The distribution and abundance of a nuisance native alga, *Didymosphenia geminata*, in streams of Glacier National Park: Climate drivers and management implications

NPS/B. SCHWEIGER

INSET: LOREN BAHLS, CURATOR, MONTANA DIATOM COLLECTION

Figure 1. Didymo bloom covering the bottom of McDonald Creek below Lake McDonald, Glacier National Park, 2009. The extent at this site was typical of many blooms in the park in 2007–2009. Inset shows light microscope image (at 400 times) of a didymo valve and its stalk.

By E. William Schweiger, Isabel W. Ashton, Clint C. Muhlfeld, Leslie A. Jones, and Loren L. Bahls

CLIMATE CHANGE AND NUISANCE (OR INVASIVE) species pose serious threats to the structure and function of aquatic ecosystems worldwide (Parmesan and Yohe 2003). Over the past 100 years, annual mean air temperatures in Glacier National Park, Montana, have increased twice as much as global temperatures, resulting in declining snowpack, increasing fire frequency, altered hydrology, and loss of the park's iconic glaciers (Pederson et al. 2010; Hall and Fagre 2003). Changes in the hydrological cycle will warm perennial streams, thereby threatening the stability of aquatic ecosystems and potentially increasing the spread of aquatic nuisance species (Rahel and Olden 2008).

Didymosphenia geminata (hereafter "didymo"; fig. 1, inset) is a diatom native to mountain habitats of North America and Europe (Blanco and Ector 2009). In recent years didymo has expanded into lower elevations, latitudes, and new regions of the globe (Kumar et al. 2009). In Montana, didymo was first reported in 1929 at Flathead Lake (Prescott and Dillard 1979) and has likely been present in the northern Rockies since at least the end of the last ice age, about 10,000 years ago (Bahls 2007). Didymo can form extensive mats (or blooms), which can be several centimeters thick and up to 20 km (12 mi) in length (Blanco and Ector 2009). Larger blooms can inhibit growth of other algal species, change the composition of aquatic communities, decrease the amount of suitable spawning habitat for fish, and cause changes in stream chemistry (Spaulding and Elwell 2007). Blooms of didymo also greatly decrease the aesthetic appeal of streams—an important consideration for a tourist destination like Glacier National Park (fig. 1). For these reasons, understanding the causes and consequences of didymo blooms is a high priority for the park, especially for predicting and, where possible, managing its spread.

Because of the lack of data, speculation exists on why there has been a change in distribution of didymo and whether it is linked to climate warming (Bothwell and Spaulding 2008). Recent research suggests that didymo is associated with high mean summer temperature, a stable base flow index (less variation in streamflow), and is more abundant in nutrient-poor systems (Kumar et al. 2009). Here we present NPS monitoring data collected from 2007 to 2009 throughout Glacier National Park to estimate the distribution of didymo and better understand some of the environmental factors associated with its spread in a relatively pristine aquatic system.

Methods

From 2007 to 2009 we sampled 49 stream sites selected by a spatially balanced probability survey design (Stevens and Olsen 2004) as part of the NPS Vital Signs Monitoring Program (Fancy et al. 2009). In some cases, sites were visited multiple times within and across seasons. At each site, we measured a suite of biological, physical, and chemical variables (Peck et al. 2006). We estimated the abundance of didymo in two ways: First we generated cell counts from composite samples collected from the

Abstract

Didymosphenia geminata (didymo) is a freshwater alga native to North America, including Glacier National Park, Montana. It has long been considered a cold-water species, but has recently spread to lower latitudes and warmer waters, and increasingly forms large blooms that cover streambeds. We used a comprehensive monitoring data set from the National Park Service (NPS) and USGS models of stream temperatures to explore the drivers of didymo abundance in Glacier National Park. We estimate that approximately 64% of the stream length in the park contains didymo, with around 5% in a bloom state. Results suggest that didymo abundance likely increased over the study period (2007–2009), with blooms becoming more common. Our models suggest that didymo abundance is positively related to summer stream temperatures and negatively related to total nitrogen and the distance downstream from lakes. Regional climate model simulations indicate that stream temperatures in the park will likely continue to increase over the coming decades, which may increase the extent and severity of didymo blooms. As a result, didymo may be a useful indicator of thermal and hydrological modification associated with climate warming, especially in a relatively pristine system like Glacier where proximate human-related disturbances are absent or reduced. Glacier National Park plays an important role as a sentinel for climate change and associated education across the Rocky Mountain region.

Key words

alga, aquatic nuisance species, climate change, diatom, *Didymosphenia geminata*, Glacier National Park

stream bottom. Second, we visually estimated the thickness and abundance of didymo mats as an index of bloom extent (Kilroy et al. 2005). We defined a "bloom" as a stream reach with a length 40 times its mean wetted width with a Kilroy index greater than 25 (at least 50% of the stream bottom covered by a mat at least 1 cm [0.4 in] thick). A mixed-effects hierarchical model was used to predict stream temperatures throughout the park stream network ($R^2 = 0.82$). We then used associated model outputs to simulate predicted temperatures using the maximum August mean air temperature from our study period (2008: 18.4°C [65.1°F]).

We used a generalized linear model (GLM) employing a log link function and Poisson error term to relate didymo abundance to several predictors, including water chemistry, substrate type, stream temperature, watershed membership, and distance downstream from lakes. Akaike's Information Criterion was used as a best subsets selection to select the final model(s). We also generated time series models to explore short-term dynamics of didymo abundance using a subset of sites with repeat visits. Finally, by using the properties of the survey design (Stevens and Olsen 2004), we estimated the length of streams across the park that had didymo presence or blooms.

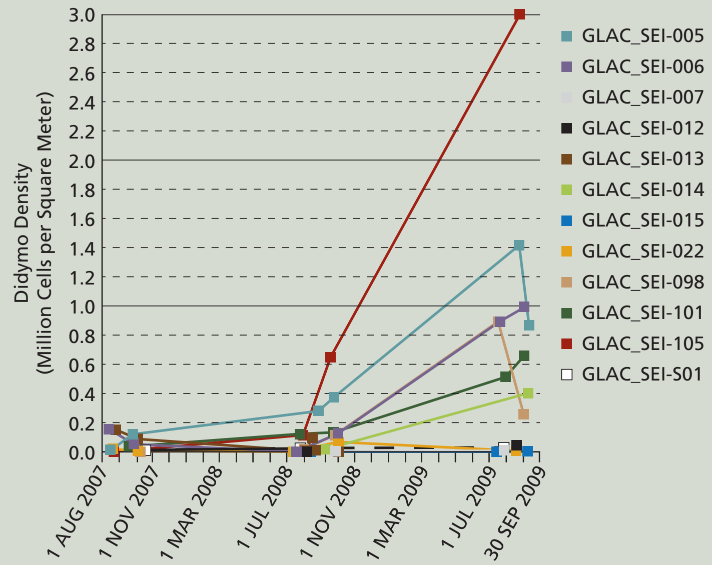

Figure 2. Time series of didymo abundance at 11 sites with repeat visits.

Results

We estimated that didymo occurred in 64% (± 17%) of the flowing water in the park, or about 1,600 km (994 mi) of stream. Furthermore, approximately 5% (± 3%) of the stream length in the park was in a bloom state. These results describe, with known confidence and controlled bias, the status of didymo across the complete stream system in the park from 2007 to 2009.

Of the 11 sites revisited in 2007–2009, didymo abundance increased at 8 and decreased at only 1 (fig. 2; the occurrence of blooms increased similarly at the revisited sites—data not shown). Where we had five or more visits, we found statistically significant increases at three sites. Abundance also varied spatially, with the highest abundances of didymo on the west side of the Continental Divide (fig. 3, next page). This suggests great spatial variation in the presence of didymo. Importantly, however, our period of record is short and the sample size of revisited sites is small.

Results from the generalized linear model suggest that didymo abundance was influenced by several environmental factors (e.g., covariates). While all the final model predictors were highly significant ($p < 0.001$ and $R^2 = 0.86$) and biologically interpretable, we suspect that a meaningful amount of variation in didymo abundance is unexplained and consider the model preliminary. Didymo abundance was positively related to summer water temperatures, the proportion of cobble substrate, and Julian date (indicating that didymo abundance increased during our sample period). Conversely, didymo abundance was negatively related to distance from lakes (with higher abundances near lake outlets), total nitrogen concentration, and specific conductance.

Other research has suggested that stable base flows can be a strong predictor of didymo occurrence and abundance (Kumar et al. 2009). We did not measure base flow at all sites in our study. However, the distance downstream from lakes that we did include in our analyses may be a useful proxy, as streamflow is generally more stable near lakes than in further downstream reaches. We suspect that didymo in Glacier National Park responds to the same hydrologic conditions (stable base flow) seen in other studies in similar landscapes (Bothwell and Spaulding 2008). Nevertheless, it is possible that some of the unexplained variance in our models is due to the lack of a detailed hydrologic covariate.

Finally, although we lack detailed data on visitor and angler use at our study sites, we found no associations between human disturbance (e.g., distance to roads or wastewater control structures) and didymo abundance. Didymo is known to be spread by gear used by anglers (Spaulding and Elwell 2007), yet we often found blooms in remote locations that are rarely or never visited.

Conclusions and management implications

Our results suggest that didymo was widespread and likely became more abundant in Glacier National Park from 2007 to 2009. Although somewhat speculative, our models are generally consistent with other studies of the factors associated with the presence and abundance of didymo (Kumar et al. 2009; Blanco and Ector 2009). Three of the most important and climate change–relevant predictors of elevated didymo abundance we found were higher stream temperature, reduced distance from upstream lakes (as a proxy for stable base flows), and lower nitrogen concentration. If current climate trends continue, each of these may change in ways that favor increased didymo abundance and blooms in Glacier National Park. Stream temperatures are expected to rise (Pederson et al. 2010). Lower summer base flows are more likely given the shift toward earlier runoff and higher contribution from surface flow (Hall and Fagre 2003). Finally, as climate change continues to reduce snowpack, groundwater recharge rates will likely decrease and surface water and rainfall may be larger contributors to base flow, both generally having lower nitrogen concentrations (Hauer et al. 2002). Though we cannot make quantitative predictions given the complexity of the response and the state of our current models, our results do suggest that additional research should be conducted to better understand the dynamics of this species, how it may be influenced by climate change, and how it may impact the aquatic ecosystems of Glacier National Park.

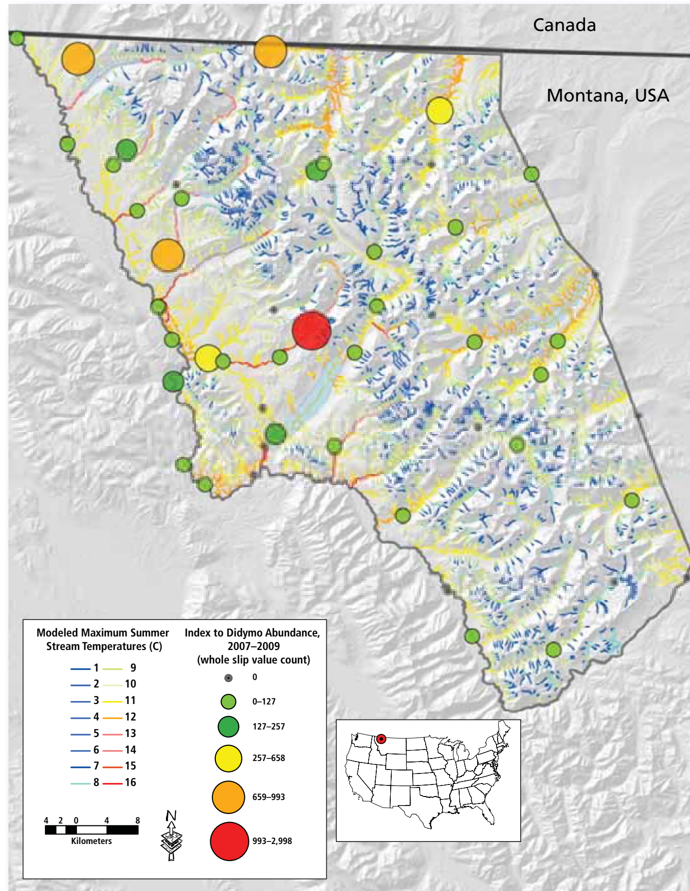

Figure 3. Didymo abundance at each of the 49 sites sampled in 2007–2009. Size and color of each point scale with abundance, with larger symbols and redder colors indicating higher abundance. The stream network in the park is displayed using the modeled maximum summer temperatures, with redder colors indicating hotter stream-water temperatures. Lakes are shown in faint blue outline.

Managing native species like didymo presents a complex challenge. National Park Service policy does provide for native species management when a population occurs in an unnaturally high or low concentration as a result of human influences and it is not possible to mitigate the effects of the human influence(s) (Section 4.4.2 in NPS 2006). Although more research is needed in specific locations like Glacier National Park and over longer time periods, the weight of evidence from multiple studies does suggest that didymo is responding to human-caused climate warming and may thus warrant careful management action.

The National Park Service is implementing education and integrated management programs to prevent and reduce the spread of didymo, such as limiting use of felt wading boots and educating visitors about the importance of cleaning fishing gear (see Spaulding and Elwell 2007 for an overview of general recommendations). Nevertheless, given the expected impacts of increased didymo abundance on stream food webs and processes (Kirkwood et al. 2007; Bothwell and Spaulding 2008), the species will likely play an important role in the ecology of the park's streams. Our results may be used to help park resource managers implement effective prevention and control measures and as motivation for more detailed research. Conducting research in places like Glacier is important because it allows study of species dynamics in the absence of most direct human stressors. Many drivers of didymo will not be directly controllable by park management. Therefore, perhaps a more important role for the National Park Service is in educating the public about climate change using species like didymo, which, like the emblematic but disappearing glaciers of the park, may be a sentinel of shifting climate regimes.

Acknowledgments

We thank our field crews and staff at Glacier National Park and the Rocky Mountain Network for their support. C. Downs, A. Steed, and J. Wullschleger provided useful reviews. This research was conducted in accordance with the Animal Welfare Act and its subsequent amendments.

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About the authors

E. William Schweiger *and* ***Isabel W. Ashton*** *are ecologists with the NPS Rocky Mountain Inventory and Monitoring Network in Fort Collins, Colorado.* ***Clint C. Muhlfeld*** *is a research aquatic ecologist and* ***Leslie A. Jones*** *is a biological science technician. Both are with the U.S. Geological Survey, Northern Rocky Mountain Science Center, Glacier National Park, West Glacier, Montana.* ***Loren L. Bahls*** *is the curator of the Montana Diatom Collection in Helena. Correspondence should be addressed to Schweiger by e-mail at billy_schweiger@nps.gov.*