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Research Article

Monitoring over 22 Years Documents Invasion of Rare Riverscour Plant Community on the Delaware River

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ABSTRACT

A rare riverscour community along the Delaware River's New Jersey shoreline that supports numerous state-listed rare plant species was monitored three times between 1998 and 2020, revealing numerous significant trends in plant species richness and abundance. Cover of nonnative species and nonnative invasive species increased annually by 3.8% and 3.7%, respectively, while nonnative and nonnative invasive species richness increased annually by 1.1% and 1.3%. Cover of native species was stable; however, native species richness declined annually by 0.42%. Cover of trees and shrubs increased significantly by nearly 6% annually, while graminoid cover declined by 1.5% annually and herbaceous cover showed no significant trend. Shifts in plant species' importance values documented the establishment and spread of several invasive shrub and herbaceous species, as well as the extensive spread of the invasive reed canarygrass (*Phalaris arundinacea*). Native grasses and sedges characteristic of the riverscour community, as well as over half of the 147 native herbaceous species identified, declined in importance value over the sampling period. Future declines in winter ice scour due to projected warmer, shorter winters underscore the importance of managing woody invasive plants at this site. Reed canarygrass and herbaceous invasive species also pose a challenge to the management and preservation of this rare community.

Index terms: invasive plants; monitoring; national park; rare plant community; riverscour

INTRODUCTION

Riverscour communities are "open habitats of stable-substrate zones (bedrock, boulder, cobble), often along high-gradient streams, where periodic high-flow events and edaphic factors inhibit woody vegetation and promote persistent shrub-grassland-open woodland communities rich in conservative heliophytes" (Estes et al. in prep). Many of these unique plant communities are considered globally rare (Sneddon 2010) and provide critical habitat for numerous rare plant species (Perles et al. 2007; Cartwright and Wolfe 2016).

The Calcareous Riverside Outcrop is a rare riverscour community that occurs along the New Jersey shoreline of the Delaware River in the Delaware Water Gap National Recreation Area (DEWA) and supports 26 state-rare plant species (Shank and Shreiner 1999; Perles et al. 2007). Ranked by NatureServe as Globally Imperiled (G2; Sneddon 2010), the Calcareous Riverside Outcrop is characterized by sparsely to densely vegetated sections of Buttermilk Falls limestone outcrops that slope on a north-northwest exposure from the adjacent forest to the river's edge. Areas of fractured limestone typically support denser aggregations of heliophytic herbaceous plants and graminoids, while smooth limestone sections often have vegetation growing only in the crevices (Perles et al. 2007). Interspersed along the length of the Calcareous Riverside Outcrop, Calcareous Riverside Seeps occur where groundwater flows out of the toe-slope at the forest edge and over the limestone bedrock. These seeps are considered a unique plant community, ranked as Globally Critically Imperiled (G1; Sneddon 2010), that support many calciphiles, rare species, and plants that are dependent on the groundwater seepage (Perles et al. 2007). Throughout the Calcareous Riverside Outcrop, plant species are distributed patchily, due to varying microsite conditions in moisture gradients (e.g., pools of standing water, seeps, droughty thin soil over rock) and substrate types (e.g., silt deposits, mix of soil and cobble, bare exposed limestone).

The three Calcareous Riverside Outcrop sites in DEWA occur in the same geomorphological position—northwest facing slope of Buttermilk Falls limestone outcrop, immediately downstream of an S-shaped meander that directs winter ice to accumulate on and scour the rock outcrop along the New Jersey shore. This spring ice-scour removes woody plants and is essential to maintaining riverscour communities dominated by graminoid and herbaceous species that regenerate from buried rootstocks (Breden 1989; Perles et al. 2007; DePhilip and Moberg 2013; Edinger et al. 2014). Although these sites are prone to frequent flooding, high summer temperatures from full exposure to afternoon sun over rock substrate causes severe drought stress, which also influences which species can thrive in the riverscour. Changing climate threatens to impact riverscour communities through unprecedented storms and droughts (Rustad et al. 2012), but warmer winter temperatures that reduce winter ice accumulation and spring ice scour are a key threat to the persistence of the Calcareous Riverside Outcrop in DEWA (Podniesinski et al. 2010; DePhilip and Moberg 2013).

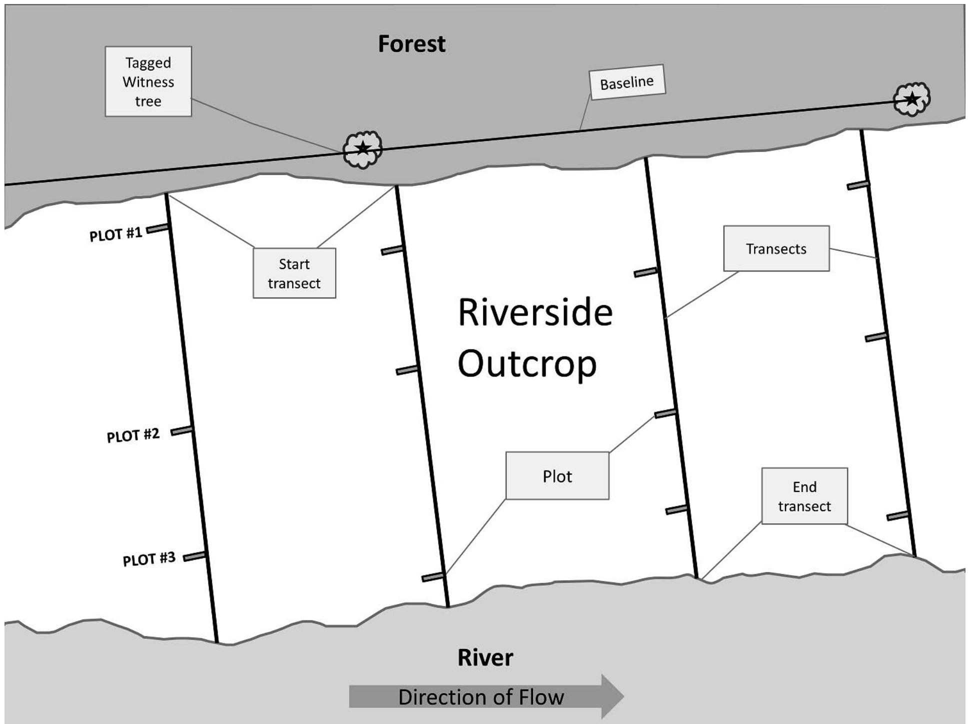

Figure 1.—Monitoring sample design for the Calcareous Riverside Outcrop along the New Jersey shoreline of the Delaware River in the Delaware Water Gap National Recreation Area.

Due to the high biodiversity value of these sites, a study was initiated in 1998 by biologists at DEWA and the New Jersey Department of Environmental Protection Office of Natural Lands Management to document the status of the rare plant species and natural communities (Shank and Shreiner 1999). Monitoring protocols that provided baseline information for documenting future trends in species composition were established only at the Dingmans Ferry site, the largest of the three Calcareous Riverside Outcrops in DEWA. Particular focus was given to the distribution and abundance of the invasive purple loosestrife (*Lythrum salicaria*) because nonnative leaf-eating *Galerucella* beetles were to be released as biological controls in DEWA the following year (Shank and Shreiner 1999). After the establishment of the National Park Service's Inventory and Monitoring Division (Fancy et al. 2009), the Eastern Rivers and Mountains Inventory and Monitoring Network (ERMN) adapted the monitoring protocols used at Dingmans Ferry to monitor riverscour communities in three national park units (including DEWA) with the objective of providing information on conditions and trends of the parks' riverscour communities to inform management decisions affecting those riparian systems (Perles et al. 2018). Monitoring data were collected by ERMN at the Dingmans Ferry site in 2010 and 2020. These data, along with those collected in 1998 by park and state personnel, provide insights into the changes that have occurred within this extensive riverscour community over 22 years. The observed trends are presented here to inform the management of riverscour communities in the eastern United States.

METHODS

Field Methods

The Dingmans Ferry Calcareous Riverside Outcrop encompasses a strip of the Delaware River shoreline approximately 15–20 m wide and 2.6 km long in New Jersey. Using restricted randomization to ensure transects were distributed throughout the site's length, 50 monitoring transects were established along a baseline that spanned the site. The locations of the baseline and monitoring transects were documented based on tagged witness trees; transects were run perpendicular to the shoreline from the forest to the river's edge, with defined criteria to consistently determine the beginning and end points of the monitoring transects (Perles et al. 2018). Along each monitoring transect, three plots were established using restricted randomization to place one plot in each third of the transect (Figure 1). The location of each transect relative to the baseline, the transect azimuth, and plot positions were recorded and replicated during subsequent sampling events.

Within each 1 m^2 plot, the substrate was characterized and all vascular plant species within the plot were recorded using standard percent cover categories (Perles et al. 2018) and nomenclature following Rhoads et al. (2000). The number of stems of purple loosestrife rooted in the plot was recorded, along with the amount of purple loosestrife defoliation observed, using standardized defoliation categories (Wilson et al. 2004; Perles et al. 2018). All 150 plots were sampled in August 1998, 2010, and 2020 when the phenology of the dominant graminoid and herbaceous plants allows for identification to species.

Table 1.—Mean effect sizes with 90% confidence intervals (CI) of year and distance from forest edge on several plant species richness and abundance measures. Significant effects are shown in bold. In the linear mixed effects models, year and distance from forest edge (i.e., plot position along monitoring transect) were included as fixed effects, and random effects for year, plot, and transect accounted for temporal and spatial correlation and variation. Random effects with variance estimates near zero were removed from the final models, leaving the random effects listed in the table.

Metric	Annual trend (% change / year)	90% CI	*P*	Distance from forest (% change / meter)	90% CI	*P*	Random effects in model
Purple Loosestrife Stem Density	**−5.97**	**(−7.39, −4.63)**	**<0.0001**	**13.66**	**(10.64, 16.77)**	**<0.0001**	Year, Plot, Transect
<u>Species Richness</u>							
Native	**−0.42**	**(−0.75, −0.08)**	**0.0408**	**−4.01**	**(−5.56, −2.43)**	**<0.0001**	Plot, Transect
Non Native	**1.14**	**(0.45, 1.83)**	**0.0062**	**−3.04**	**(−4.34, −1.73)**	**0.0002**	Year, Plot, Transect
Invasive	**1.30**	**(0.71, 1.89)**	**0.0003**	**−1.90**	**(−2.99, −0.80)**	**0.0046**	Plot, Transect
<u>Abundance (Cover)</u>							
Native	0.19	(−1.14, 1.54)	0.8169	**−5.12**	**(−7.33, −2.87)**	**0.0002**	Year, Plot, Transect
Non Native	**3.80**	**(2.74 , 4.88)**	**<0.0001**	−0.97	(−3.27, 1.39)	0.4960	Year, Plot, Transect
Invasive	**3.71**	**(2.47, 4.96)**	**<0.0001**	0.89	(−1.78, 3.64)	0.588	Year, Plot, Transect
Tree	**5.57**	**(2.80, 8.42)**	**0.0008**	**−11.11**	**(−15.20, 6.82)**	**<0.0001**	Year, Plot
Shrub	**5.90**	**(3.68, 8.16)**	**<0.0001**	**−26.27**	**(−31.97, −20.11)**	**<0.0001**	Plot
Graminoid	**−1.47**	**(−2.60, −0.32)**	**0.0355**	**6.08**	**(3.32, 8.90)**	**0.0002**	Year, Plot, Transect
Herbaceous	0.37	(−0.49, 1.24)	0.4754	**−3.61**	**(−5.42, −1.75)**	**0.0015**	Plot, Transect
Vine	0.70	(−2.48, 1.04)	0.5100	**−26.84**	**(−32.06, −21.2)**	**<0.0001**	Plot, Transect

Data Analysis

Using nativity assigned by Rhoads et al. (2000) and an invasive plant species list developed by ERMN (Perles et al. 2018), richness for native, nonnative, and nonnative invasive plant species was summarized for each plot. Although its nativity is debated (Barkworth et al. 2007), reed canarygrass (*Phalaris arundinacea*) was considered a nonnative invasive species in this analysis due to its aggressive growth and ability to invade riparian plant communities (Barnes 1999; Fierke and Kauffman 2006).

Percent cover categories were converted to midpoint cover values and then used to sum plot-level total cover of native, nonnative, and nonnative invasive plants, as well as total cover by plant guild (i.e., tree, shrub, graminoid, herbaceous, vine). Total cover values could exceed 100% for plots that sampled dense vegetation. Ferns were not sufficiently abundant to be included in the plant guild analysis. Importance values were calculated from the average of relative plot frequency and relative cover, for all taxa observed by year.

We fit linear mixed effects models (Bolker et al. 2009) using the *glmmTMB* package (Brooks et al. 2017) in the R 4.1.1 software (R Core Team 2021) to estimate change in plant species richness and abundance measures (Table 1). Year and distance from forest edge (i.e., plot position along monitoring transect) were included as fixed effects, and random effects for year, plot, and transect accounted for temporal and spatial correlation and variation. Random effects with variance estimates near zero were removed from the final models (Table 1). To model purple loosestrife stem density, the negative binomial error distribution was used and the variance was assumed to be a linear function of the mean (nbinom1 error family distribution). Poisson distribution was utilized in species richness models, and the Tweedie error distribution was used in models of total plant cover. Model fit was assessed using the *DHARMa* package (Hartig and Lohse 2020), and trends were considered significant when $\alpha \leq 0.05$.

RESULTS

Numerous significant trends over time were observed in plant species richness and abundance (Table 1). Purple loosestrife stem density decreased nearly 6% annually over the study period (90% confidence interval [CI]: –7.4%, –4.6%), and showed spatial trends such that plots near the river contained more purple loosestrife stems than plots closer to the forest (Figure 2). In 1998, purple loosestrife ranked highest in importance value (7.8%), nearly double that of the next most important species (Table 2, Figure 3). Over the study period, purple loosestrife experienced the largest decrease in importance (–2.6%) of any observed taxon; however, it still ranked as the third highest in importance in 2020 (Table 2).

Nonnative and nonnative invasive species richness increased annually by 1.1% (90% CI: 0.4%, 1.8%) and 1.3% (90% CI: 0.7%, 1.9%), respectively (Figure 4), while cover of nonnative and nonnative invasive species increased annually by 3.8% (90% CI: 2.7%, 4.9%) and 3.7% (90% CI: 2.5%, 5.0%), respectively (Figure 5). Cover of native species was stable (Figure 5); however, native species richness declined annually by 0.42% (90% CI: –0.7%, –0.1%; Figure 4). Cover of trees and shrubs increased significantly by nearly 6% annually, while graminoid cover declined by 1.5% (90% CI: –2.6%, –0.3%) annually (Figure 6). Herbaceous and vine cover showed no significant trends (Table 1, Figure 6).

As indicated by changes in species' importance values (Table 2, Figure 3, Supplemental Appendix A), increases in invasive species richness, invasive cover, and shrub cover were driven by the establishment and spread of invasive shrubs such as autumn olive (*Elaeagnus umbellata*), bush honeysuckles (*Lonicera morrowii* and others), and multiflora rose (*Rosa multiflora*), along with numerous herbaceous invasive species, including common wormwood (*Artemisia vulgaris*), Japanese knotweed (*Polygonum cuspidatum*), Oriental lady's thumb (*Polygonum caespitosum*), Asiatic tearthumb (*Polygonum perfoliatum*), pale

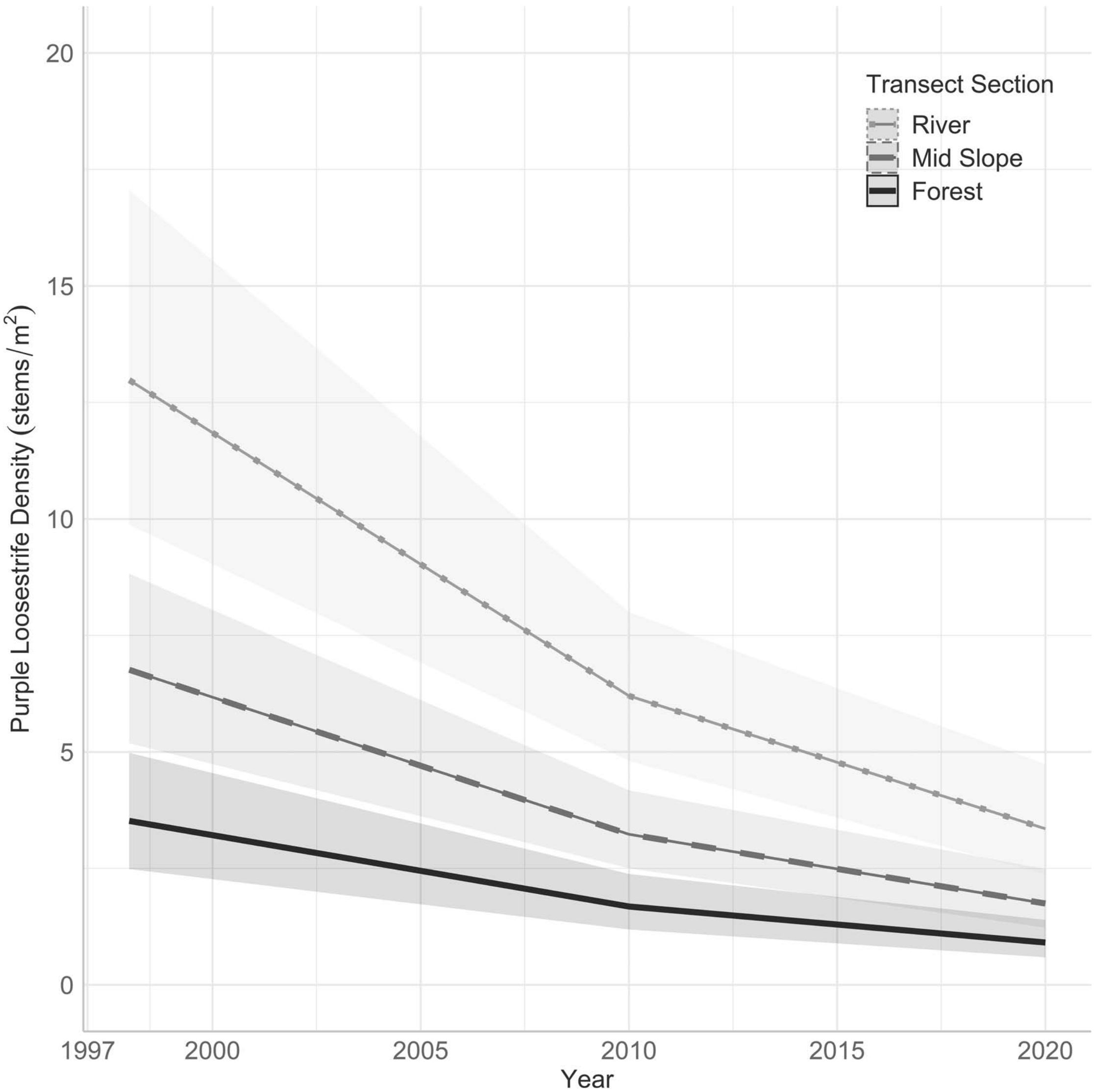

Figure 2.—Predicted means and 90% empirical confidence intervals for purple loosestrife stem density in the three sections of monitoring transects at the Dingmans Ferry riverscour site in the Delaware Water Gap National Recreation Area.

yellow iris (*Iris pseudacorus*), dames rocket (*Hesperis matronalis*), and narrowleaf bittercress (*Cardamine impatiens*). Gains in invasive species cover were also driven by reed canarygrass (*Phalaris arundinacea*), which showed the largest increase in importance over the study period and ranked highest in importance value in 2020, with nearly double the importance value of the second ranked species (Table 2).

Native shrubs, including common ninebark (*Physocarpus opulifolius*), alders (*Alnus incana* and *A. serrulata*), dogwoods (*Cornus racemosa* and *C. sericea*), and viburnums (*Viburnum acerifolium* and *V. lentago*), showed declines in importance values over the same period. Native trees typical of the Delaware River floodplain, such as American elm (*Ulmus americana*), silver maple (*Acer saccharinum*), and American sycamore (*Platanus occidentalis*), accounted for the increases in tree cover. Over half (53.7%) of the 147 native herbaceous species identified over the three sampling periods declined in importance value, including asters (*Symphyotrichum lanceolatum*, *S. lateriflorum*, *S. novae-angliae*, *S. puniceum*), goldenrods (*Solidago canadensis*, *S. rugosa*, *Euthamia graminifolia*), and other tall-statured herbaceous species characteristic of river shorelines (Supplemental Appendix A).

The declines in graminoid cover are particularly noteworthy in light of the strong increase in reed canarygrass. Native graminoids characteristic of the Calcareous Riverside Outcrop and Calcareous Riverside Seep communities, such as big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), and sedges (*Carex viridula* and *C. granularis*), declined in importance and were not observed in plots in 2020 (Table 2, Supplemental Appendix A). Japanese stiltgrass (*Microstegium vimineum*) also declined in importance, likely due to its intolerance of late summer drought conditions on the outcrop.

Table 2.—Change in importance values for common nonnative and native plant species in the Dingmans Ferry Calcareous Rock Outcrop over three sampling periods (1998–2020). Nonnative invasive species are denoted with an X in the Invasive column. Importance values, nativity, and invasive status for all species observed are shown in Supplemental Appendix A.

				Importance value (%)			
Latin name	Common name	Plant guild	Invasive	1998	2010	2020	Change 1998–2020
Nonnative							
Phalaris arundinacea	reed canarygrass	Graminoid	X	3.99	5.59	9.75	5.76
Elaeagnus umbellata	autumn olive	Shrub	X	0.00	3.36	5.69	5.69
Artemisia vulgaris	common wormwood	Herbaceous	X	0.00	2.24	4.20	4.20
Lonicera morrowii	Morrow's honeysuckle	Shrub	X	0.00	1.57	2.52	2.52
Glechoma hederacea	ground ivy	Herbaceous	X	0.61	1.86	2.62	2.00
Myosotis scorpioides	true forget-me-not	Herbaceous	X	0.11	0.85	1.29	1.19
Polygonum caespitosum	Oriental ladysthumb	Herbaceous	X	0.00	0.13	1.14	1.14
Rosa multiflora	multiflora rose	Shrub	X	0.00	0.51	1.08	1.08
Polygonum hydropiper	marshpepper knotweed	Herbaceous	–	0.00	0.67	0.99	0.99
Silene vulgaris	maiden's tears	Herbaceous	–	0.00	0.00	0.99	0.99
Agrostis stolonifera	creeping bentgrass	Graminoid	–	0.00	0.00	0.86	0.86
Alliaria petiolata	garlic mustard	Herbaceous	X	0.18	0.18	0.95	0.76
Sedum sarmentosum	stringy stonecrop	Herbaceous	X	0.25	1.05	1.00	0.76
Agrostis gigantea	redtop	Graminoid	–	0.00	1.04	0.06	0.06
Myosoton aquaticum	giant chickweed	Herbaceous	–	0.93	0.52	0.86	−0.07
Melilotus alba	white sweetclover	Herbaceous	–	0.97	0.04	0.04	−0.93
Lychnis flos-cuculi	ragged robin	Herbaceous	X	1.80	0.63	0.00	−1.80
Microstegium vimineum	Japanese stiltgrass	Graminoid	X	3.88	2.59	1.71	−2.17
Lythrum salicaria	purple loosestrife	Herbaceous	X	7.78	6.28	5.17	−2.61
Native							
Impatiens capensis	jewelweed	Herbaceous	–	0.00	1.94	1.67	1.67
Equisetum arvense	field horsetail	Herbaceous	–	0.00	1.06	1.65	1.65
Solidago gigantea	giant goldenrod	Herbaceous	–	1.19	2.91	2.40	1.21
Carex torta	twisted sedge	Graminoid	–	0.00	2.43	1.21	1.21
Galium tinctorium	stiff marsh bedstraw	Herbaceous	–	0.00	2.65	1.16	1.16
Ulmus americana	American elm	Tree	–	0.00	0.15	1.13	1.13
Leersia virginica	whitegrass	Graminoid	–	0.00	0.65	1.08	1.08
Acer saccharinum	silver maple	Tree	–	0.02	0.00	1.10	1.07
Xanthium strumarium	rough cocklebur	Herbaceous	–	0.00	0.43	1.00	1.00
Leersia oryzoides	rice cutgrass	Graminoid	–	0.00	0.63	0.95	0.95
Eupatoriadelphus maculatus	spotted trumpetweed	Herbaceous	–	1.47	1.34	2.34	0.88
Pilea pumila	Canadian clearweed	Herbaceous	–	0.89	0.63	1.75	0.86
Bidens frondosa	devil's beggartick	Herbaceous	–	0.00	0.00	0.78	0.78
Platanus occidentalis	American sycamore	Tree	–	0.24	0.64	1.00	0.76
Parthenocissus quinquefolia	Virginia creeper	Vine	–	0.43	0.65	1.15	0.72
Toxicodendron radicans	eastern poison ivy	Vine	–	1.17	1.65	1.68	0.51
Spartina pectinata	prairie cordgrass	Graminoid	–	0.00	1.53	0.36	0.36
Symphyotrichum lateriflorum	calico aster	Herbaceous	–	0.59	0.86	0.36	−0.23
Apios americana	groundnut	Vine	–	0.85	0.95	0.47	−0.37
Thelypteris palustris	eastern marsh fern	Fern	–	1.12	1.85	0.73	−0.39
Solidago rugosa	wrinkleleaf goldenrod	Herbaceous	–	0.85	1.56	0.18	−0.67
Euthamia graminifolia	flat-top goldentop	Herbaceous	–	1.09	0.45	0.39	−0.70
Solidago canadensis	Canada goldenrod	Herbaceous	–	0.95	0.00	0.19	−0.76
Symphyotrichum lanceolatum	white panicle aster	Herbaceous	–	2.62	1.50	1.64	−0.98
Physocarpus opulifolius	common ninebark	Shrub	–	1.22	0.14	0.21	−1.01
Andropogon gerardii	big bluestem	Graminoid	–	1.62	0.34	0.00	−1.62
Ageratina altissima	white snakeroot	Herbaceous	–	1.67	0.48	0.00	−1.67
Galium boreale	northern bedstraw	Herbaceous	–	1.93	0.77	0.00	−1.93

The location of the monitoring plots within the riverscour, as measured by distance from the forest edge (i.e., start of monitoring transect), was also a significant predictor of plant species richness and abundance (Table 1). Significantly greater species richness, regardless of nativity or invasive status, was observed on the upper slopes of the riverscour, closer to the forest. Greater cover of native species was also observed closer to the forest; however, nonnative and nonnative invasive plant cover did not show significant trends with distance from forest. Cover by guild decreased significantly across the riverscour

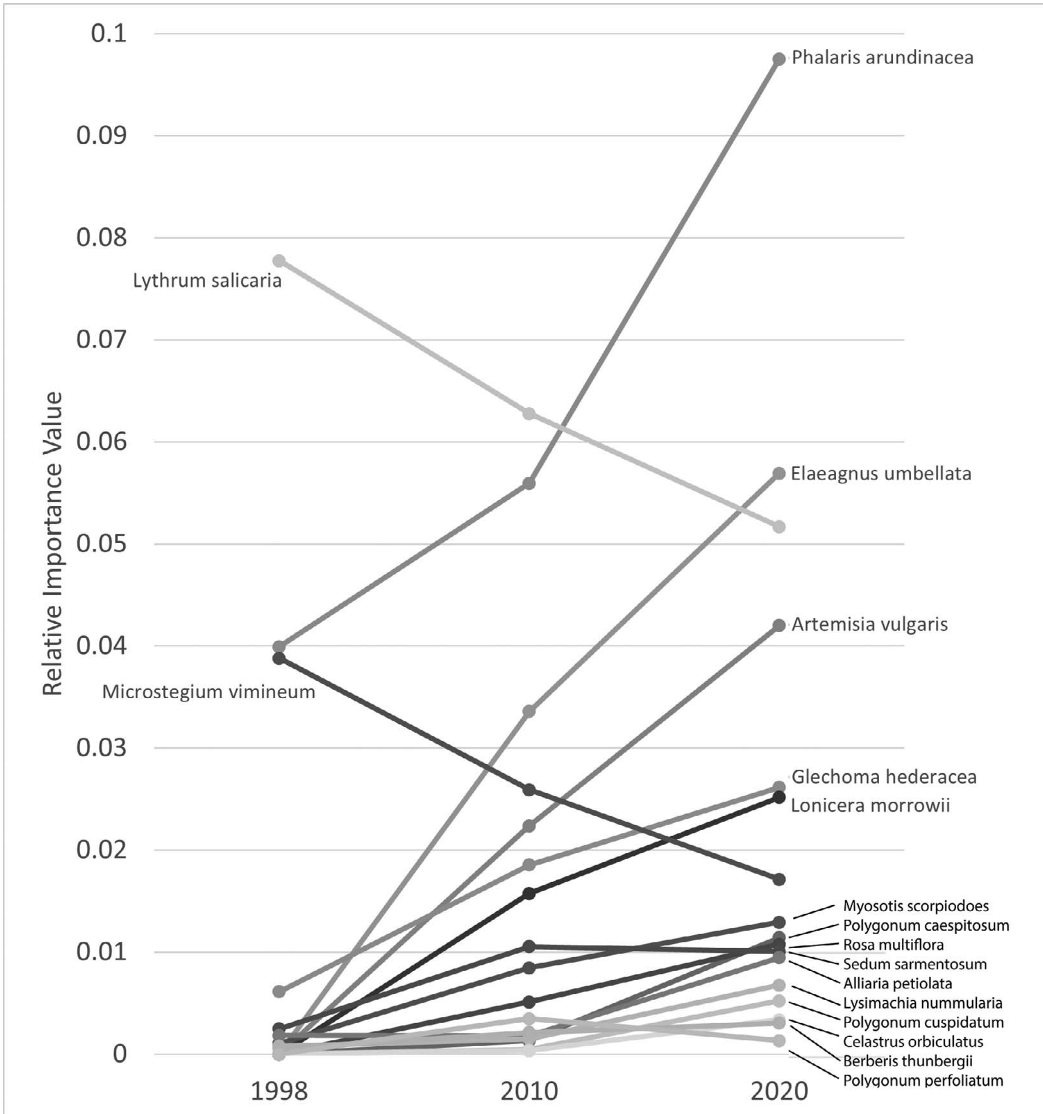

Figure 3.—Changes in importance values over time of selected nonnative invasive species at the Dingmans Ferry riverscour site in the Delaware Water Gap National Recreation Area.

from forest to river for trees, shrubs, graminoids, herbaceous plants, and vines (Table 1). These trends were most likely driven by frequency and duration of flooding, as plots on the upper slopes closer to the forest experienced fewer and shorter inundation periods, in addition to sediment accumulation patterns on the sloped rock outcrop.

DISCUSSION

Over the 22 y study period, the Calcareous Riverside Outcrop at Dingmans Ferry experienced dramatic increases in the richness and abundance of invasive plants, with concurrent declines in native plant richness and cover, including species characteristic of this globally rare community. The changes at this site illustrate a wider trend in biotic homogenization (McKinney and Lockwood 1999; Olden and Rooney 2006) where unique habitats and conservative plants are replaced by generalist and invasive species that have wider environmental tolerances. At the Dingmans Ferry riverscour site, species composition transitioned from being dominated by heliophytic grasses, calciphytic sedges, and herbaceous plants typical of open river shores, to dominance by reed canary grass and other invasive shrub and herbaceous species. Current species composition is similar to a Reed Canarygrass Floodplain Grassland, a ruderal plant community found along the river within the park (Perles et al. 2007) that is increasing throughout the mid-Atlantic region (NatureServe 2020). Reed canarygrass has reduced native plant diversity in riparian areas (Barnes 1999; Fierke and Kauffman 2006) and affected the flow regimes in many river systems throughout the United States (Waggy 2010; Carter et al. 2012).

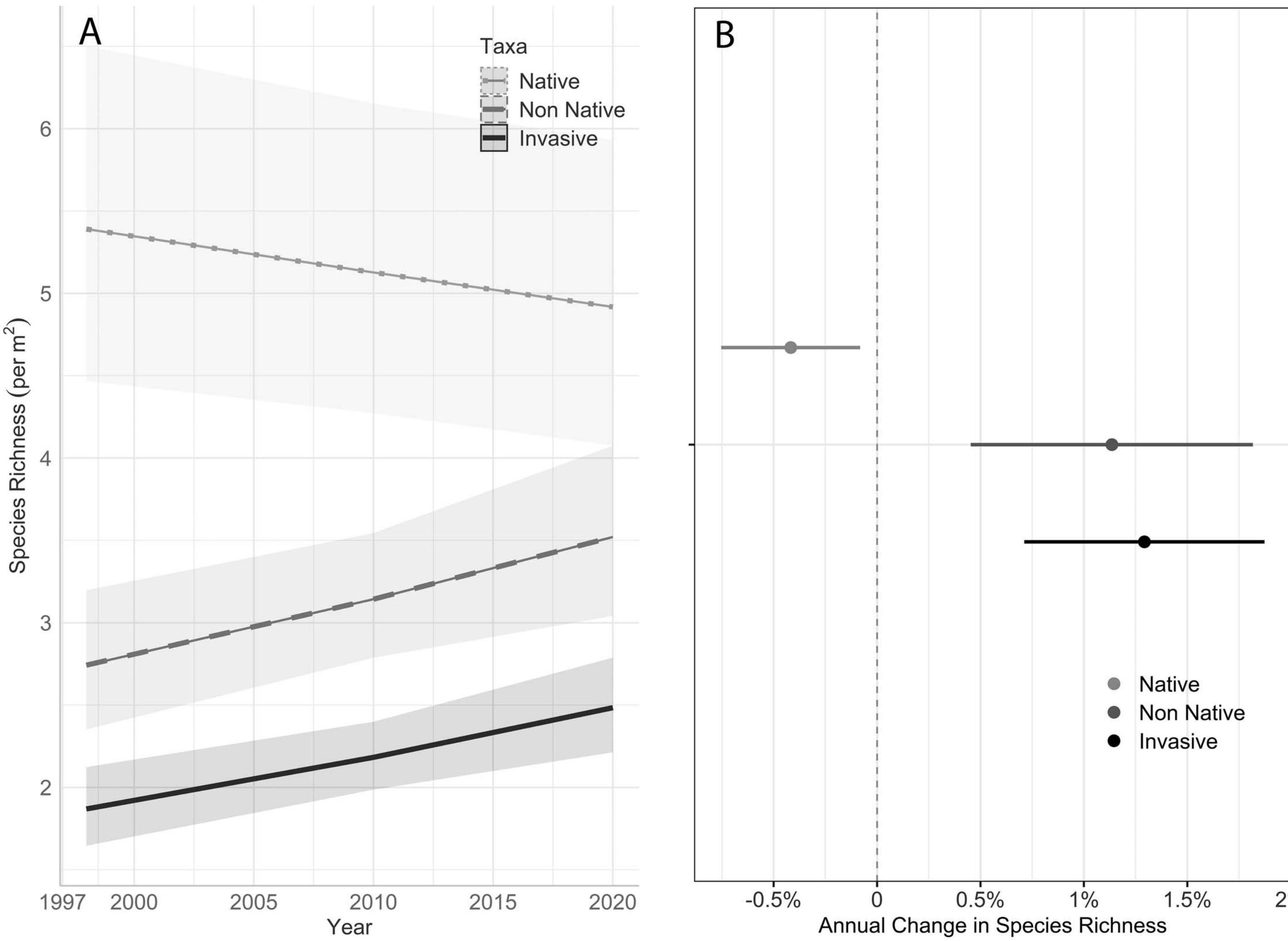

Figure 4.—Modeled trends and 90% confidence intervals in native, nonnative, and nonnative invasive plant species richness (per m^2) at the Dingmans Ferry riverscour site in the Delaware Water Gap National Recreation Area, shown as (A) mean species richness over time, and (B) annual change in species richness.

Riparian plant communities are particularly susceptible to invasive plants due to frequent disturbance, influx of propagules, adjacent land uses, and rich, mesic sediments (Planty-Tabacchi et al. 1996; Hood and Naiman 2000; Naiman et al. 2005). Previous research on the distribution of invasive plants in DEWA noted that riparian areas contained higher invasive plant abundance within the park (Eichelberger and Perles 2009). Prioritizing invasive plant treatments in rare riparian communities can be a strategic focus for park management to maintain the unique character of these sites that provide habitat for rare plants. Invasive woody shrubs can be cut and treated with herbicides during the winter or early spring to avoid harming native plants or disturbing the seeps. However, common wormwood and reed canarygrass are more difficult to treat, especially in sensitive areas such as globally rare communities.

The release of leaf-eating *Galerucella* beetles in 1999 likely contributed to the decline in purple loosestrife at the site, as these beetles or evidence of their herbivory were observed during all three sampling events, and they have been widely successful at reducing purple loosestrife throughout the eastern United States (Malecki et al. 1993). However, the *Galerucella* beetles did not eliminate purple loosestrife, which ranked as third highest in importance in 2020. In addition, a weevil (*Rhinoncomimus latipes*) was released at several riparian sites in DEWA starting in 2008 as a biological control for mile-a-minute weed (*Polygonum perfoliatum*). Mile-a-minute weed was unknown to occur in the park in 1998, but its importance declined between 2010 and 2020 (Figure 3, Supplemental Appendix A), likely a result of the weevil, which has effectively reduced mile-a-minute weed abundance at other riparian sites in New Jersey (Hough-Goldstein et al. 2015).

As the climate warms, the expected reduction of winter ice scour will be an important driver in the plant community changes at Dingmans Ferry. Mean annual temperature in

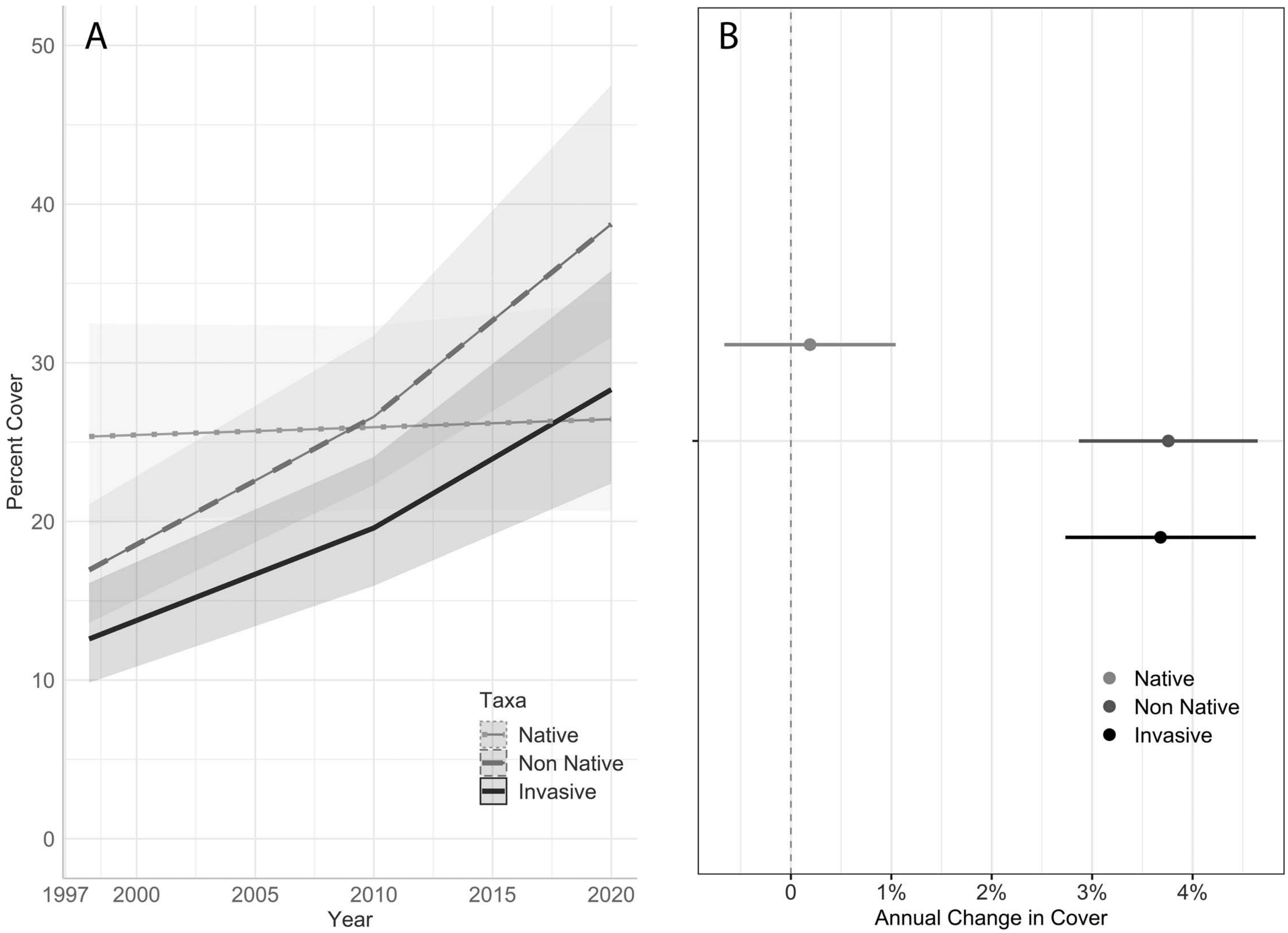

Figure 5.—Modeled trends and 90% confidence intervals in native, nonnative, and nonnative invasive plant cover at the Dingmans Ferry riverscour site in the Delaware Water Gap National Recreation Area, shown as (A) mean percent cover over time, and (B) annual change in percent cover.

DEWA increased significantly at an average rate of 1.1 ± 0.5 °C per century from 1950 to 2010 (Gonzalez 2016), with historic highs in mean annual temperatures experienced during this study's sampling period compared to records dating back to 1901 (Monahan and Fisichelli 2014). Of particular importance to winter ice formation, the frost-free season from 1991 to 2012 was 10–14 d shorter in the northeastern United States compared to 1901–1960, with projections of warmer, shorter winters including fewer days with temperatures below freezing and higher mean and minimum winter temperatures over the next century (Paradis et al. 2007; Walsh et al. 2014; Gonzalez 2016). Warmer, shorter winters will likely result in less of the ice scour that has heretofore maintained the diverse open, graminoid-dominated riverscour community. Periodic removal of woody plants, especially invasive shrubs, from the riverscour must be conducted by park management to maintain this rare community.

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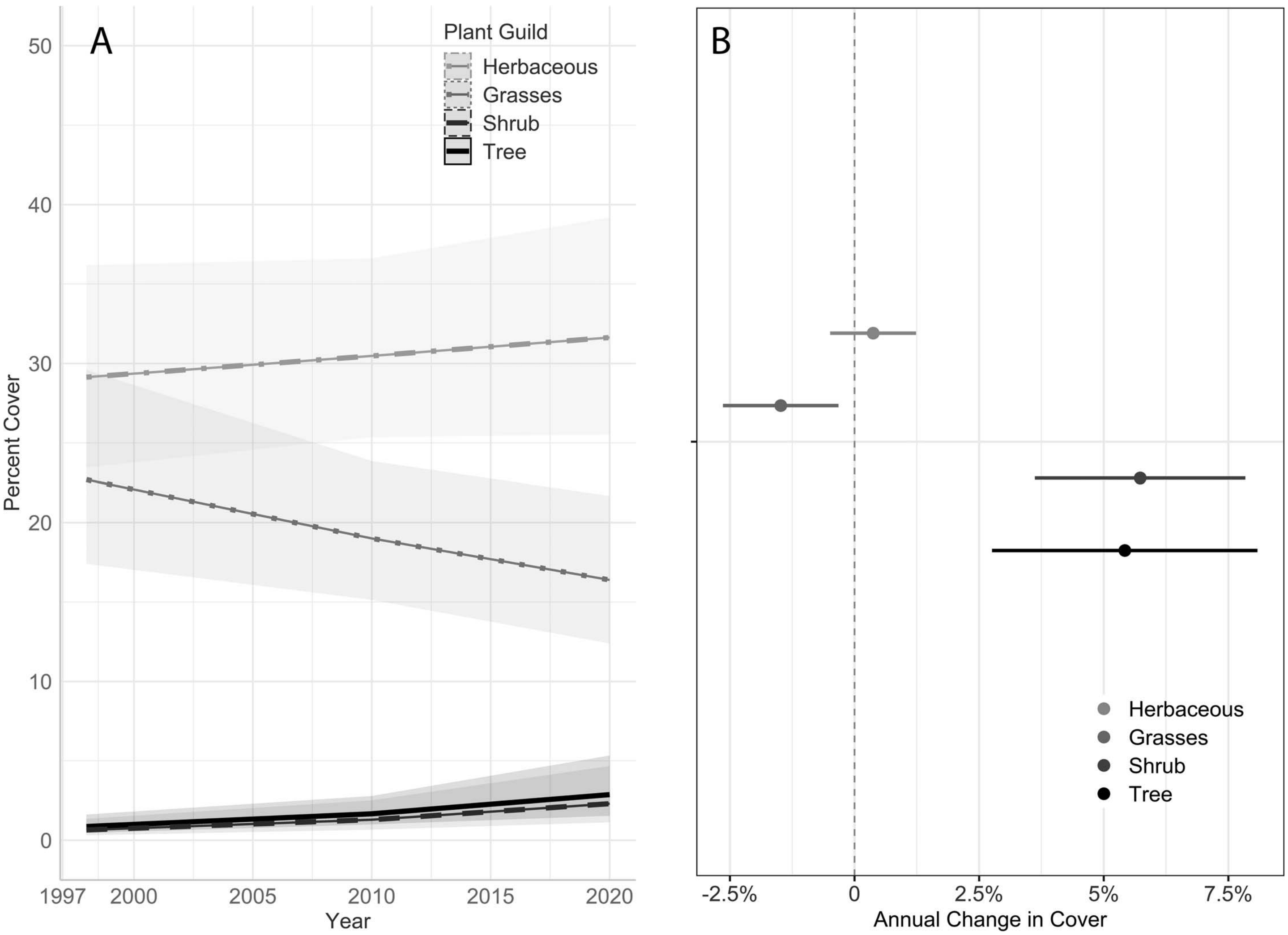

Figure 6.—Modeled trends and 90% confidence intervals in herbaceous, graminoid, shrub, and tree cover at the Dingmans Ferry riverscour site in the Delaware Water Gap National Recreation Area, shown as (A) mean percent cover over time, and (B) annual change in percent cover.

Jeff Shreiner recently retired from the Natural Resources branch of the Delaware Water Gap National Recreation Area, where he coordinated the park's Inventory & Monitoring program. Collaborating with the New Jersey Natural Heritage Program in 1997–1998, he conducted surveys of the riverscour communities at Dingmans Ferry and two additional sites in the park.

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LITERATURE CITED

Barkworth, M.E., K.M. Capels, S. Long, L.K. Anderton, and M.B. Piep, eds. 2007. Flora of North America North of Mexico. Volume 24: Magnoliophyta: Commelinidae (in part): Poaceae, part 1. Oxford University Press, New York.

Barnes, W.J. 1999. The rapid growth of a population of reed canarygrass (*Phalaris arundinacea* L.) and its impact on some riverbottom herbs. Journal of the Torrey Botanical Society 126:133–138.

Bolker, B.M., M.E. Brooks, C.J. Clark, S.W. Geange, J.R. Poulsen, M.H.H. Stevens, and J.S.S. White. 2009. Generalized linear mixed models: A practical guide for ecology and evolution. Trends in Ecology & Evolution 24:127–135.

Breden, T.F. 1989. A preliminary natural community classification for New Jersey. Pp. 157–191 *in* E.F. Karlin, ed., New Jersey's Rare and Endangered Plants and Animals. Institute for Environmental Studies, Ramapo College, Mahwah, NJ.

Brooks, M.E., K. Kristensen, K.J. van Benthem, A. Magnusson, C.W. Berg, A. Nielsen, H.J. Skaug, M. Maechler, and B.M. Bolker. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R Journal 9:378–400.

Carter, W.C., M.D. Dixon, M.L. Scott, L. Rabbe, G. Larson, M. Volke, and B. Werner 2012. Forty years of vegetation change on the Missouri River Floodplain. BioScience 62:123–135.

Cartwright, J.M., and W.J. Wolfe. 2016. Insular ecosystems of the southeastern United States—A regional synthesis to support biodiversity conservation in a changing climate. U.S. Geological Survey Professional Paper 1828, Reston, VA.

DePhilip, M., and T. Moberg. 2013. Ecosystem flow recommendations for the Delaware River basin. The Nature Conservancy, Harrisburg, PA.

Edinger, G.J., D.J. Evans, S. Gebauer, T.G. Howard, D.M. Hunt, and A.M. Olivero, eds. 2014. Ecological Communities of New York State. 2nd ed. A Revised and Expanded Edition of Carol Reschke's Ecological Communities of New York State. New York Natural Heritage Program, New York State Department of Environmental Conservation, Albany, NY.

Eichelberger, B.A., and S.J. Perles. 2009. Determining the status and trends of key invasive plant species in the Delaware Water Gap National Recreation Area. Technical Report NPS/NER/NRTR—2009/134. National Park Service, Philadelphia, PA.

Fancy, S.G., J.E. Gross, and S.L. Carter. 2009. Monitoring the condition of natural resources in US National Parks. Environmental Monitoring and Assessment 151:161–174.

Fierke, M.K., and J.B. Kauffman. 2006. Invasive species influence riparian plant diversity along a successional gradient, Willamette River, Oregon. Natural Areas Journal 26:376–382.

Gonzalez, P. 2016. Climate change trends, vulnerabilities, and hydrology in Delaware Water Gap National Recreation Area, USA. National Park Service unpublished report.

Hartig, F., and L. Lohse. 2020. Package 'DHARMa'. Residual diagnostics for hierarchical (multi-level/mixed) regression models. <https://cran.r-project.org/web/packages/DHARMa/DHARMa.pdf>

Hood, W.G., and R.J. Naiman. 2000. Vulnerability of riparian zones to invasion by exotic vascular plants. Plant Ecology 148:105–114.

Hough-Goldstein, J., E. Lake, R. Reardon, and Y. Wu. 2015. Biology and biological control of mile-a-minute weed. Technology Transfer Biological Control, USDA Forest Service FHTET-2008-10.

Malecki, R.A., B. Blossey, S.D. Hight, D. Schroeder, L.T. Kok, and J.R. Coulson. 1993. Biological control of purple loosestrife. BioScience 43:680–686.

McKinney, M.L., and J.L. Lockwood. 1999. Biotic homogenization: A few winners replacing many losers in the next mass extinction. Trends in Ecology & Evolution 14:450–453.

Monahan, W.B., and N.A. Fisichelli. 2014. Climate exposure of US national parks in a new era of change. PLOS One 9(7):e101302.

Naiman, R.J., H. Decamps, and M.E. McClain. 2005. Riparia: Ecology, Conservation, and Management of Streamside Communities. Elsevier, New York.

NatureServe. 2020. International ecological classification standard: International vegetation classification. NatureServe, Arlington, VA. <https://explorer.natureserve.org/>

Olden, J.D., and T.P. Rooney. 2006. On defining and quantifying biotic homogenization. Global Ecology and Biogeography 15:113–120.

Paradis, A., J. Elkinton, K. Hayhoe, and J. Buonaccorsi. 2007. Role of winter temperature and climate change on the survival and future range expansion of the hemlock woolly adelgid (*Adelges tsugae*) in eastern North America. Mitigation and Adaptation Strategies for Global Change 13:541–554.

Perles, S.J., G.S. Podniesinski, E. Eastman, L.A. Sneddon, and S.C. Gawler. 2007. Classification and mapping of vegetation and fire fuel models at Delaware Water Gap National Recreation Area: Volume 2 of 2 – Appendix G. Technical Report NPS/NER/NRTR—2007/076. National Park Service, Philadelphia, PA.

Perles, S.J., DR. Manning, K.K Callahan, and M.R. Marshall. 2018. Rare riparian prairie monitoring protocol for the Eastern Rivers and Mountains Network: Protocol narrative version 1.0. Natural Resource Report NPS/ERMN/NRR—2018/1733. National Park Service, Fort Collins, CO.

Planty-Tabacchi, A.M., E. Tabacchi, R.J. Naiman, C. Deferrari, and H. Decamps. 1996. Invasibility of species rich communities in riparian zones. Conservation Biology 10:598–607.

Podniesinski, G.S., M. Furedi, B.A. Eichelberger, and S.J. Perles. 2010. Conceptual models and recommendations for monitoring riparian plant communities within riverine parks of the Eastern Rivers and Mountains Network. Natural Resource Report NPS/NER/NRR—2010/023. National Park Service, Philadelphia, PA.

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>

Rhoads, A.F., T.A. Block, and A. Aniśko. 2000. The Plants of Pennsylvania: An Illustrated Manual. University of Pennsylvania Press, Philadelphia, PA.

Rustad, L., J. Campbell, J.S. Dukes, T. Huntington, K. Fallon Lambert, J. Mohan, and N. Rodenhouse. 2012. Changing climate, changing forests: The impacts of climate change on forests of the northeastern United States and eastern Canada. General Technical Report NRS-99. USDA Forest Service, Northern Research Station, Newtown Square, PA.

Shank, L.K., and J. Shreiner. 1999. Globally threatened calcareous riverside seep and calcareous riverside outcrop communities along the New Jersey shoreline of the Delaware River: Summary of rare plant census, community sampling, and recommended monitoring protocol. Department of Environmental Protection, Division of Parks and Forestry, Office of Natural Lands Management, Trenton, NJ.

Sneddon, L.A. 2010. Global conservation status ranks of state-rare vegetation associations in the Eastern Rivers and Mountains Network. Technical Report NPS/NER/ERMN/NRTR—2010/151. National Park Service, Philadelphia, PA.

Waggy, M.A. 2010. *Phalaris arundinacea*. In: Fire Effects Information System. USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Accessed 4 January 2022 from <https://www.fs.fed.us /database/feis/plants/graminoid/phaaru/all.html>.

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, and J. Willis. 2014. Our changing climate. *In* J.M. Melillo, T.C. Richmond, and G.W. Yohe, eds., Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, Washington, DC.

Wilson, L.M., M. Schwarzlaender, B. Blossey, and C.B. Randall. 2004. Biology and biological control of purple loosestrife. USDA Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV.