Diatom Indicators of Climate Change in Glacier National Park

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Abstract

Permanent slides in the Montana Diatom Collection representing periphyton samples collected during the 2007 field season and samples collected in prior years were examined to determine the distribution and abundance in and near Glacier National Park of two diatom species: *Didymosphenia geminata* and *Distrionella incognita* (Kingdom Plantae, Phylum Bacillariophyta). *Didymosphenia geminata* ("didymo", "rock snot") is becoming a nuisance in the west and will probably increase in abundance in response to global warming and reduced stream flows. *Distrionella incognita* ("glacier gold") is a rare glacial relict species and will probably decrease in abundance in response to predicted climate change. *Didymosphenia* has been widely distributed and locally abundant in the Park since 1976. Large populations of this diatom have been recorded in all three of the Park's major drainage basins: Pacific, Atlantic, and Hudson Bay. Samples collected in 2007 from Duck Lake, Kintla Lake, and St. Mary Lake document the first large populations of *Distrionella* to be recorded in North America. The genus *Distrionella* is known only from cold, mountainous, and glaciated regions of the world.

Key words: biodiversity, climate change, didymo, *Didymosphenia*, *Distrionella*, diatoms, glacier gold, Glacier National Park, global warming, invasive species, relict species, rock snot

Introduction

A 3-yr survey of diatom (Kingdom Plantae, Phylum Bacillariophyta) biodiversity in Glacier National Park was initiated during the 2007 field season. Supplemented by records from 1976-2006, the survey will produce a checklist of diatom species from the Park with photographic documentation of voucher specimens. Distribution of species throughout the Park and their relative abundance in various habitats will also be recorded. The survey was predicated on three assumptions: 1) aquatic habitats of Glacier support diverse associations of largely native diatom species; 2) diatom flora of Glacier National Park will include species that are endemic to the region and new to science; and 3) diatom flora of Glacier National Park will include species that are sensitive to global warming, atmospheric deposition, and other ecological perturbations.

Two diatom species in particular, both presumably native to the Park, have promise as indicators of environmental change—one as an "increaser" and the other as a "decreaser".

Didymosphenia geminata ("didymo," "rock snot"; Fig. 1) is an aggressive invader that forms conspicuous growths on stream bottoms (Fig. 2), which may reach nuisance levels for public recreation (Spaulding and Elwell 2007). Growths of *D. geminata* have been known to alter food web structure and stream ecosystem function, degrade water supplies, modify stream hydraulics, and strain regional and national economies through impacts on fisheries, tourism and hydropower (U. S. Environmental Protection Agency 2007).

Distrionella incognita or "glacier gold" (Fig. 3) is a relatively rare diatom and a glacial relict species. Until recently, *D. incognita* had been reported only from lakes in the British Isles and European Alps (Krammer and Lange-Bertalot 1991). In 2005 a team of researchers reported small

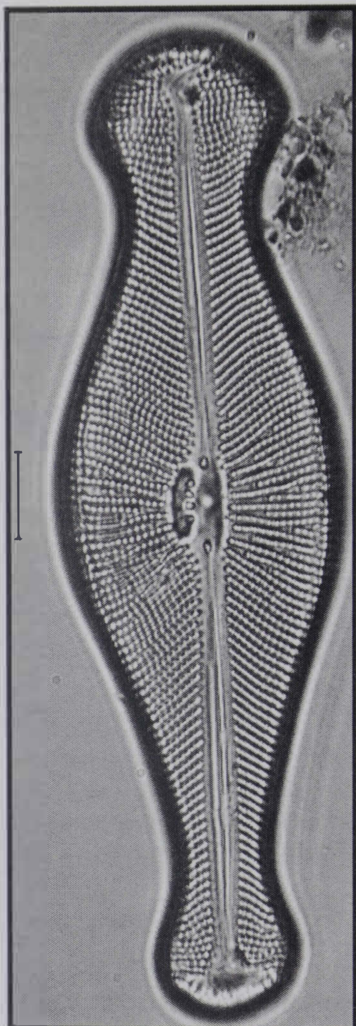

Figure 1. Photomicrograph of *Didymosphenia geminata* (rock snot) from Two Medicine Creek, Glacier National Park. Scale bar = 10 µm.

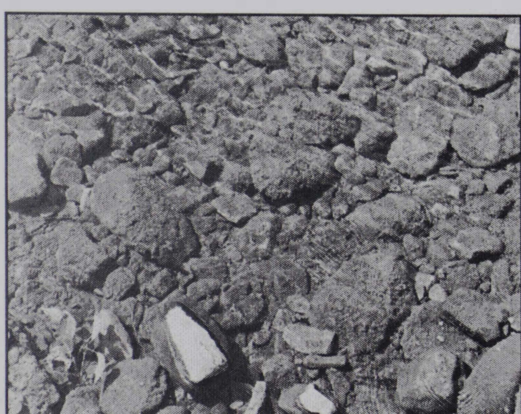

Figure 2. Rocks covered with *Didymosphenia geminata* (rock snot) in Two Medicine Creek below Running Eagle Falls, September 2007.

Figure 3. Photomicrograph of *Distrionella incognita* (glacier gold) from Kintla Lake, Glacier National Park. Scale bar = 10 µm.

populations of *D. incognita* from several streams that drain the Canadian Rockies Ecoregion in northwestern Montana (Morales et al. 2005). These researchers speculated that much larger populations of *D. incognita* might be found in lakes of Glacier National Park.

Sample Sites

Forty-six periphyton samples were collected under various projects at 20 sites from 1976 through 2006, and another 68 samples were collected at 68 new sites in 2007 (Fig. 4). Slides representing all of these samples have been deposited in the Montana Diatom Collection (maintained by the author in Helena, Montana) and will be included in the biodiversity study.

The 88 total sites included 33 standing waters and 55 flowing waters. Forty-two sites were west of the Continental Divide (Pacific drainage), 28 are north of the Divide (Hudson Bay drainage), and 18 were east of the Divide (Atlantic drainage). All sites occurred along motor routes or within a 1-day

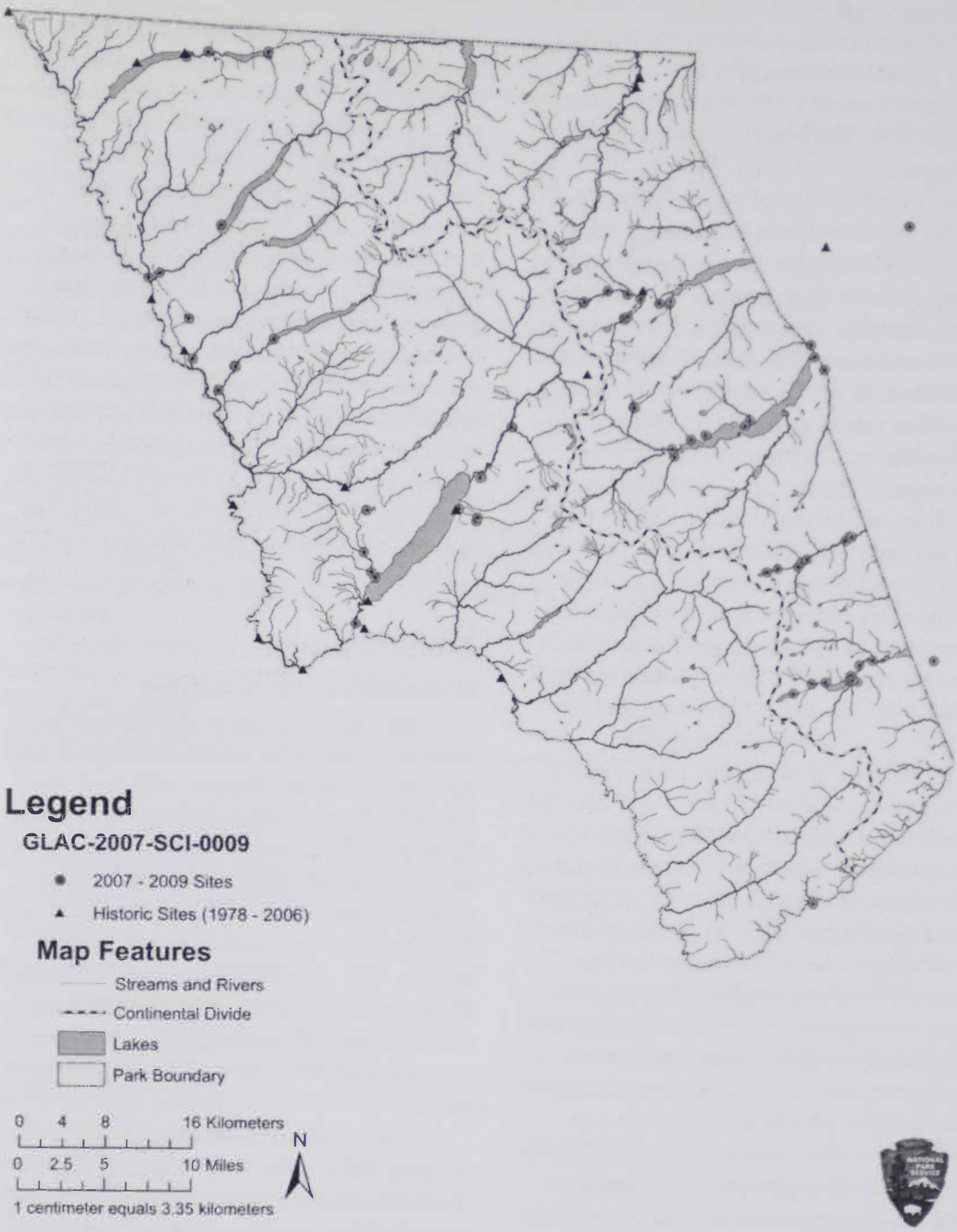

Figure 4. Diatom biodiversity sampling stations in Glacier National Park, 1976-2007.

hike from a trailhead. Most were front country sites near the lower ends of the Park's major catchments. Two sites that were sampled in 2007—Duck Lake and Lower Two Medicine Lake—and one pre-2007 site—Swiftcurrent Creek near mouth—are located near the Park but outside the Park boundary.

Methods And Materials

2007 Samples

Periphyton samples were collected following Montana Department of Environmental Quality Standard Operating Procedure 12.1.2 for water quality monitoring, available at www.deq.state.mt.us/wqinfo/monitoring/SOP/sop.asp. This is a targeted multihabitat method in which available substrates (rocks, wood, sediment, mosses and higher plants) were sampled in proportion to their importance at a site, and conspicuous algal growths (filaments and colonies) were also selected for sampling. Samples from various substrates and of conspicuous algal growths were combined in a single sample container. All samples were collected within wading distance from stream banks or lake shores. Samples were preserved with Lugols (IKI) solution and kept dark during transport and storage. In the lab samples were treated with concentrated sulfuric acid, potassium dichromate, and hydrogen peroxide to remove organic matter. I prepared three permanent slides of randomly strewn diatom frustules in Naphrax® and accessioned them into the Montana Diatom Collection. The slide with the most even distribution of frustules on the cover glass was chosen for analysis. I stored the remaining cleaned diatom material in glass vials for future SEM work and for making more slides if necessary.

Because of its large size, *Didymosphenia geminata* could be identified and counted under low magnification (100X). For each slide, I scanned the entire 18-mm x 18-mm cover glass and counted all valves of *D. geminata*. Each diatom cell or frustule consists of two valves, one fitting inside the other like an old-fashioned pillbox. The number of valves divided by 2 equals the number of cells. Because samples were representative of substrates and conspicuous growths and because slides are prepared to achieve as even a distribution of diatoms as possible, this method will approximate relative abundance of *Didymosphenia* at a site compared to other sites.

For *Distrionella incognita*, a much smaller diatom, I scanned each slide at 400X to determine if the taxon was present. If present a proportional count of 600 valves was conducted with a 1000X oil immersion objective (1.4 NA) on a Leica DMLB2 research microscope. In this count, valves of *D. incognita* were counted versus valves of all other species. This method also approximated relative abundance of *Distrionella* at a site compared to other sites.

Pre-2007 Samples

Pre-2007 samples were collected in the same manner as 2007 samples except that samples from Lake Winona, Lake McDonald, and Swiftcurrent Lake were taken at a depth requiring a wet suit and SCUBA gear. Pre-2007 samples were processed in the same manner as 2007 samples except that only one or two slides were prepared, cover glasses were variable in size, various mounting media (Carmount®, Hyrax®, Naphrax®) were used, and cleaned diatom material was not retained. Slides made from pre-2007 samples were scanned at 100X and 400X to determine the presence of *Didymosphenia geminata* and *Distrionella incognita*, respectively. If *Distrionella incognita* was present, a 600-valve count was performed at 1000X.

Results

Didymosphenia geminata

Didymosphenia geminata was present in 36 of 46 pre-2007 samples (Table 1). Earliest records of this species were from the North Fork and Middle Fork of the Flathead River in 1976. Numerous valves of *D. geminata* were observed on slides made from samples collected in 1976 at Polebridge and Big Creek on the North Fork and from the Middle Fork at its mouth. At pre-2007 sites, *D. geminata* was present in 35 of 39 samples collected from flowing waters and in one of seven samples collected from standing waters.

D. geminata was found in 36 of the 68 samples collected in 2007 (Table 2, Fig. 5). It occurred in 30 of 41 flowing waters (73%) and in 6 of 27 standing waters (22%). Large populations (> 200 valves) of *Didymosphenia geminata* were recorded in all three of the Park's major drainage basins: Atlantic, Pacific, and Hudson Bay. Lake McDonald was the only standing water that supported a large population of this diatom. Sites that supported conspicuous growths of this species (as in Fig. 2) were all exposed to direct sunlight in openings of the forest canopy (field notes). Several of these locations are flowing waters below waterfalls or lake outlets. Smaller

Table 1. Presence or absence of *Didymosphenia geminata* in periphyton samples collected in or near Glacier National Park from 1976 through 2006. Water body names followed by an asterisk are the author's names for water bodies not named on USGS topographic maps.

Water Body and Location	Sample Year(s)	No. Samples	*Didymosphenia*
North Fork Flathead River at Canadian Border	1976	1	0/1
North Fork Flathead River at Polebridge	1976	1	1/1
North Fork Flathead River at Big Creek	1976	1	1/1
Middle Fork Flathead River at mouth	1976	1	1/1
North Fork Flathead River near Columbia Falls	1978-1980, 2001-2003	4, 3	3/4, 3/3
Middle Fork Flathead River near West Glacier	1978-1980, 2001-2003	4, 3	4/4, 3/3
Swiftcurrent Creek near mouth	1978-1980	4	4/4
Kintla Lake near inlet	1979	1	0/1
Kintla Spring* to Kintla Lake about half way up north shore	1979	1	0/1
Belly River at Threemile Camp	1980, 1996	2	1/1, 1/1
Lake McDonald near Apgar	1993	1	1/1
Belly Spring Brook* alongside Belly River near Threemile Camp	1996	1	0/1
Middle Fork Flathead River below Nyack Creek, downwelling area	1997	4	3/4
Middle Fork Flathead River below Nyack Creek, neutral VHG	1997	4	4/4
Middle Fork Flathead River below Nyack Creek, upwelling area	1997	4	4/4
Lake Winona	1999	1	0/1
Lake McDonald at mouth of Sprague Creek	1999	1	0/1
Swiftcurrent Lake at boat ramp near picnic area	1999	1	0/1
Weeping Wall, Logan Pass	1978	1	0/1
Camas Creek 250 yards above Inside North Fork Road	2006	2	2/2

numbers of *D. geminata* were recorded at some higher elevation sites, e.g. Siyeh Creek, and in presumably near pristine waters, e.g., Wild Creek.

Distrionella incognita

Among pre-2007 samples, I detected *D. incognita* in the North Fork Flathead River near Columbia Falls and in the Belly River at Threemile Camp, where it accounted for 7 percent and 1 percent of diatom valves, respectively. These specimens may have originated in any one of several upstream lakes. None of the pre-2007 lake samples included this species.

In 2007 large populations of *Distrionella incognita* (> 200 valves) were recorded in Kintla Lake, St. Mary Lake and Duck Lake (Table 2, Fig. 6) that confirmed this diatom as primarily a species of large lakes. Smaller populations were found in Swiftcurrent Lake, Lake Josephine, and Bowman Lake. Among streams, the largest number of valves (104) was recorded in the St. Mary River below St. Mary Lake. Much smaller numbers were recorded in Bowman Creek below Bowman Lake, Quartz Creek near its mouth, and in McDonald Creek below Lake McDonald. The presence of *D. incognita* in Quartz Creek suggested that it also occurred in one or both of the Quartz Lakes. Although it was not found in the sample collected from Lake McDonald, its presence in lower McDonald Creek suggested that it was present there also.

Discussion

Didymosphenia geminata is likely native to Glacier National Park. It was first reported from Montana in 1929 when C. J. Elmore found *Gomphonema geminatum* (Lyngbye) Agardh in collections from Flathead Lake (Prescott and Dillard 1979). Records derived from slides deposited in the Montana Diatom Collection indicated that this taxon is widely distributed in the Pacific Northwest (Bahls 2004). Because of its large size, *Didymosphenia geminata* is often missed during diatom proportional counts, which are conducted at high microscope magnifications. Therefore, this taxon

Table 2. Total number of Didymosphenia geminata valves per slide and number and percent of Distrionella incognita valves in counts of 600 diatom valves in periphyton samples collected in or near Glacier National Park in 2007. Water body names followed by an asterisk are the author's names for water bodies not named on USGS topographic maps.

Water Body and Location	*Didymosphenia* No. Valves	*Distrionella* No. Valves	*Distrionella* %
Fish Creek at campground	19		
Kintla Lake		280	46.7
Kintla Spring Pool* on trail between upper and lower Kintla Lakes			
Kintla Creek above upper Kintla Lake			
Two Medicine Lake (north shore)	18		
No Name Creek* below No Name Lake and Twin Falls	373		
Upper Two Medicine Lake (east end)			
Two Medicine Spring* at N. Shore Two Medicine Lake Trail			
Paradise Creek at mouth (at Two Medicine Lake)	37		
Paradise Pond* near Paradise Cr. on S. Shore Two Medicine Lake Trail			
Two Medicine Creek below Pray Lake at Two Medicine Campground	116		
Lower Two Medicine Lake near reservation boundary			
Two Medicine Creek below Running Eagle Falls	99		
Paradise Spring Brook* (outlet from Paradise Pond*)	6		
Duck Lake		227	37.8
Swiftcurrent Lake west shore at trail		22	3.7
Cataract Creek above Lake Josephine	7		
Josephine Wetland* along boardwalk at head of Lake Josephine			
Lake Josephine, southeast shore near boat dock	3	8	1.3
Sherburne Spring Seep* at head of Lake Sherburne near Cracker Flats			
Allen Creek at Cracker Lake trail	2		
Canyon Creek near mouth on Cracker Flats			
Redrock Lake at trail	6		
Bullhead Lake, north shore near trail and constriction	2		
Windmaker Creek* at trail near Bullhead Lake	5		
Swiftcurrent Creek below Wilbur Creek and above campground	7		
Logging Seep* next to Logging Lake trail at upper edge of 1988 Burn			
Logging Lake at Logging Lake Campground			
Logging Creek near upper edge of 1988 Burn	890		
Quartz Creek at Quartz Creek Campground	231	1	0.2
Hidden Meadow Lake near lone pine			
Bowman Lake southwest shore near ranger station		6	1.0
Bowman Creek 0.85 miles above Inside North Fork Road	429	18	3.0
Akokala Creek below Inside North Fork Road	39		
Logging Creek east branch at Logging Creek Campground Unit 2	189		
Bear Creek at US Highway 2 below Autumn Creek and Skyland Creek	939		
Atlantic Creek below Atlantic Falls	504		
Medicine Grizzly Lake near outlet			
Atlantic Pond* on trail below Medicine Grizzly Lake			
Amphitheater Creek* above North Fork Cut Bank Creek Trail	10		
Cut Bank Pond* along North Fork Cut Bank Creek Trail			
Eagle Plume Creek* near mouth	2		
Kupunkamint Creek* above North Fork Cut Bank Creek Trail			
North Fork Cut Bank Creek at Cut Bank Campground	42		
Saint Mary River at Saint Mary Campground footbridge	235	104	17.3
Divide Creek above Saint Mary townsite			

Table 2. cont.

Water Body and Location	*Didymosphenia* No. Valves	*Distrionella* No. Valves	*Distrionella* %
Wild Creek below Glacier National Park Boundary	5		
Rose Creek at Rising Sun	232		
Saint Mary Lake at Golden Stairs		438	73.0
Lost Lake on Going-to-the-Sun Road			
Siyeh Creek above Siyeh Bend	20		
Siyeh Seep* along Going-to-the-Sun Road at Siyeh Bend			
Virginia Creek below Virginia Falls	2		
Dusty Star Creek* above trail to Virginia Falls			
Saint Mary River above Saint Mary Falls	266		
Baring Creek below Baring Falls	2		
Howe Creek at trail below outlet from Lower Howe Lake			
Lower Howe Lake			
Howe Creek at Inside North Fork Road			
Fern Creek at Inside North Fork Road	2		
Lake McDonald at glacier exhibit on GTTS Road above Sprague Creek	207		
Avalanche Creek at mouth	2		
McDonald Creek above Avalanche Creek	3		
Johns Lake			
Johns Fen* south of Johns Lake on Johns Lake Loop Trail			
Fish Lake			
Sprague Creek at Fish Lake Trail			
McDonald Creek near mouth above Quarter Circle Bridge	10	2	0.3

is probably much more widespread than reported.

Based on pre-2007 samples, *Didymosphenia geminata* was widely distributed in and near Glacier National Park. It occurred in 78 percent of all samples and in 90 percent of flowing water samples collected from 1976 through 2006. Slides made from samples collected in 1976 from the lower North and Middle Forks of the Flathead River suggest that both rivers supported heavy growths of *Didymosphenia geminata* that year. Samples collected in 2007 indicated that *Didymosphenia geminata* remains widely distributed and locally abundant in Glacier National Park.

Available data were not sufficient to determine whether populations of *D. geminata* were increasing, decreasing, or stable in the Park. Elsewhere, this species is rapidly expanding its range and becoming a nuisance (U.S. Environmental Protection Agency 2007). In the United States, streams with higher base flow index at higher elevations in cooler climates have the highest probability of *D. geminata* presence (Kumar et al. unpublished data). The base flow index is base flow—the component of stream flow attributed to groundwater discharge—computed as a percentage of total stream flow. Preliminary modeling suggests that mean temperature of the warmest calendar quarter and the base flow index are the two best predictors of potential suitable habitats for *D. geminata* (Kumar et al. unpublished data).

In Glacier and elsewhere in the Canadian Rockies Ecoregion, warmer temperatures, shrinking glaciers and lower stream flows (Rood et al. 2005, Fagre 2007) may favor growth of *D. geminata* over the long term. Short-term cycles of drought may also be a factor. In the summer of 2007, both Flathead and Glacier Counties were in the midst of "severe drought" (Montana Natural Resources Information System 2007). Some effects of global warming and drought in the Park have been lower peak runoff, lower base flows, and disappearing streams (Fagre 2007, Jamison 2007). The lack of substrate-scouring flows in the spring may allow

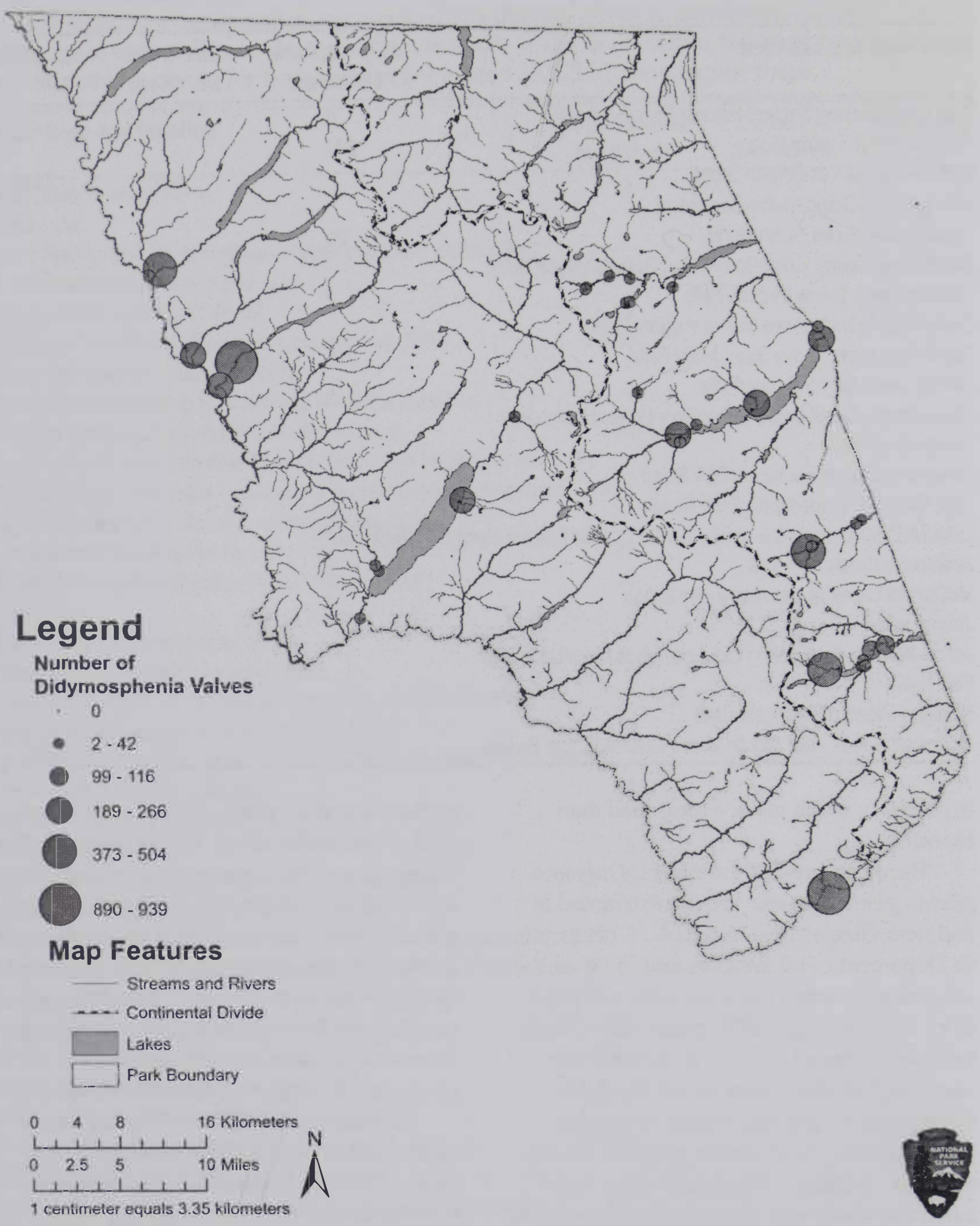

Figure 5. Distribution and relative abundance of *Didymosphenia geminata* (rock snot) in Glacier National Park, 2007.

Didymosphenia colonies to persist from one year to the next. Lower base flows may concentrate nutrients and elevate summer water temperatures to levels that are more amenable to the growth of *Didymosphenia*. Given current drought conditions and local abundance of *Didymosphenia*, and given projected climate changes and observed hydrologic trends in the Park, populations of *Didymosphenia* will probably increase in the future.

Samples from Kintla, Duck, and St. Mary Lakes were the first records of large populations of *Distrionella incognita* in

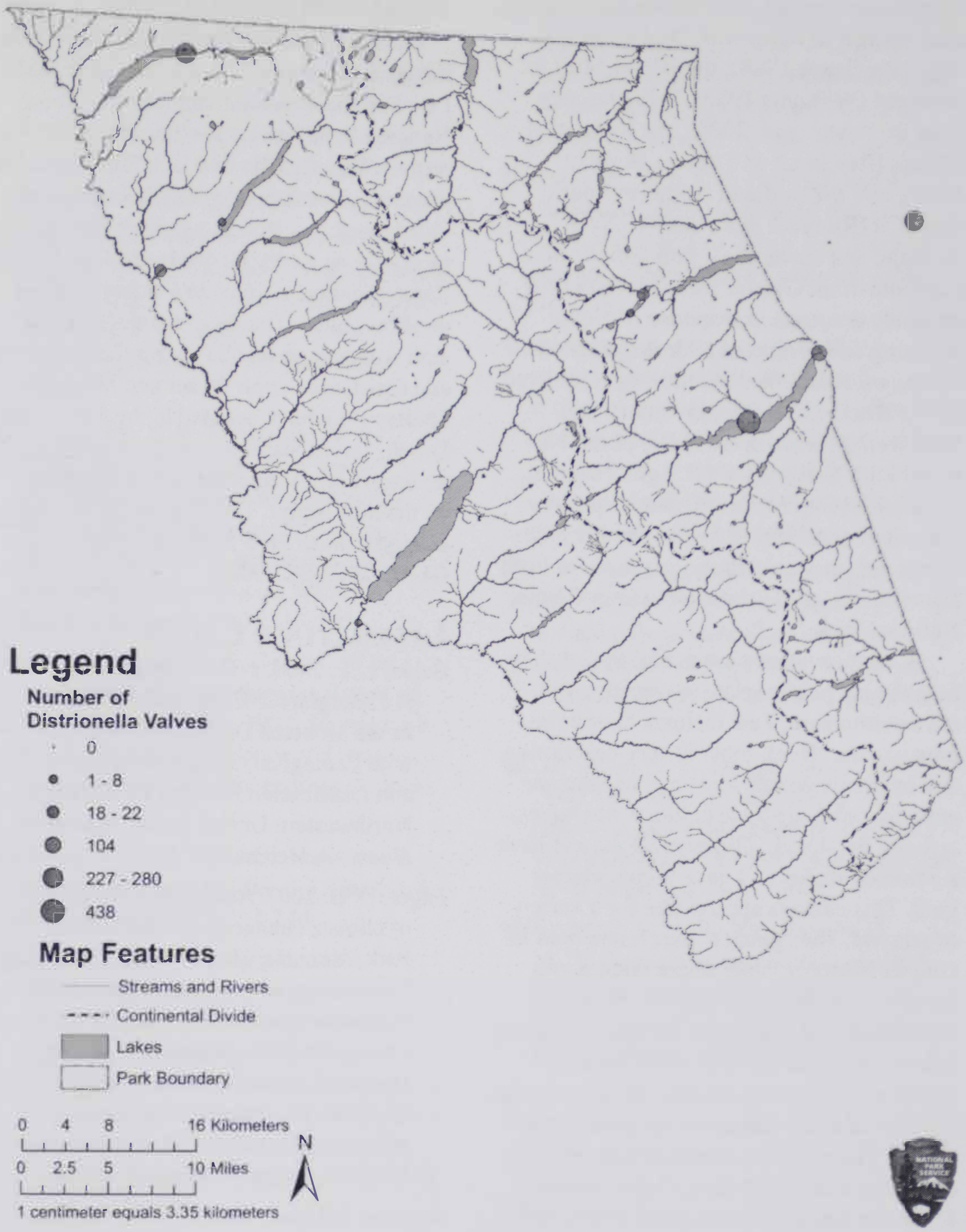

Figure 6. Distribution and relative abundance of *Distrionella incognita* (glacier gold) in Glacier National Park, 2007.

North America. These samples confirm that the preferred habitat for *D. incognita* is large glacially scoured lakes in the Canadian Rockies Ecoregion. Smaller glacial lakes, e.g., Josephine and Swiftcurrent lakes, also support this diatom. Smaller numbers of this diatom have been recorded in streams (Morales et al. 2005, this study). As with the St. Mary River below St. Mary Lake, most if not all individuals of this species that have been recorded in streams probably originated in upstream lakes.

Distrionella incognita and other *Distrionella* species are restricted in their distribution to cold, mountainous, and glaciated regions of the world: the European Alps (Reichardt 1988), the Isle of Mull in Scotland (Williams 1990), Subantarctica (Van de Vijver et al. 2000), the Kerguelen Islands (Reichardt and Lange-Bertalot 1990), and the southern Andes in South America (Rumrich et al. 2000). Given its range and autecology, populations of *Distrionella* in Glacier National Park will probably decrease in response to global warming and projected hydrologic trends. *Periphyton* and other monitoring conducted by the Rocky Mountain Inventory and Monitoring Network (ROMN) of the National Park Service's Vital Signs Program, available at http://science.nature.nps.gov/im/units/romn, may help elucidate population trends and contributing factors for both *Distrionella* and *Didymosphenia* in Glacier National Park.

Common names are useful in that they help the lay public relate to organisms in our environment. Few diatoms have common names. "Rock snot" is very descriptive and evidently coined by someone who has experienced large fresh colonies of *Didymosphenia* first hand. *Distrionella* did not have a common name, so I gave it one: glacier gold. This name is appropriate for a variety of reasons. The "glacier" part refers both to Glacier National Park, where large populations of this species were first found in North America, and to the diatom's preferred habitat, which is literally in the wake of glaciers. This is true not only of *D. incognita* but also of other species in the genus *Distrionella*. The periphyton assemblage on rocks along the shore of St. Mary Lake, where I found the largest percentage of *Distrionella* (73%), had a bright golden color. Coincidentally, I collected the St. Mary Lake sample at a place along the Going-To-The-Sun Road called Golden Stairs, which is named for a distinctive limestone formation. The word "gold" also conveys a sense of value and rarity—*D. incognita* is a rare diatom, at least in the conterminous United States. Finally, glacier gold is a reference to the "mother lode" (primary *in situ* deposit) of this diatom in North America: Glacier National Park.

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