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Didymo Control: Increasing the Effectiveness of Decontamination Strategies and Reducing Spread

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Didymo Control: Increasing the Effectiveness of Decontamination Strategies and Reducing Spread

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ABSTRACT: Nuisance algal blooms formed by the benthic diatom *Didymosphenia geminata* (*didymo*) have been spreading rapidly, with negative ecological and economic effects. This microscopic alga is transported on fishing equipment, and controlling the spread of *didymo* involves proper cleaning of gear. Our study experimentally tested several common decontamination treatments and determined the response of state agencies and fishermen to decontamination procedures. In testing decontamination products, we found that dish liquid detergent was the most effective, followed by bleach, Virkon, and salt. Decontaminants were more effective on cells that were not still attached to their stalks. From the fishermen's perspective, *didymo* was the aquatic invasive species of highest concern, but there was a wide range of approaches to *didymo* control. Our final recommendations concentrate on the importance of comprehensive information sources and standards for *didymo* decontamination and education, specifically, and for invasive/nuisance species more generally.

INTRODUCTION

Nonnative and nuisance species represent one of the largest threats to biodiversity in aquatic systems (Dudgeon et al. 2006). *Didymosphenia geminata*, commonly known as “*didymo*” or “*rock snot*,” is a species of diatom that is currently associated with nuisance blooms in streams. The diatom was historically widespread (Blanco and Ector 2009; Whitton et al. 2009), but the nuisance blooms appear to be a more recent phenomenon (Blanco and Ector 2009; Bothwell et al. 2009; Segura 2011), the causes of which remain poorly understood. In the northeastern United States, *didymo* blooms were officially confirmed in 2007 in New York, Vermont, and New Hampshire. Since then, *didymo* blooms have been found in five additional streams just within New York—one of which was confirmed right after ice melt in March 2011. The number of affected rivers and streams is likely to continue to rise across the United States in the future (Kumar et al. 2009).

Like many nuisance species, *didymo* presents both ecological and economic threats (Branson 2006; Spaulding and Elwell 2007; Kumar et al. 2009). When large mats are present, *didymo* may impact plant, invertebrate, and fish communities (Larned

Control de didymo: incremento en la efectividad de estrategias descontaminantes y para reducir la expansión

RESUMEN: Los afloramientos nocivos generados por la diatomea *Didymosphenia geminata* (*didymo*) se han expandido rápidamente, provocando efectos ecológicos y económicos negativos. Esta alga microscópica es transportada en equipos de pesca y su control implica una limpieza adecuada de los artes. En este estudio experimental se prueban varios tratamientos descontaminantes y se estudia la respuesta de las agencias estatales y de los pescadores ante los procedimientos de descontaminación. Al probar los productos descontaminantes, se encontró que el líquido detergente para trastes fue el más efectivo, seguido por los blanqueadores, el Virkon y la sal. Los descontaminantes probaron ser más efectivos en las células que aun no se encontraban fijas a su tallo. Desde la perspectiva de los pescadores, *didymo* fue la especie acuática invasiva de mayor cuidado, pero hubo una enorme variedad de enfoques para el control del alga. Las recomendaciones finales se concentran, de manera general, en la importancia de fuentes de información comprensibles, estándares para la descontaminación por *didymo* y educación, y de manera particular en el control de especies invasivas/nocivas.

et al. 2007; Bergey et al. 2009; Blanco and Ector 2009; Kilroy et al. 2009; Gillis and Chalifour 2010; James et al. 2010). Impacts to aesthetics are common, with reports of unsightly masses that appear like strands of toilet paper, generating mistaken public concerns about sanitation and sewer malfunctions (Kilroy 2004). The heavy, slippery brownish mats degrade swimming areas, although direct human impacts may be limited to swimmers complaining of eye irritation after swimming in affected areas (Kilroy 2004). Economic impacts include fouling of water intakes that can affect water supply (Kawecka and Sanecki 2003) and, in heavily infested areas, *didymo* may be linked to a decline in tourism and freshwater angling, particularly fly fishing. In the United States, fly fishing is a \$0.9 billion dollar industry that involves 5.6 million people (The Outdoor Foundation 2010). Fly fishermen spend an average of 15.6 days fishing each year and about half of all excursions are overnight trips, which provide additional benefits to local economies (Outdoor Industry Association 2006).

The appearance of *didymo* blooms in new streams has generally been linked to fly fishing activity and the use of felt-soled waders (Bothwell et al. 2009). When *didymo* appear in new

locations, the spread is usually related to the fishing industry—either because the site is known to be used by fly fishermen (Kilroy et al. 2008; Bothwell et al. 2009) or through fish stocking introductions (Bhatt et al. 2008). Individual didymo cells are microscopic and hard to detect on gear. Thus, they can easily be transported between streams, and the felt sole common on most waders acts like a sponge that is able to hold enough water to keep didymo cells alive and viable for up to 40 days (Kilroy 2005, cited by Spaulding and Elwell 2007). Even cleaning or soaking felt soles with disinfectant products is not enough to ensure that all didymo cells are dead, because the disinfectant products may not thoroughly reach the innermost parts of the soles (Kilroy et al. 2007).

Our work on didymo in New York streams indicated that there were large discrepancies in how fishermen were being alerted to the presence of didymo and how they were being advised to treat their gear for didymo. Though there were signs warning fishermen about didymo on the Ausable River (didymo-free), the Esopus Creek, where didymo was first reported in 2007, did not have signage at all fishing access points. On the Battenkill River in Vermont, signs advised fishermen to clean gear in “HOT tap water and lots of soap ... for 30 minutes,” whereas on the same stream across the border in New York they were told to “soak all equipment for 10 minutes with a household cleanser/disinfectant containing alkyl dimethyl benzyl ammonium chloride.” In general, the U.S. Environmental Protection Agency recommendations are to “check–clean–dry” using 2% bleach, 5% salt water, or dishwashing detergent (Spaulding and Elwell 2007).

In actuality, very little work has been done to evaluate the effectiveness of decontamination methods. A broad survey of more than two dozen decontamination methods was carried out for Biosecurity New Zealand in 2006–2007 (Kilroy et al. 2007). This study included a wide range of decontamination techniques, such as heating/freezing, drying, submerging in seawater, and applying a cleaning product or detergent, over a time range from 1 min to 48 h. Some of the most commonly used decontaminants (detergent, 2% household bleach, 10% salt water, and 1% Virkon Aqua [an aquatic disinfectant]) were all said to be 100% effective at killing didymo cells after a 1-min submersion. However, as Kilroy et al. (2007) pointed out, this study did not resolve all of the important questions. This study was done only one time, and similar experiments have not been repeated for other regions or at different stages during didymo blooms.

In order to maintain the quality of the mountain streams around the United States, a universal method for controlling didymo must be established with effective outreach and education. To address this, our study examined two components that are critical to decontamination. First, we experimentally evaluated the effectiveness of four commonly used and recommended products (detergent, bleach, salt water, and Virkon Aqua) twice during the summer season using didymo in New York. Second, because didymo control is dependent in part on how informed people are and whether they take action, we also surveyed how

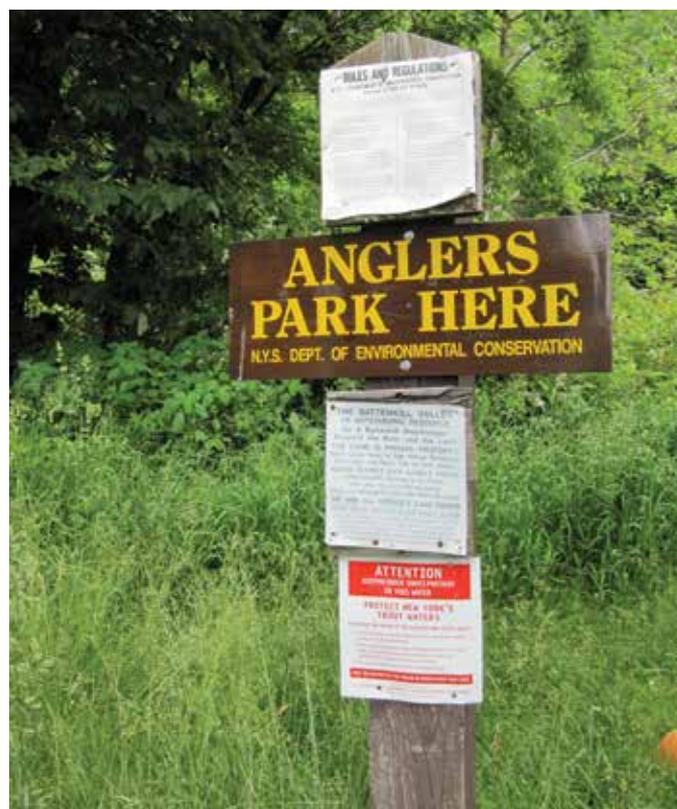


Image 1. There are several information signs posted at fishing access sites on the Battenkill River in New York State. Photo credit: Samantha Root.

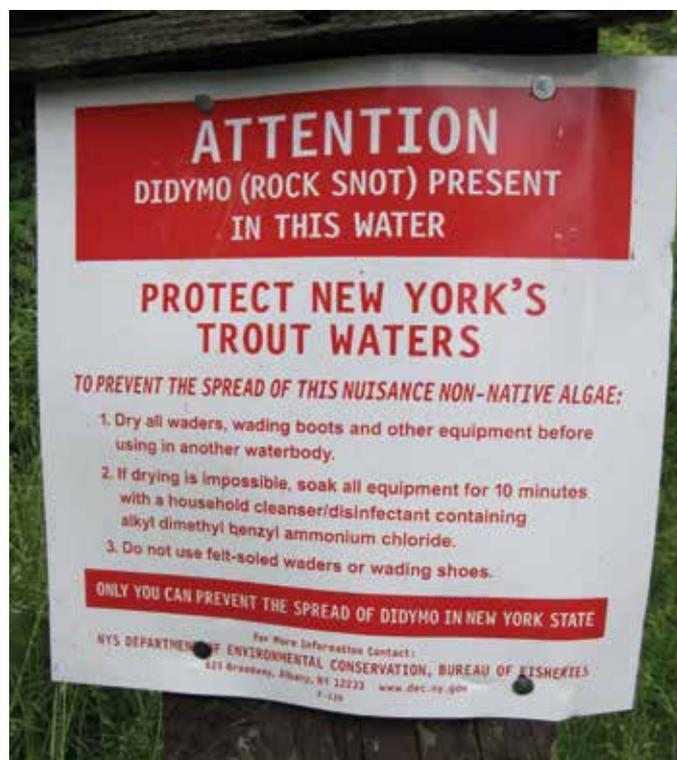


Image 2. Didymo information signs posted at the Battenkill River and other streams in New York recommend drying fishing gear or cleaning with household cleanser/disinfectant. Photo credit: Samantha Root.

fishermen were responding to didymo and then compiled the information provided by different state agencies in the north-eastern United States. Finally, we synthesized our information to present some general recommendations regarding control of didymo, with broader implications for the management of other invasive/nuisance species.

METHODS

Our study examined two different aspects of didymo control through decontamination experiments and by surveying fishermen and state agencies.

Didymo Decontamination Experiment

We investigated the effectiveness of commonly recommended decontamination products. To do this, we conducted experimental laboratory studies that compared treated and untreated didymo samples. In 2010, we chose three of the most popular decontamination treatments used by environmental agencies and households in New York State: 10% salt water, 2% Clorox® bleach, and 1% Virkon® Aqua (an aquatic disinfectant). In 2011, in an effort to find products that had a less degrading impact on the environment and on fishing gear, we chose three additional decontamination treatments: 10% Green Works® chlorine-free bleach, 5% Dawn® dish detergent, and 5% Green Works® dish detergent. Recognized by the Environmental Protection Agency's Design for the Environment Program, Green Works® products are made with plant- and mineral-based ingredients, are biodegradable, and are available in most grocery stores. Each decontamination product was diluted with tap water and stored in a 1-L Nalgene bottle. We tested the effectiveness of the decontamination products by measuring percentage mortality compared to a control of tap

water using fresh didymo samples from local blooms. Didymo-covered rocks were collected from the Esopus Creek, New York, in 2010 and the Rondout Creek, New York, in 2011 and then placed in plastic containers filled with stream water. The containers were kept in an ice-filled cooler for transport to the laboratory, where they remained at 10°C in a cold room. All tests were run within 4 days of didymo sample collection. We tested cell mortality in tap water periodically throughout July to see whether there were natural changes over time and tested every potential treatment product two different times 2 weeks apart during July.

The effectiveness of the decontaminant products was determined using a cell viability assessment. For each test, a 2 × 2 × 2 cm piece of didymo was removed from the rocks and split into two equal pieces. One piece was placed in control (tap) water and the other piece was placed in a decontaminant treatment. The samples were left in the solutions for either 1- or 5-min intervals. There were five such paired replicates for each treatment and time interval. The samples were then transferred to a 0.5% neutral red solution to stain the cells for 30 min. After the neutral red stain, subsamples of the didymo pieces were observed at 400× total magnification. Live cells have dark red spots inside the cell walls, whereas dead cells do not have any spots (Kilroy et al. 2007; Lagerstedt 2007), making it straightforward to assess percentage mortality. In 2010, for each didymo sample we assessed 200 cells: 100 cells that were attached to stalk material and 100 cells that were not attached to stalks. Because unattached cells had consistently higher mortality rates and were thus unlikely to be a major source of contamination, we simplified our live–dead analysis in 2011 to focus on counting 100 attached cells only. We used paired t-tests to examine differences in mortality between the treatment and the control and to examine the difference in mortality

between attached and unattached cells for salt, Virkon, and bleach in 2010. We used a two-way analysis of variance to compare 1- and 5-min submersion times for each treatment, taking cell attachment into account. We used Bonferroni corrections in all cases where there were multiple comparisons. We used regression analyses to look for changes in mortality of tap water–treated controls over the summer. To be conservative, we used alpha = 0.01. Data were log-transformed as necessary.

Didymo Survey

Because fly-fishing is a key vector for the transport of didymo (and is highly affected by its presence) we conducted a survey of fly fishermen. The goals of the survey were to collect information about what fishers thought regarding the

TABLE 1. Questions that were used in the online survey for this study.

Question	Response options
1. How did you connect to this survey?	One selection from list, with "other" option
2. In which state or province do you do most of your coldwater stream fishing?	One selection from list
3. How many years have you been fishing?	One selection from list
4. On a typical day fishing, how many sites do you fish? No. of rivers? No. of sites in each river?	One selection from list One selection from list
5. Which aquatic invasive species is of the single greatest concern in the coldwater streams you fish in?	One selection from list, with "other" option
6. How did you first learn about [your species of greatest concern]?	One selection from list, with "other" option
7. Do the sites where you fish most of the time have signs posted about [your species of greatest concern]?	Yes/no
8. Has [your species of greatest concern] changed where you fish? How often you fish?	Yes/no
9. How often do you clean your gear?	At the end of a trip/between every site/never
10. If you do clean, what parts of your gear do you clean?	Waders/all gear
11. If you do clean any gear, what do you do?	Comment box
12. What makes it difficult for you to clean your gear?	Multiple selections from list
13. Do you use felt-bottomed waders?	Yes/no

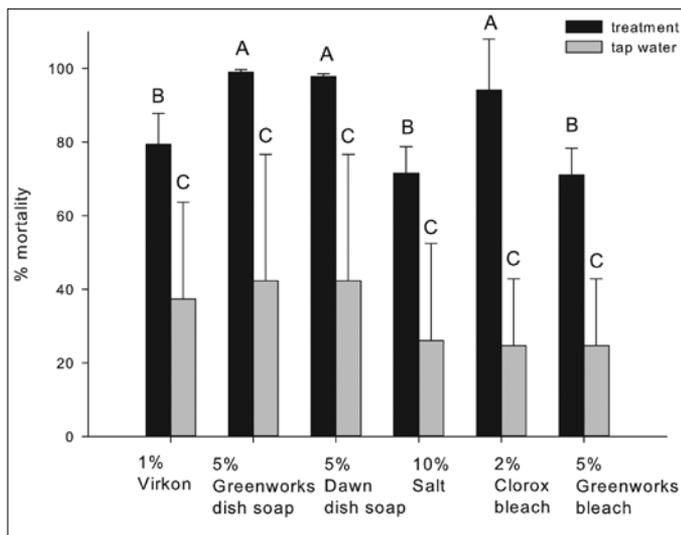


Figure 1. Effectiveness of decontamination treatments compared to a control of tap water. Treatments were significantly more effective than tap water. Letters show significant differences among the treatments. Data are means (n = 10) with standard error.

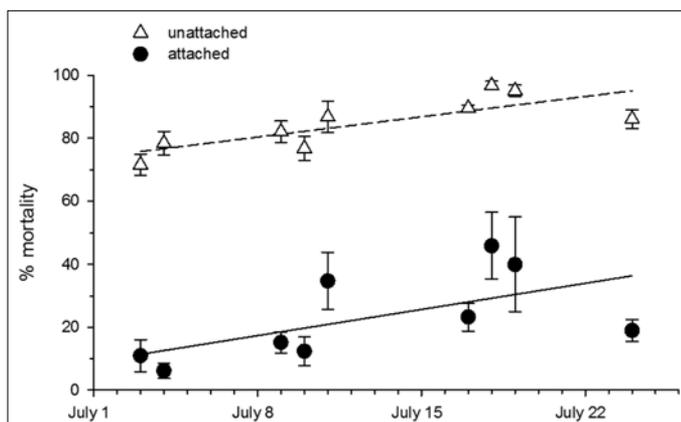


Figure 2. Mortality rates of the tap water-treated didymo samples over the course of July 2010 showed that cells attached to their stalk had significantly lower mortality than unattached cells. Additionally, didymo mortality increased significantly over the summer. Data points are means (n = 5) with standard error; lines are linear regressions.

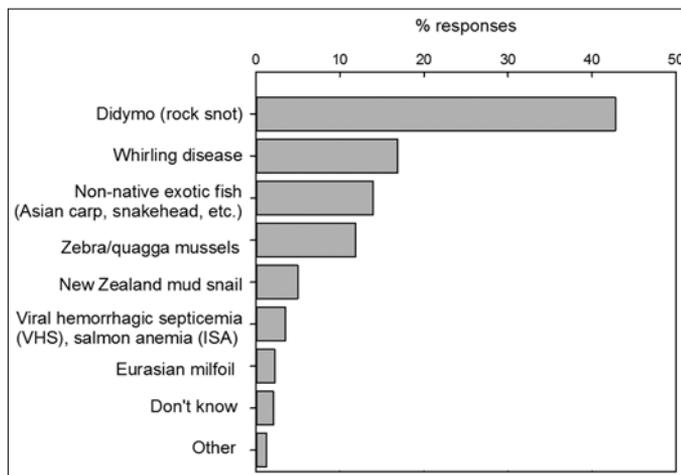


Figure 3. Fishermen's responses to the question "Which aquatic invasive species is of the single greatest concern in the coldwater streams you fish in?" (n = 623). Crayfish was the most consistent response to "other."

threat of didymo compared to other invasive species and what they did for didymo decontamination. The survey was conducted online over 8 weeks in early 2012 in collaboration with Trout Unlimited (TU), with links posted on TU's home page, blog, and Facebook and on Orvis's online newsletter, Twitter, and Facebook, and several other personal web pages. Questions used in this study are presented in Table 1. State agencies are often considered to be a primary source for regulatory and preventative information regarding invasive/nuisance species. To assess the type of information provided by state agencies regarding didymo, we focused on the northeastern United States during the summer of 2010, when didymo blooms first became a widespread emerging threat throughout that region (Maine, Massachusetts, Rhode Island, Connecticut, New York, New Hampshire, Pennsylvania, and Vermont). We determined current regulations and guidelines regarding didymo control by contacting staff at these state agencies and looking at their websites. We were interested in the following: (1) the extent to which state agencies provided information about didymo through signage and/or websites and (2) what methods the state agencies recommended for cleaning fishing gear/boats.

RESULTS AND DISCUSSION

Didymo Decontamination Experiment

We found that none of these decontamination products were 100% effective, contrary to previous work. The decontamination products were always more effective at killing didymo cells than tap water (Figure 1, paired t-test, $P < 0.0001$); the effectiveness was higher for Green Works® dish detergent, Dawn® dish detergent, and Clorox® bleach than for the other products (Figure 1; Tukey's honestly significantly different test, $P > 0.01$). Longer submersion time did not lead to significantly greater mortality for any treatment (analysis of variance, $P > 0.01$), suggesting that a 1-min submersion time is sufficiently effective for these decontamination products. However, mortality was significantly less effective on didymo cells that were still attached to stalk material compared to free-floating cells that were unattached to stalk material for both treatments and tap water (Figure 2; paired t-test, $P < 0.001$). Based on our tap water control samples, there was a significant increase in mortality for both unattached and attached cells over the course of the summer season (Figure 2; linear regression, $P < 0.001$). This increase in mortality over the summer emphasizes the importance of early season decontamination and may misleadingly cause decontamination products tested during the later weeks of the didymo bloom to appear more effective than they would be during the early weeks of the bloom. The persistent resistance of attached cells to treatment suggests that stalks may play an important role in maintaining the viability of the cell and underscores the importance of removing clumps of material from gear, where cells are likely to remain attached to their stalks.

Based on our results, both dish detergent and bleach were the most effective methods of killing attached didymo cells (Figure 1). Bleach solutions are commonly used as disinfectants

and are effective at killing other potential aquatic invaders, but bleach is toxic to both humans and the environment and slowly discolors and degrades fishing waders and gear. The dish detergent solutions offer a much less harmful alternative to humans that is also less toxic to the environment. The Green Works® dish detergent that we used is an environmentally friendly solution that is 97% naturally derived. This suggests that Green Works® or other similar dish detergents might be the best option for decontamination.

Didymo Survey—Fishermen

Six hundred and thirty-nine people responded to the survey, and the average question response rate was 76%. About half of these people initially accessed the online survey via Trout Unlimited and half via Orvis. There was wide representation from across the United States (as well as the Canadian provinces Alberta, British Columbia, Newfoundland, Nova Scotia, Ontario, and Quebec), with every state except Alabama, Delaware, Florida, Hawaii, Indiana, Kansas, Louisiana, Mississippi, Nebraska, and North Dakota represented. The responses were dominated by people who did most of their coldwater fishing in Pennsylvania (9%), New York (8%), Wisconsin (8%), Colorado (7%), California (5%), Utah (5%), Montana (4%), Michigan (4%), and Virginia (4%). Most people had been fly-fishing for more than 20 years (58%), followed by those who had fished up for up to 5 years (13%), 5–10 years (9%), 10–15 years (8%), and 15–20 years (12%).

Didymo was overwhelmingly the aquatic invasive species of most concern in the waters that people fished. Of the seven different categories of invasive species listed, didymo rated the “single greatest concern” for 43% of the responses (Figure 3). Surprisingly, 3% of respondents did not know whether there were any species of concern, and comments indicated that some fishermen had never thought about invasive species before. Fishermen’s concerns regarding invasive species came from news stories (26%) and conservation organizations (23%), as well as from conversations with friends, family, or colleagues (13%) and posted signs (9%). Relatively few fishermen first learned about the invasive species from state agency web sites (7%), fishing stores (4%), guides or outfitters (3%),

or when they got a fishing license (2%). Other reported sources of information were magazines (2%), online forums (2%), and coursework (2%). This suggests that potentially valuable contact points such as fishing stores and licensing procedures are not being effectively used to disseminate information. There was a wide range of approaches to and challenges for decontamination (Table 2). Most people conducted some sort of decontamination (81%), which was typically done at the end of a fishing trip (62%) but was only rarely done between every site (18%). Most fishermen rinsed (using hose or tap water) and then dried their gear; other typical methods were a diluted bleach or soap/detergent. A few fishermen had multiple sets of waders that they used exclusively on separate rivers. The most frequently identified challenge for decontamination was not knowing what to do or use (37%), and many comments expressed frustration regarding not knowing what treatment was most effective. Additionally, people said that they did not have the time (18%), especially with respect to letting gear dry, or have a good place to decontaminate (14%). Several fishermen used local decontamination stations (Maryland, Idaho) or mentioned that such stations should be established.

On a typical fishing day, the majority of people fish one river (60%) or two rivers (35%) and stop at multiple sites along a river. The number of sites fished was predominantly four or more (32%), followed by two to three (28%). Fishermen rarely fished at only one river site (5%). Given that decontamination while on a fishing trip is not common, the pattern of fishing multiple sites on a single river increases the likelihood of spreading didymo. Fishermen said that didymo had not affected how often they fish (95%) but has somewhat affected where they fish (20%). Fishermen’s comments indicated that they stopped fishing in infected streams either altogether or at least temporarily when the bloom was obvious. Instead, they seem to either reduce their fishing during bad blooms or switch to fishing on other streams. If fishermen are more mobile because of didymo presence, the spread to new noninfected streams is likely to be exacerbated. Sixty percent of the fishermen said that they were using felt waders at the time of the survey, and of the fishermen who were not using felt waders, most had only recently switched due to didymo, indicating that fishermen are responsive and willing to take some actions to protect stream environments.

Didymo Survey—State Agencies

Recommendations from state agencies in the northeastern United States varied widely. Some state agencies only suggested one decontamination method, whereas others offered as many as six different techniques. In New York State, identifying a proper decontamination method can be especially confusing because the signs posted at fishing access sites offer decontamination instructions that differ from the state’s Department of Environmental Conservation website. In all states, the signs and websites generally provide contact information, but this was not always considered helpful because it often resulted in unanswered phone calls, bounced e-mails, or websites that did not directly address didymo or aquatic invasive species.

TABLE 2. Responses to “How often do you clean your gear?” ($n = 590$), “If you do clean, what parts of your gear do you clean?” ($n = 502$), and “If you do clean any gear, what do you do?” ($n = 437$) were sorted and categorized to show the proportion of fishermen who decontaminated their gear and the method they used.

Decontamination?	Method	%
Yes—waders 45%	Bleach	21
Yes—all gear 36%	Other chemical	7
	Salt	3
	Dry	8
	Freeze	3
	Soap/detergent	14
	Rinse	42
	Have separate gear	3
No 19%		

WARNING

The invasive algae "didymo" is present in this river

STOP ROCK SNOT

After leaving this water:

CHECK - Remove all visible clumps of algae and plant material from fishing gear, waders, clothing, water shoes and sandals, canoes and kayaks, **and anything else** that has been in the water.

CLEAN - Using **HOT** tap water and lots of soap: **Scrub** boats and other "hard" items thoroughly; **Soak** clothes, felt-sole waders and other "soft" items for **30 minutes!!!!**

Get more information:
In Vermont, contact the VT DEC at 802-241-3777
or visit www.anr.state.vt.us/dec
In New Hampshire, contact the NH DES at 603-271-2248
or visit www.des.state.nh.us/wmb/exoticspecies

Please do your part - Don't Spread Didymo!

NEW HAMPSHIRE
DEPARTMENT OF
Environmental
Services

VERMONT
AGENCY OF NATURAL RESOURCES

Image 3. Didymo information signs posted at the Battenkill River and other streams in Vermont recommend removing visible algae clumps from all gear and cleaning with hot water and lots of soap. Photo credit: Vermont Department of Environmental Conservation.

Sign-posting by state agencies seemed to occur primarily at locations where didymo was already present, rather than at highly frequented fishing sites. In fact, fishermen indicated that sites where they fished most of the time did not have signs posted about invasive species (68%). Across the northeastern United States, posting generally seems to happen only after didymo is confirmed at that site. One exception to this was the Ausable River in the Adirondack Mountains, where signs were posted as early as 2007 but where didymo had not yet been detected as of August 2010 (at the time we conducted this survey). We suspect that our survey, though focused on northeastern states, is generally representative of the wide variety of means used to provide information to fishermen and the public across the country.

RECOMMENDATIONS

In summary, our findings lead to several broader outcomes. Our recommendations focus on two different management approaches: to (1) create more targeted and consistent outreach and education strategies and (2) facilitate and develop consistent recommendations for decontamination. Both of these goals are most efficiently accomplished by a more coordinated regional or federal effort, including collaboration between scientists and government agencies (Chapin et al. 2000). For didymo, the best management strategies will concentrate on preventing didymo cells from being transferred to new streams (Floder and Kilroy 2009) because blooms are difficult to manage (Clearwater et al. 2011).

WARNING

Attention anglers, boaters, swimmers and tubers, the invasive alga "didymo" is present in this river

The invasive alga "didymo" (a.k.a. "Rock Snot") has recently been found in the Farmington River. Didymo has the potential to alter food webs and degrade habitat in many Connecticut trout rivers.

The microscopic cells can cling to fishing gear, waders (especially those with felt soles), clothing, boots and boats, and remain viable for months under even slightly moist conditions. It is recommended that everyone entering these waters practice **CHECK, CLEAN, DRY** procedures to prevent transport to new areas:

When leaving these waters:

CHECK: Before leaving the water, remove all obvious clumps of algae and plant material from fishing gear, waders, clothing & footwear, canoes & kayaks and anything else that has been in the water. Leave them at the site. If you find any later, clean your gear and dispose of all material in the trash.

CLEAN: Soak/spray & scrub boats and all other "hard" items for at least one minute in either very hot (140°F) water, a 2% bleach solution, or a 5% dishwashing detergent solution. Absorbent materials such as clothes and felt soles on waders should be soaked for at least 40 minutes in very hot water (140°F), or 30 minutes in hot water (115°F) with 5% dishwashing detergent. **FREEZING THOROUGHLY WILL ALSO KILL DIDYMO.**

DRY: Drying will also kill didymo, but items must remain completely dry (inside and out) for at least 48 hours.

Thank you for your cooperation!

State of Connecticut
Department of Environmental Protection
Bureau of Natural Resources
Inland Fisheries Division
www.ct.gov/dep

For more information contact:
860-424-3474
des.inlandfisheries@ct.gov

Image 4. Didymo information signs posted on the Farmington River in Connecticut have the most cleaning recommendations of all states in the Northeast. Photo credit: Connecticut Department of Environmental Protection.

As for didymo treatment, we recommend that states consider and encourage the installation of decontamination stations at easily accessible locations, as has been done throughout New Zealand. New Zealand has created a wide range of decontamination station types that are dependent on location and type of user. For example, some locations are self-serve to facilitate an individual's use of detergent packets by providing barrels and water; some locations provide multiple barrels with choices of products (salt, detergent) and include freshwater for rinsing afterwards; and some locations are set up to allow kayakers to wipe down their boats. In addition to location-specific stations, New Zealand has also set up some general-access stations at gas stations, state agency offices, and sporting goods stores. In high-priority regions, they have also incorporated cleaning regulations into certain angling licenses that require the witnessing of their fishing gear being decontaminated at supervised stations. Spray bottles (detergent or disinfectant) and detergent packets are also made available to the general public for hiking, mountain biking, etc.

Although there are challenges, there are many possible ways to facilitate decontamination. Currently, there are a few stations in the Atlantic region. Starting in the summer of 2012, fly-fishing in Maine is supporting three stations in the state, which will be maintained by volunteers and with funding support from L.L. Bean. In Maryland, where felt waders were banned in March 2011, there are several stations located at



Image 5. Found on rocks in the streambed, didymo is easily identified by its light brown color and hairy texture that feels like wet cotton. Photo credit: Samantha Root.



Image 6. Didymo is able to form nuisance blooms that cover up to 100% of the streambed and stretch for miles downstream. This is an example of part of the didymo bloom on the Esopus Creek in New York. Photo credit: Samantha Root.

popular locations, and volunteers are involved in maintenance. Both states use a 5% salt solution in their stations, but based on our work we would recommend using a 5% dish detergent solution. Dipping gear into the solutions for 1 min would be effective at killing didymo cells, although we recognize that these solutions may become less effective over time through dilution and degradation. Additionally, we strongly recommend banning felt-soled waders, which would facilitate decontamination and reduce spread.

We recommend a reconsideration of the phrase “check-clean-dry” for several reasons. From comments in our survey, it appears that many fishermen are interpreting “clean” to mean rinsing with tap water, which, from our controls, we know is not effective at killing didymo. In the survey, 28% of the responses including the comment that they dried their gear after treating it—a common response was “rinse and dry.” Additionally, 8% of fishermen used drying as their main method for decontamination, and we know that this is likely only effective

for non-felt gear, because didymo can survive for over a month in felt (Kilroy 2005, cited by Spaulding and Elwell 2007). Using the word “dry” implies that it is a viable decontamination method, but the reality is that it will not be effective with felt waders, so this phrase should not be used unless felt waders are banned, which was the case in New Zealand when this phrase was first coined. A more appropriate phrase might use the word “treat,” which is more specific, and not include “dry,” which is not necessarily an option given that most fishermen fish at multiple sites in a typical day.

Didymo signage and online information should be universal across all state agencies and should include a standard set of information. Important items include the following: (1) basic information about the impacts of didymo, (2) pictures of didymo from U.S. streams and identification criteria, (3) decontamination procedures, (4) information as to why felt-soled waders should be banned or at least an encouragement of alternatives, and (5) accurate contact information for general questions and where/how to report/identify didymo sitings. Many current signs make it difficult for people to identify didymo because they use photos from major blooms in New Zealand, which local blooms do not resemble, and they do not include any descriptive characteristics. In addition, many people do not know the environmental consequences or why they should be concerned about the presence of didymo in their streams. Signs should be posted at all frequently used fishing access locations, rather than only at sites where didymo has been confirmed, and could be made available for fishing stores, guides, etc.

Signage is only one aspect of educating people about didymo control. One recommendation in response to the imminent spread of didymo is to provide more effective educational outreach—a common suggestion by fishermen in our survey. Targeted didymo education programs are essential for getting the word out, and state agencies could make direct contact with fly-fishing organizations, such as Trout Unlimited, and environmental agencies that frequent the rivers and streams. These programs should cover species’ information, species’ spread, the significance of felt-soled waders, identification facts, how to report sightings, and decontamination methods.

A sustainable management plan integrates environmental, social, and economic components of invasive species (Larson et al. 2011). Effective management includes engaging with stakeholders to increase education and involvement, because the stakeholders are often also responsible for the spread (Epanchin-Niell et al. 2010; Rothlisberger et al. 2010). Our study suggests that agency outreach regarding didymo was mostly ineffective, because fishermen were learning primarily through other sources. Agencies could work more closely with related national nonprofit organizations (e.g., Trout Unlimited), with local economic venues (e.g., fly fishing stores), or through existing regulatory mechanisms (e.g., licensing, signage) to directly provide information.

Potential pathways for the spread of aquatic invasive species can be identified through spatially explicit models that

incorporate human activities (Hulme 2009). Predictive models could be developed based on behaviors and preferences of fishermen and used to identify hotspot sites where nuisance/invasive species might be likely to appear as well as for targeting key locations for decontamination stations (Rothlisberger et al. 2010). In the context of didymo, these models would be particularly useful for states where the species has not yet been detected but its arrival is imminent (i.e., Oregon) and could be coupled to other relevant invasive species (e.g., whirling disease, New Zealand mudsnail). This landscape-level approach is useful for within regions and across state boundaries, scales that are becoming increasingly important for invasive species management (Peters and Lodge 2009; Epanchin-Niell et al. 2010; Paini et al. 2010).

Finally, our recommendations are broadly applicable to other species, and our study adds more support to recent calls to create a more comprehensive national approach to invasive species management that would allow for better coordinated responses (Lodge et al. 2006; Peters and Lodge 2009; Paini et al. 2010). Having a national-level task force or center that could make immediate recommendations would be more efficient and effective than having individual states reinvent the wheel, which in the case of didymo seems to lead to inconsistencies and confusion. Ultimately, a nationally coordinated response would create a more rapid and consistent regulatory approach that would facilitate proactive measures, assess spatial and temporal dynamics at relevant scales, and allow for appropriate flexibility in management strategies over time.

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