Aquatic Invasive Species (AIS) Control Plan: Didymo

This control plan is a living document and will be updated, as needed, to reflect the status of this species in Pennsylvania

Natural History

Description: "Didymo" is a colonial microscopic diatom alga also colloquially known as 'rock snot'.

Taxonomy

Common name: **Didymo**
Family : **Gomphonemataceae**
Species: ***Didymosphenia geminata***
Integrated Taxonomic Information System (ITIS) Serial Number: **591283**

Morphology: Didymo is a large (>100 microns), single-celled, 'bottle" or "vase' shaped alga known as a diatom (Figure 1). Didymo cells can form large colonies or "mats" and produce an extracellular, branched stalk made of mucopolysaccharides which can form strong attachments to a variety of substrates, including plants and hard substrates such as stones. When Didymo "blooms" occur, Didymo stalks elongate to form dense mats in order to compete with other algae. These long stalks give mats of Didymo a characteristic rough 'wet cotton' feel when handled (after water is squeezed out). This can help to distinguish it from most other species of filamentous algae which generally are slimy to the touch. However, identification typically must be confirmed using microscopy or genetic analysis.

Figure 1.
1a (Top). Microscopic didymo cell. (Photo: Sarah Spaulding, Montana Natural Heritage Program).
1b (Middle). Didymo clump from upper Delaware River.
(Photo: Tim Daley, PA DEP).
1c (Bottom). Mats of Didymo.
(Photo: Fish and Game New Zealand).

Origin: Didymo is thought to historically have a native range within the circumboreal regions of North America, Europe, and Asia. However, in recent years it has expanded its range and habitat tolerance to include warmer climates and more productive waters where it was previously undocumented (Spaulding and Elwell 2007).

Food Preferences: Didymo is a photosynthetic organism that can be both phosphorus and nitrogen limited. However, Didymo is notable in being able to form large nuisance mats in nutrient-poor environments (Bothwell and Kilroy 2011). Soluble reactive phosphorus has been identified as a key limiting nutrient for Didymo (Bothwell et al. 2014; Shank et al. 2016; Shank 2019).

Reproductive Behavior: The life history of most diatoms includes both vegetative and sexual reproduction although the sexual stage is uncommon in Didymo (Bothwell and Spaulding 2007). When Didymo cells divide via vegetative cell division, the stalk also divides, forming dense mats (nuisance blooms) under certain environmental conditions (Spaulding and Elwell 2007).

Notable Characteristics: Didymo can consolidate in mats of up to 20 cm (~ 8 inches) in thickness on the bottom of colonized waterways. However, mats observed in Pennsylvania are typically thinner than this.

Historic Vectors: In general, historical reports of Didymo are sparse and voucher specimens uncommon (Spaulding and Elwell 2007). Therefore, the method(s) by which Didymo expanded its range across northern North America during the 20th century are largely unknown. Recent discussion within the scientific literature may suggest that in some areas, such as New York State, Didymo may be a "native nuisance" species that is beginning to re-establish and expand its range due to restoration of its preferred habitat variables (Richardson et al. 2014). Low levels of soluble reactive phosphorus have been implicated in Didymo bloom formation; therefore, Didymo may have been present but unnoticed in waters until nuisance blooms formed due to nutrient reductions resulting from the restoration of water quality (Bothwell et al. 2014; Shank 2019).

Current Pathways/Vectors: Dispersal mechanisms are most commonly related to angling and other in-stream recreation activities when gear is not properly decontaminated between waterbodies. Kilroy (2005) documented the ability of Didymo to survive outside of a stream in cool, damp, dark conditions for at least 40 days. Recreational equipment that may sustain Didymo in environments suitable for dispersal include waders, wetsuits, fishing tackle, compartments on boats, and other equipment.

Preferred Habitat: Didymo may occur in a system completely unnoticed until environmental conditions promoting nuisance mat formation occur. The ecological preferences related to the forming of nuisance mats appears to be related to cool, nutrient-poor habitats with stable flows. Physical and chemical habitat features with high relative importance for promoting the presence of Didymo include the following: flow regulation (presence of lakes/impoundments upstream contributing to stable flows) water temperatures lower than 18^{o}C for at least 90% of days, adequate light (>10 m stream channel width), low (preferably less than 2µg/L) Soluble Reactive Phosphorus (SRP), and pH greater

than 6.7 (reviewed by Shank et al. 2016). In a recent study of Didymo mat severity within the Pine Creek watershed, Pennsylvania, Shank (2019) identified low SRP (<2µg/L), stable streamflow, and cold temperatures as the most important variables to predict mat severity. Important, but less critical, stream variables identified for Didymo include rocky large gravel/cobble substrate, low turbidity, low gradients, >2.5 mg/L sulfate, >1.8 mg/L calcium, < 1 mg/L Nitrate, and <6.5 mg/L total organic carbon (reviewed by Shank et al. 2016). Due to these habitat preferences, a unique problem to consider may be that risk of Didymo colonization and mat formation may increase with improvements to water quality (Shank 2019). It should be noted that mats may form seasonally and that high water events caused by heavy rains may reduce or completely scour nuisance mats.

Distribution and PA Legal Status

Distribution: Nationally, Didymo has been confirmed in at least 18 states, with locations primarily occurring in the northeast and western United States (Figure 2).

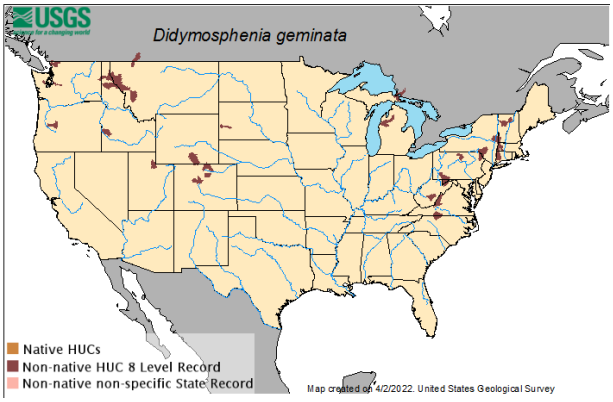

Figure 2. Distribution of Didymo in the continental United States. Source: USGS.

Although recent evidence suggests Didymo may be native to adjacent New York state (Richardson et al. 2014), it is currently unknown if Didymo is an invasive or "native nuisance" species within Pennsylvania (Shank et al. 2016; Shank 2019). It is also possible Didymo may be native some major river drainages in Pennsylvania, but not others. While paleolimnological studies are needed to ascertain the native or invasive status of Didymo in Pennsylvania, Didymo appears to have expanded its known range within Pennsylvania in recent decades.

The earliest record of Didymo in Pennsylvania is by Boyer (1916) who reported it in the Delaware River in the vicinity of Philadelphia (although the current status of Didymo in this area is unknown). To date, Didymo has been documented in at least 13 Pennsylvania counties (Figure 3). In Pennsylvania, Didymo is widespread within the Delaware River, with records occurring from Wayne County downstream through Pike, Monroe, Northampton, and Bucks counties. In the Delaware basin, Didymo is also known from East Branch Dyberry Creek in Wayne County. Didymo also occurs in the West Branch Susquehanna River basin in Trout Run, Clearfield County and throughout the Pine Creek watershed in Lycoming, Tioga, and Potter counties. In southwestern Pennsylvania, Didymo occurs within the Youghiogheny River in Fayette and Westmoreland counties and in Quemahoning Creek, Somerset County.

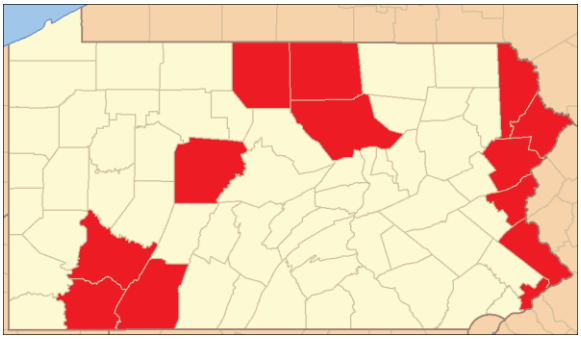

Figure 3. County-level distribution of Didymo in Pennsylvania (April 2022).

Pennsylvania Legal Status: As of April 2022, Didymo is not regulated in 58 Pa. Code §71.6 and §73.1.

Threats

Ecological: Ultimately, data on the ecological impacts of Didymo report varying results. Didymo may cause macroinvertebrate community shifts due to the diatom's extensive coverage of exposed substrates. However, results of studies are ambiguous in that some report a minor loss of macroinvertebrate biodiversity and/or sensitive taxa (e.g., Spaulding and Elwell 2007; Anderson et al 2014; Richardson et al. 2014), while others report an increase of diversity and/or sensitive taxa in response to Didymo blooms (e.g., Brand and Grech 2020; see also review on Richardson et al. 2014) which is attributed to sheltering macroinvertebrates from predators. Anecdotally, Didymo may have some degree of a negative effect on macroinvertebrates by blocking hatches by nuisance blooms (Klauda and Hanna 2016).

The effects of Didymo on freshwater mussel populations are largely unknown (Clancy et al. 2020). However, due to the ability of nuisance blooms to cover stream substrates, it is possible that mussels may suffer from reduced ability to suspension feed. However, the habitat preferences of Didymo likely does not majorly overlap with most native freshwater mussels, with some exceptions (e.g., Eastern Pearlshell, *Margaritifera margaritifera*; Dwarf Wedgemussel, *Alasmidonta heterodon*). Studies evaluating the potential impacts of Didymo on freshwater mussels of concern in Pennsylvania are needed.

The direct effects of Didymo on sport fish, primarily trout, and other fish species have not been well-studied. Clancy et al. (2021) found Didymo had no significant impacts on a fish community, and Didymo appears to have negligible impacts on trout fisheries (Klauda and Hanna 2016).

Economic: While detailed economic threat studies of Didymo impacts in the United States appear to have not been conducted, a study focused on New Zealand anglers found that Didymo reduced fishing values by approximately $30 USD per angler visit to invaded sites (Bellville et al. 2012). In Maryland, some anglers have reported that the presence of Didymo diminished their fishing experience (Klauda and Hanna 2016). Anecdotally, Didymo blooms have impeded angler success and enjoyment (particularly for fly fishing) in Pennsylvania waters.

Human Health: Didymo is not considered to be a risk to human health.

Management

Management Goals: While the ecological impacts of Didymo are ambiguous or understudied, Didymo blooms may be harmful to aquatic life and undoubtably diminish the quality of fishing experiences for anglers. Therefore, management should focus on containing/managing existing populations to prevent spread to additional

waterways where Didymo is not known to occur.

Containment and Prevention Options:

- Continue promoting public education efforts to acquaint the populace with the threats of and measures to prevent the spread of aquatic invasive species and aquatic nuisance species such as Didymo.

- Determine the native nuisance or invasive status of Didymo within Pennsylvania (i.e., conduct or support paleolimnological studies; Shank et al. 2016).

- Encourage the incident reporting of aquatic invasive/nuisance species such as Didymo within Pennsylvania. Online reporting can now be conducted at the following PFBC web site: https://pfbc.pa.gov/forms/reportAIS.htm as well as PA iMapInvasives at: https://www.paimapinvasives.org/ and at the national level, USGS Nonindigenous Aquatic Species website: https://nas.er.usgs.gov/SightingReport.aspx

- Continue to post Didymo signs at recreational access areas within invaded waters to inform the public of the presence of Didymo and instruct on proper cleaning of gear. Effective decontamination strategies for Didymo include: freezing gear solid for at least 5 hours, soaking and scrubbing gear in either hot (>140^{o}F) water or a 5% solution of household bleach, salt, or dishwashing detergent, or making sure all items are dry to the touch for at least 48 hours (Root and O'Reilly 2012). Drying is ineffective for felt-soled waders, which should either be soaked in the solutions noted above for at least 40 minutes or frozen solid for at least 5 hours.

- Initiate and support research to ascertain the potential of Didymo on sport fisheries and freshwater mussels of concern in Pennsylvania.

- Consider initiating angler opinion surveys for Commonwealth waters with Didymo blooms to evaluate the recreational impacts Didymo may pose in Pennsylvania.

Rapid Response Treatments:

- Several treatment options have been evaluated for Didymo. Of these, chelated copper formulations and pine oil formulations are the most effective in treating Didymo (Jellyman et al. 2011). However, these treatments may need multiple applications to achieve effectiveness and have negative consequences on macroinvertebrates and fish (Clearwater et al. 2011; Jellyman et al. 2011). Furthermore, aquatic herbicide applications in Pennsylvania are typically not conducted in flowing waters, such as where Didymo may occur due to complications with application and potential impacts to aquatic life.

- Where feasible in Pennsylvania, a practical control option may be to coordinate with appropriate entities to manage streamflow downstream of hypolimnetic (bottom release) reservoirs occurring within known or at-risk Didymo waters to ensure artificially stable flows do not promote Didymo bloom formation. This would entail periodic short-term

releases of higher volumes of normal flow in order to discourage or scour Didymo bloom formation, particularly where tailwater trout fisheries occur.

References

Anderson, I.J., Saiki, M.K., Sellheim, K., and Mertz, J.E. 2014. Differences in benthic macroinvertebrate assemblages associated with a bloom of *Didymosphenia geminata* in the Lower American River, California. Southwestern Naturalist. 59: 389-395.

Bellville, S.T., Kerr, G.N., and Hughley, F.D. 2012. Valuing impacts of the invasive alga *Didymosphenia geminata* on recreational angling. Ecological Impacts. 82: 1-10.

Bothwell M.L. and Spaulding, S.A. 2007. Synopsis: 2007 International Workshop on *Didymosphenia geminata*. Proceedings of the 2007 International Workshop on *Didymosphenia geminata.* Canadian Technical Report of Fisheries and Aquatic Sciences 2795.

Bothwell, M.L. and Kilroy, C. 2011. Phosphorus limitation of the freshwater benthic diatom *Didymosphenia geminata* determined by the frequency of dividing cells. Freshwater Biology 56: 565-578.

Bothwell, M.L., Taylor, B.W., and Kilroy, C. 2014. The Didymo story: the role of low dissolved phosphorus in the formation of *Didymosphenia geminata* blooms. Diatom Research. 29: 229-236.

Boyer, C.S. 1916. The Diatomaceae of Philadelphia and Vicinity. J.B. Lippincott Co., Philadelphia.

Brand, C. and Grech, M. 2020. Recent invasion of *Didymosphenia geminate* (Lyngbye) M. Schmidt in a Patagonian regulated river promotes changes in composition and density of macroinvertebrate community. Biological Invasions. 22: 1903-1905.

Clancy, N.G., Brahney, J., Curtis, J., and Budy, P. 2020. Consequences of Didymo blooms in the transnational Kootenay River basin. Report to BC Parks from the Department of Watershed Sciences at Utah State University, Logan, UT.

Clancy, N.G., Brahney, J., Dunnigan, J. and Budy, P. 2021. Effects of a diatom ecosystem engineer (*Didymosphenia geminata*) on stream food webs: implications for native fishes. Canadian Journal of Fisheries and Aquatic Sciences. 78: 154-164.

Clearwater, S.J., Jellyman, P.G., Biggs, B.J.F., Hickey, C.W., Blair, N., and Clayton, J.S. 2011. Pulse-dose application of chelated copper to a river for *Didymosphenia geminata* control: effects on macroinvertebrates and fish. Environmental Toxicology and Chemistry. 30: 181-195.

Jellyman, P.G., Clearwater, S.J., Clayton, J.S., Killroy, C., Blair, N., Hickey, C.W., and Biggs, B.J.F. 2011. Controlling the invasive diatom *Didymosphenia geminata*: an ecotoxicity assessment of four potential biocides. Archives of Environmental Contamination and Toxicology. 61: 115-127.

Kilroy, C. 2005. Tests to determine the effectiveness of methods for decontaminating materials that have been in contact with *Didymosphenia*

geminata. Biosecurity New Zealand. National Institute of Water and Atmospheric Research Ltd.

Klauda, R.J. and Hanna, K.V. 2016. *Didymosphenia geminata* infestation in Maryland: reactions and responses by the Maryland Department of Natural Resources, 2008-2014. Maryland Department of Natural Resources Resource Assessment Service. 36 pp.

New Zealand Institute of Economic Research. 2006. *Didymosphenia geminata* economic impact assessment. Final report to Biosecurity New Zealand.

Richardson, D.C., Olesky, I.A., Hoellein, T.J., Arscott, D.B., Gibson, C.A., and Root, S.M. 2014. Habitat characteristics, temporal variability, and macroinvertebrate communities associated with a mat-forming nuisance diatom (*Didymosphenia geminata*) in Catskill mountain streams, New York. Aquatic Sciences. 76: 553-564.

Root, S. and O'Reilly, C.M. 2012. Didymo control: increasing the effectiveness of decontamination strategies and reducing spread. Fisheries. 37: 440-448.

Shank, M.K., Potapova, M., Maloney, K., Honeyfield, D., and Spooner, D. 2016. *Didymosphenia geminata* in Pennsylvania: an investigation of current and historic distribution, habitat suitability, and nutritional content. Susquehanna River Basin Commission Technical Report. 55 pp.

Shank, M.K. 2019. Physicochemical controls on spatiotemporal distribution and benthic mat severity of *Didymosphenia geminate* in Pine Creek, an unregulated watershed in northern Pennsylvania. Northeastern Naturalist. 26: 420-445.

Spaulding, S. and L. Elwell. 2007. Increase in Nuisance Blooms and Geographic Expansion of the Freshwater Diatom *Didymosphenia geminata.* U.S. Environmental Protection Agency.