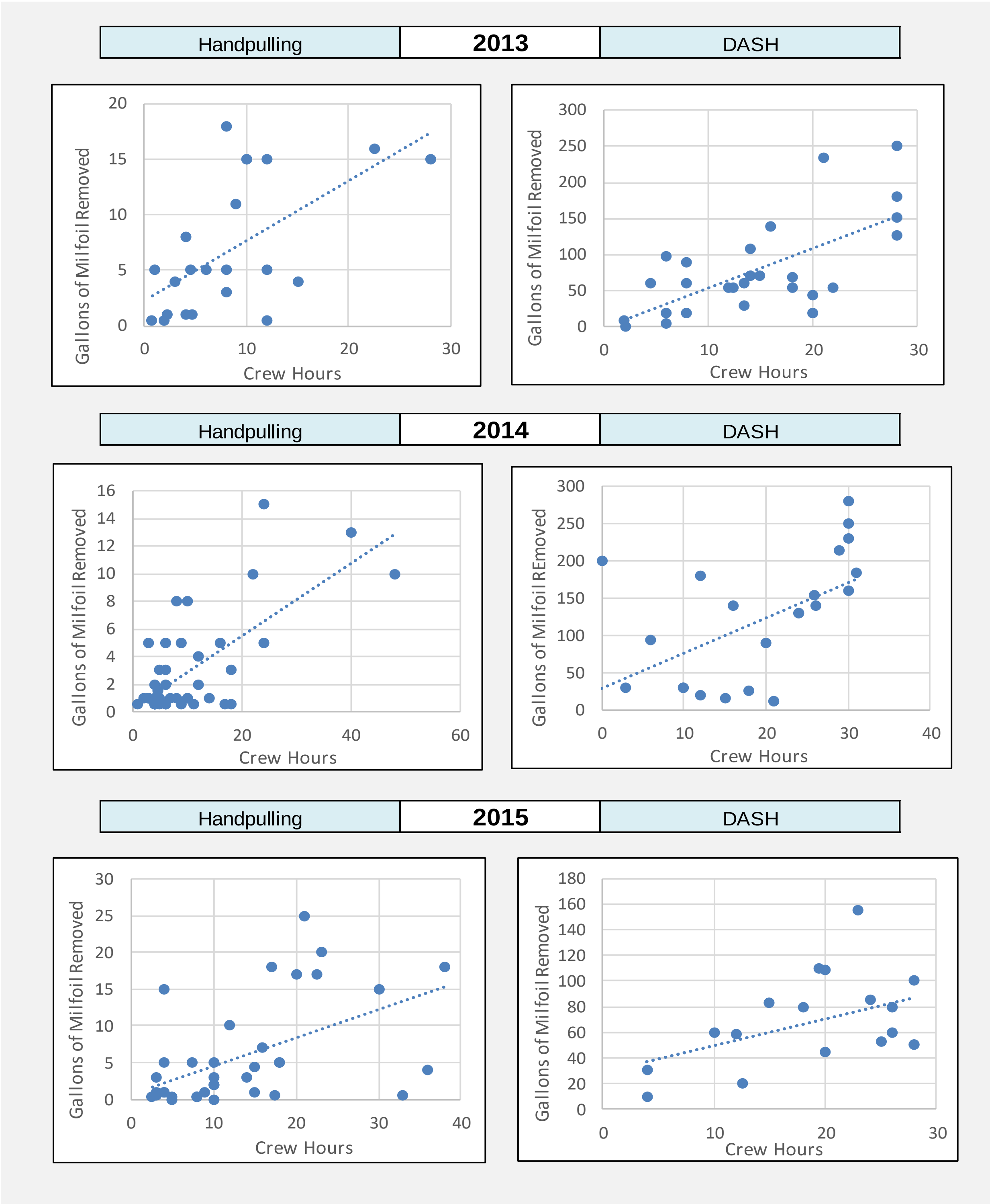


Figure 6. Crew Hours vs. Gallons of Milfoil Removed from 2013 to 2015

Each of the 6 graphs shown in the figure correspond to DASH and hand-pull results from 3 different milfoil removal seasons. All graph trendlines show a positive trend between crew hours and gallons of milfoil removed. DASH and hand-pull hours were only displayed if either method was exclusively utilized during that work day.

Table 2. Regression Analysis Results of Crew Hours and Gallons Removed

Year	Method	P Value	R	R^2	SE	Observations
2013	Hand-pull	0.03691	0.42805	0.18323	5.52300	24
	DASH	0.00012	0.67425	0.45462	49.17757	27
2014	Hand-pull	0.00000	0.70552	0.49776	2.50320	47
	DASH	0.01125	0.51853	0.26888	74.79112	23
2015	Hand-pull	0.00118	0.51259	0.26275	6.13394	37
	DASH	0.05485	0.45985	0.21146	32.54508	18

Shown above are the results of multiple linear regressions using crew hours and total gallons of milfoil removed as variables. The p-value, R, R^2, standard error, and the number of observations are displayed. An alpha value of 0.05 was used to determine if p-values are within the 95% confidence interval. The p- values for 2013, 2014, and 2015 hand-pull are all below 0.05, indicating that the null hypothesis stating that the there is no correlation between the two variables is rejected. We fail to reject the alternative hypothesis for these values. The p-value for 2015 DASH of 0.054 is greater than 0.05, which means that we fail to reject the null hypothesis, ascertaining that we are not 95% confident that there is a correlation between crew hours and total gallons of milfoil removed for DASH utilized in 2015.

Table 3. Squam Lakes Rate of Removal T-test Results

Year	Method	Mean	StDev	Observations	Df	P-value
2013	Hand-pull	0.96	1.05	24	19	1.85E-06
	DASH	5.59	3.92	27		
2014	Hand-pull	0.31	0.3	47	21	2.69E-06
	DASH	5.98	4.18	22		
2015	Hand-pull	0.47	0.66	37	30	3.83E-07
	DASH	3.92	1.88	18		

A t-test was performed to evaluate the difference in average gallons removed per hour using DASH and hand-pulling. The mean, standard deviation, number of observations, degrees of freedom, and p-values are calculated for each method between 2013 and 2015. All DASH means that range from 3.92 to 5.59 are significantly than hand-pulling means which are all lower than 1. However, DASH use is associated with higher standard deviations for each year. The p-values for all years are significantly lower than the 95% confidence interval using an alpha of 0.05.

The null hypothesis is rejected and we fail to reject the alternative hypothesis, which states that there is a significant difference between DASH and hand-pulling removal rates.

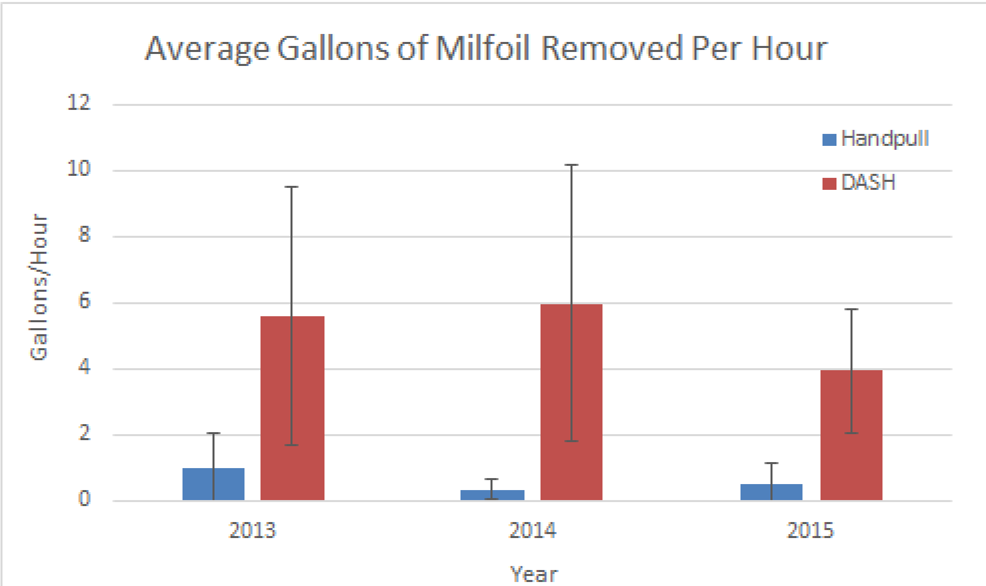


Figure 7. DASH and Hand-pull Average Gallons of Milfoil Removed Per Hour

Displayed are the average gallons of milfoil removed per hour by each method for each year. It is clear that hand-pull averages are much lower than DASH averages. The standard deviation is much higher for DASH than it is for hand-pulling every year, ranging from 3.92 to 4.18.

Lake Winnipesaukee

Table 4. Lake Winnipesaukee Total Gallons Removed T-Test

Year	Method	Mean	StDev	Observations	DF	P-Value
2014	Hand-pull	9.08	8.56	37	103	7.58E-14
	DASH	64.56	61.04	95		

A t-test was performed during 2014 to compare the gallons of milfoil removed by DASH and hand-pull. The mean, standard deviation, number of observations, degrees of freedom, and p-value are displayed. The mean for DASH is around 55 gallons higher than that of hand-pulling, although its standard deviation of 61.04 is much higher. The p-value of 7.58E-14 is much lower than the 0.05 alpha value for 95% confidence so the null hypothesis is rejected and we fail to reject the alternative hypothesis. There is a significant difference between the gallons of milfoil removed by DASH and by hand-pulling.

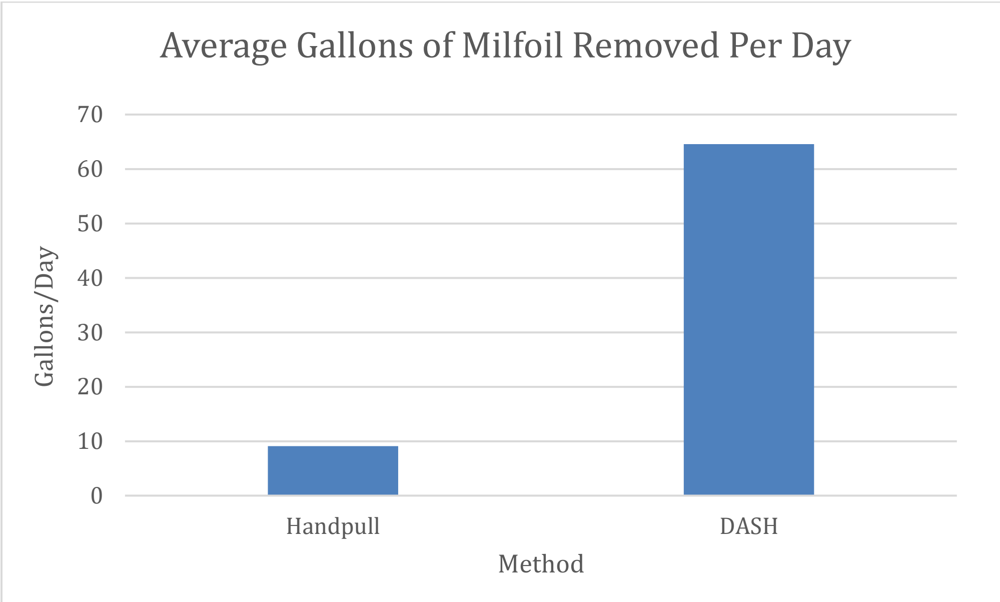


Figure 8. Average Gallons of Milfoil Removed Per Day Using DASH and Hand-pulling

DASH and hand-pull average gallons removed per work day are displayed. Hand-pull has a much smaller mean of 9.08 gallons/day whereas DASH has a mean removal rate of 64.56 gallons/day.

Discussion

It was found that the original hypothesis is supported in this study. The hypothesis states that DASH will remove greater amounts of milfoil than hand-pulling. For Squam Lakes from 2013 to 2015, greater amounts of milfoil were removed per hour using DASH than hand-pull. Greater amounts of milfoil were removed per day using DASH at Lake Winnipesaukee in 2014. All t-tests resulted in miniscule p-values that were much lower than the 95% confidence interval level of a 0.05 alpha value.

This study also supports the hypothesis that there exists a correlation between the number of hours worked per day and the gallons of milfoil removed at Squam Lakes. All 6 p-values for each year and corresponding method resulted in low p-values except for the p-value of 2015

DASH which was 0.054. This could be due to a low observation number of 18, which is the lowest of all other observation values that range from 23 to 47.

Study Limitations

While this study analyzes the efficiency of DASH, it does not provide any analysis of effectiveness. It is supported that DASH use results in greater amounts of milfoil removed per hour, day, and year, but little is known about the complications that DASH could introduce to an ecosystem. Hand-pulling and DASH involve uprooting aquatic plants, which inevitably creates unwanted fragmentation. Fragments that are created are often collected by dive tenders, but there is no certainty that all fragments will be collected before the end of a work day. This could lead to fragments re-rooting themselves in the same location that plants were pulled, or to new locations that were unaffected by milfoil prior to the use of diver-related removal techniques. Along with fragmentation, the way a plant is uprooted can be a cause for concern. All root bulbs must be removed completely for a milfoil plant to be removed effectively. If any major roots are left behind, it may lead to potential regrowth of a plant that was once thought to be removed. It only takes one left-behind plant to induce unwanted infestations. The quality by which an individual diver or dive team is successful in uprooting milfoil, gathering all plants in a specific area, and assuring that all plant segments are collected into a bag or vacuum hose are subjective. Bottom sediments such as rocks could affect a diver's ability to effectively remove a rooted plant. Not all divers utilize the same removal techniques and it is difficult to ensure that divers are removing each plant appropriately every time a dive takes places. The removal philosophies held by individuals and organizations may be influenced by cost, efficiency, and their personal connections to affected bodies of water. The time that each individual devotes to removing each individual milfoil plant effectively varies greatly. Many variables influence the efficiency of milfoil removed and not all variables are accounted for in this study, nor is the effectiveness of removal analyzed.

Data that were provided present inconsistencies that may have impacted the outcome of this study. The gallons of milfoil removed for each day are not entirely reliable because the volumetric measurement of milfoil gallons may vary depending on whether the milfoil was wet or dry when evaluated. How each individual measures gallons could vary as well. Some individuals may have packed-down collected plants into measuring containers, whereas others might have measured plant masses loosely. Also, days in which both DASH and hand-pulling were utilized were left-out in this study. These data were excluded because the number of hours spent utilizing each method is unknown. Results may differ slightly if these days were included with the actual hours spent removing milfoil using each method. Data does not take into consideration how much time was spent on each day performing other tasks such as surveying, preparing equipment, taking breaks, or experiencing technical difficulties. The reasons for employing either DASH or hand-pulling on each work day are also unknown. It is likely that DASH was utilized in areas where milfoil patches are dense and hand-pulling was utilized in areas where DASH may not have been feasible or productive to run.

DASH Implications

DASH removes milfoil at much higher rate than hand-pulling, but its use may introduce adverse effects. Little about the long-term effects of DASH on an ecosystem are known. This removal technique presents a mild level of habitat intrusion, as the equipment used may place unnecessary stressors on native organisms. Some DASH engines produce noise pollution and vibrations that may impact both terrestrial and aquatic organisms. Equipment such as large vacuum hoses can potentially damage a habitat if they are not properly handled at all times. Fish and other aquatic life may become stressed if DASH is continually used in a particular area and may lead to temporary or permanent native species relocations. Variable milfoil, Eurasian milfoil, or other weeds may be misidentified by DASH divers which could lead to the accidental removal of native species or the failure to remove target invasive plants. Some argue that DASH hoses fragment more milfoil than hand-pulling alone. DASH units are costly to build and the workforce required to run such devices introduces high cost, therefore, DASH may not be economically feasible for some organizations.

Future Studies

If limitations such as time and funds were not an issue present in this study, more inclusive studies that consider other contributing variables relating to efficiency and effectiveness could be performed. To more confidently determine the rate at which DASH removes milfoil compared to hand-pulling, controlled experiments in the field that use the same controls for each method could be pursued. This will create a standard for comparison between the two methods since water conditions, removal guidelines, and specific techniques may vary between AIS removal organizations. To measure the effectiveness of hand-pulling and DASH, the conditions of areas that have utilized these methods must be tracked for milfoil reoccurrences, water quality changes, and any potential adverse effects. Future research should focus on the effectiveness of milfoil removal techniques. Only two bodies of water were analyzed in this study, so more bodies of water that utilize these techniques could be assessed.

Importance of Conservation

Humans have greatly influenced the spread of AIS both nationally and internationally, leading to the degradation of many ecosystems. Native organisms continue to be negatively impacted by the introduction of AIS and the removal of aquatic invasive species using hand-pulling, DASH, and other means is integral in preserving the quality of waterbodies. Responsible environmental stewardship involves prevention and timely, effective, and efficient eradiation of exotic species. It is important to continually monitor the presence of native species and the water quality to assess lake health and to take appropriate action against AIS dispersal. To determine the quality of a waterbody, changes in dissolved oxygen (DO), pH, nitrogen, phosphorous, temperature, turbidity, and biochemical oxygen demand (BOD) could be tracked. The values of these water quality tests may indicate clues as to what is occurring within an aquatic ecosystem. Additionally, the presence of macroinvertebrates, fish, or other native species may provide information about lake health. Species including dobsonfly, alderfly, stonefly, and water snipefly larvae which are sensitive to pollution, are indicator species and their presence aids in assessing the severity of water quality degradation. These assessments along with site-specific monitoring techniques can help protect the livelihood of native organisms. Ongoing AIS prevention, monitoring, and management is necessary in order to effectively conserve our waters.

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