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Natural Resource Stewardship and Science

Identify and Suppress Invasive Exotic Plants in Priority Hemlock Ecosystems

Delaware Water Gap National Recreation Area

Natural Resource Report NPS/DEWA/NRR—2023/2505





ON THIS PAGE
Yellow birch trees (*Betula alleghaniensis*) colonizing a downed hemlock stand in Childs Park at Delaware Water Gap National Recreation Area.
Photo by NPS

ON THE COVER
Invasive tree-of-heaven (*Ailanthus altissima*) invading a downed stand of Eastern hemlock.
Photo by NPS

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April 2023

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Hilaire, L., W. Strubert, J. Schuon, and K. Deutsch. 2023. Identify and suppress invasive exotic plants in priority hemlock ecosystems: Delaware Water Gap National Recreation Area. Natural Resource Report NPS/DEWA/NRR—2023/2505. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2297282

NPS 620/188091, April 2023

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Abstract

Eastern hemlock (*Tsuga canadensis*) is a keystone species having many factors currently contributing to a steep decline in numbers across most of its native range; these include the hemlock wooly adelgid (HWA) (*Adelges tsugae),* elongate hemlock scale (EHS) (*Fiorinia externa*), deer browsing, climate change, and the spread of invasive plants. Because of their ecological and cultural importance, efforts are being made to promote the continued health of these stands. In recent years however, strong storms have damaged and uprooted weakened trees in some areas, opening locations conducive to invasive species encroachment. The goals of this project are to identify, prioritize, and treat invasive plants in stands of eastern hemlock in the Pennsylvania portion of Delaware Water Gap National Recreation Area (DEWA). Site prioritization was based on an importance rating scale from "Invasive Species/Habitat Management Prescription Workbook (ISMPT) (Gover 2016)." Eleven (11) hemlock sites were investigated totaling 424.46 acres. Of these 11 areas, invasive plant species were identified and treated within the riparian areas of six. Treated areas included Adams Creek, Childs Park, Dingmans Creek, Hackers Trail, Raymondskill Creek, Toms Creek in 2021. In 2022, an additional 98.83 acres were treated. Ground cover of invasive species within these downed hemlock areas comprised a percent average of 23% in 2021 before treatment, and 4% in 2022 before retreatment. Treatment resulted in a marked decline of invasive species prevalence which allows for the potential of natural regeneration of native flora.

Acknowledgments

Funding provided by the National Park Service 2021–22 Regional Block Grant

Thanks to Stephanie Perles and Jonathan Malzone for their constructive reviews.

Acronyms Used

DEWA: Delaware Water Gap National Recreation Area

ELS: Elongate hemlock scale

GIS: Geographic Information Systems

GPS: Global positioning system

HMZ: Habitat management zone

HWA: Hemlock woolly adelgid

PEMA: Pennsylvania Aerial Imagery Program

Introduction

The goals for this report are to document control and treatment of invasive exotic plants in critical hemlock areas of the park. Project goals include limiting the spread of invasive species in hemlock areas, creating detailed GIS mapping of zones to be treated, then subsequently treating and collecting treatment data. This was accomplished by completing preliminary mapping of treefall locations through satellite imagery, and then ground truthing these locations and others noted while searching. Afterward, based on a priority list, selected areas were revisited, where invasive plants were treated by cutting and applying appropriate herbicide(s).

Delaware Water Gap National Recreation Area (DEWA) encompasses over 70,000 acres that border 40 miles of the Delaware River at the northeastern boundary of Pennsylvania and the northwestern boundary of New Jersey. Multiple studies of eastern hemlock have been completed over the past three decades in DEWA, forming a large repository of data. In the northeastern United States, hemlocks perform important ecological functions, and the importance of their decline cannot be overstated. Many studies focused on the loss of certain important trees due to pests, resulting in increased disturbance in the areas affected (Stone et al 1996). Hemlocks are known for providing acidic leaf litter, cooler temperatures and heavy shade, which are quite unique and make the eastern hemlock a species upon which multiple plant and animal species depend. DEWA is well known for having high quality streams, and some of the organisms inhabiting in these streams are dependent on the conditions provided by hemlocks. For example, native brook trout (*Salvelinus fontinalis*) require cooler stream temperatures than nonnative brown trout (*Salmo trutta*) (Snyder et al. 2015). Stream temperature and habitat changes have already been documented in DEWA (Ross et al. 2003) because of hemlock decline.

Site prioritization was based on an importance rating scale from "Invasive Species/Habitat Management Prescription Workbook (ISMPT) (Gover 2016)." Eleven (11) hemlock sites were investigated totaling 424.46 acres. Of these 11 areas (Figure 1), invasive plant species were identified and treated within the riparian areas of six. Large scale outbreaks of invasive flora and fauna can dramatically alter an ecosystem, both by eliminating native species and replacing them. The eastern hemlock has seen widespread mortality across its range due to a combination of factors, most notably the spread of hemlock woolly adelgid (HWA). Other contributors to the decline of the hemlock include warmer winters associated with climate change, deer herbivory and the invasion of exotic plants. The spread of invasive plant species such as multiflora rose (*Rosa multiflora*), Japanese barberry (*Berberis thunbergii*), oriental bittersweet (*Celastrus orbiculatus*), Tree-of-heaven (*Ailanthus altissima*) and other species damage the environment that the hemlocks maintain. They compete with the hemlocks themselves, thereby hastening their decline. Although the conditions that persist in hemlock stands often ward off invasive plant species, when hemlocks die due to HWA or elongated hemlock scale (EHS), or are uprooted due to severe windstorms, a treefall sunlight gap is opened which is ripe for the establishment of invasive species. If invasive species can get established, they can further damage the surrounding area, leading to even more invasive species colonization, and subsequently creating a self-perpetuating cycle.

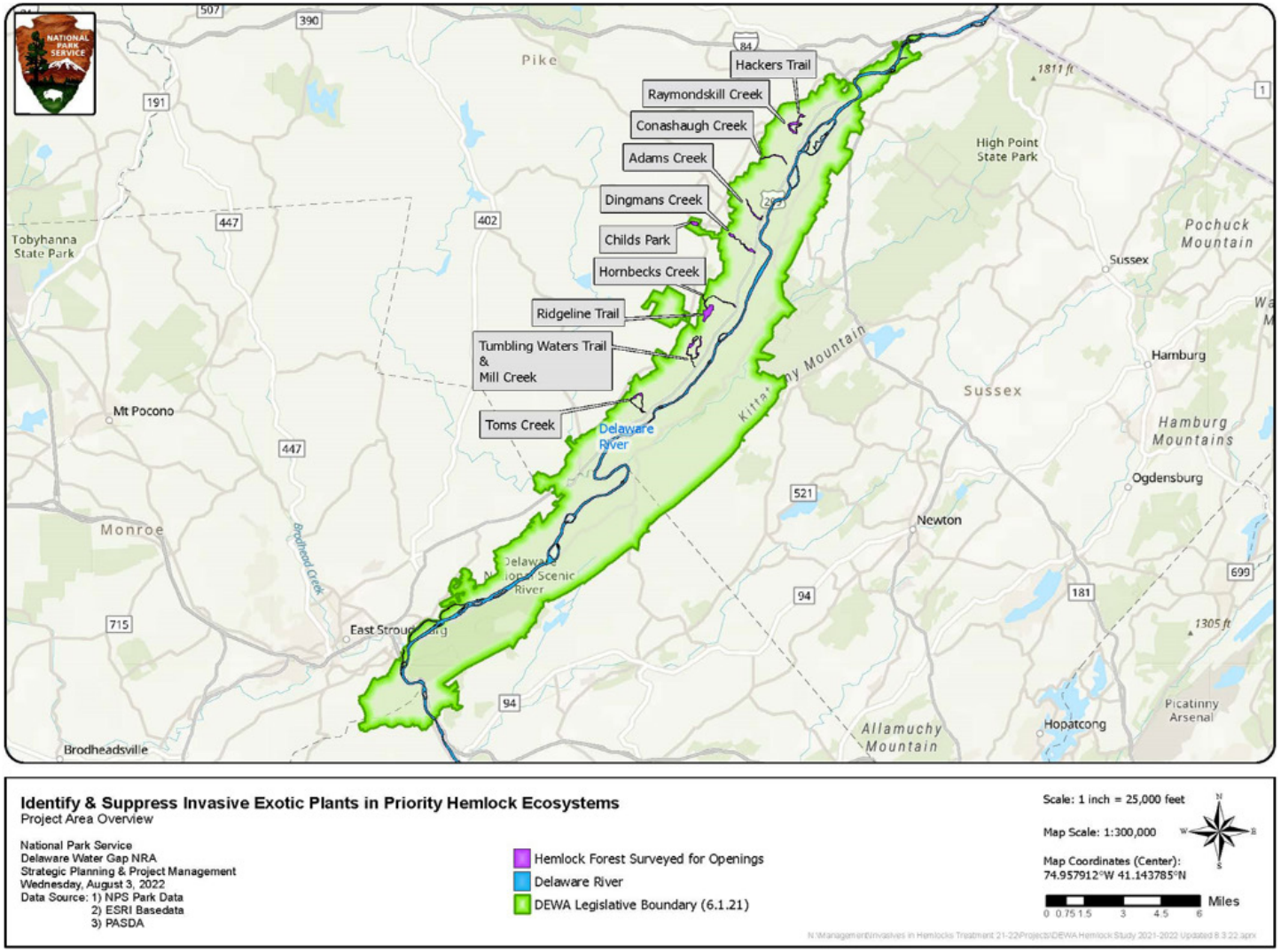


Figure 1. Surveyed hemlock stands for invasive plants. Location map of surveyed hemlock areas on the Pennsylvania side of the Delaware Water Gap National Recreation Area (DEWA).

The National Park Service has invested in projects over the last twenty years in cooperation with the USDA Forest Service to manage core areas of selected hemlock stands. Projects included chemical and biological controls of HWA, EHS and invasive plants, most recently in 2007 (Estruth et al. 2013). Park staff continue to treat areas as time and funding are available, and biocontrols for HWA have been released in the park which are at least partially successful. Two hemlock areas have been fenced to reduce deer browse as they have a high priority for long-term hemlock regeneration. Continued upkeep of hemlock stands is important to counteract future increases in stressors.

Some hemlock dominated sites that were treated in 2007 (i.e., Adams, Conashaugh, Dingmans, Hornbecks, Raymondskill, and Tom's creeks) suffered many broken and uprooted trees in a severe 2018 winter storm event. These sites were already weakened by HWA and EHS infestations. Due to this storm event, these hemlock ravines have exposed soils and open canopy providing ideal conditions for exotic invasive species to colonize these highly sensitive areas. While natural regeneration is occurring with young hemlock, other native trees like white pine and mixed hardwoods are also establishing themselves. This natural process helps to reduce competition from invasive plants. Furthermore, these hemlock forests contain several state-listed species of concern that can quickly be outcompeted by non-native plants. Without intervention, invasive woody species will limit the growth of native tree species which are critical to provide stabilization of the steep riparian environments, cover and food for wildlife, a healthy ecosystem, and ultimately resiliency to floods and adaptability to climate change.

Methods

Eastern hemlock habitat and growth patterns were studied to determine optimal/potential vegetative community locations that included riparian areas and low-lying ravines. A GIS database was created to help manage the project data. Next, high quality aerial imagery from the 2018 Pennsylvania Aerial Imagery Program (PEMA) was gathered to be used as a base layer in the GIS to identify potential sites. Additionally, park-collected data from previous damage assessments showing treefall gaps were added to the database. These formed the foundation of the base map.

We used the data from the GIS base map to find places we wanted to investigate, and eleven were chosen. Six of these eleven areas were used to verify aerial mapping for openings in the preliminary search. Following, all eleven sites were visited and evaluated for vegetative information, especially for the dominance of invasive cover. Further information was gathered if the area was selected for treatment.

We visited each area and logged the best locations with a GPS. Sites were targeted based on hemlock-dominant canopy cover (>40% hemlock), accessibility, >30% canopy cover overall, presence of invasive plants, and the presence of trail corridors in riparian zones. The outer area boundary was mapped as a polygon, excluding out-of-reach areas which were simply mapped with the GIS. Out-of-reach areas were not treated however, and subsequently were not included in the final mapping. Additional sites were evaluated by finding the approximate center point in open hemlock stands with 40% canopy cover and recording a GPS point(s). Once the point was established, a modified version of the U.S. Army Corps of Engineers (2012*) plot and sample sizes delineating determinations for hydrophytic vegetation communities* was established around this point, i.e., a 15 x 15-foot quadrat, in a nested plot design using the shrub strata.

As most openings were smaller pieces of a larger opening, each small opening received a point and was compiled to determine an average for the entirety of the larger opening. Each hemlock area assessed was labeled as a habitat management zone (HMZ). Thus, the numbers of quadrats varied per habitat management zone because they were based on the number of smaller, connected openings (Appendix A). Data collected included hemlock canopy dominance, canopy opening percentage, plant species found within the quadrat, and the percent cover of each invasive species. With stem species like multiflora rose, we utilized the total stem area perimeter for the cover measurement. Normally no species would be counted if under 5% dominance; this was done for all plant species within the quadrat.

Using the established quadrats within each HMZ, the percent cover of each invasive plant species was determined by an observational estimate. Subsequently, the added percentages of invasive plant cover were summed to obtain the total estimated coverage of invasive plants within each quadrat. Then, total invasive plant cover was averaged across quadrats for each HMZ (See Treatments and Results sections, below).

After site assessments were completed, the data collected were consolidated and entered into the Invasive Species Management Planning Tool (ISMPT) provided by Penn State researchers (Gover 2016, Perles 2021) to help prioritize HMZs for invasive species control efforts. Using the outputs as a baseline, treatments were planned, prioritized and approved to control the invasive plants recorded (Table 1, 2).

Table 1. Prioritization matrix for invasive species management in hemlock ravines in the Delaware Water Gap National Recreation Area, showing prioritization scores for each invasive plant species in each habitat management zone. RC stands for riparian corridor habitat type. Stewardship Index and Outreach Index values range from 0 to 2 and indicate the zone's ecological and cultural values, respectively, with higher numbers indicating higher value. Within the matrix, higher numbers denote higher priority for treatment, such that 8–9 are highest priority (shaded in red), 6–7 are moderate priority (7 shaded in gold; 6 shaded in yellow), and 5–0 are lower priority (no shading). Source: Gover 2016, Perles 2021.

HMZ Name	Adams Creek	Dingmans Falls	Toms Creek	Conashaugh	Raymondskill	Hackers	Hornbecks	Mill Creek	Ridgeline Trail	Childs Park	Tumbling Waters Trail
Habitat Type	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC	RC
Stewardship Index	2	2	2	1	2	1	2	1	1	1	1
Outreach Index	1	2	2	1	2	1	1	2	2	2	2
Japanese Stiltgrass	7	0	0	3	7	5	0	7	6	6	6
Dames Rocket	6	6	0	3	0	0	0	0	0	0	0
Garlic Mustard	0	6	0	3	0	0	0	0	0	0	0
Japanese Knotweed	0	7	0	3	0	0	0	0	0	0	0
Mugwort	7	7	0	3	7	0	0	0	0	0	0
Autumn Olive	0	0	0	4	8	0	0	0	0	0	0
Japanese Barberry	8	8	9	4	8	6	7	0	7	0	0
Multiflora Rose	8	8	0	4	8	0	7	0	7	0	0

Table 1 (continued). Prioritization matrix for invasive species management in hemlock ravines in the Delaware Water Gap National Recreation Area, showing prioritization scores for each invasive plant species in each habitat management zone. RC stands for riparian corridor habitat type. Stewardship Index and Outreach Index values range from 0 to 2 and indicate the zone's ecological and cultural values, respectively, with higher numbers indicating higher value. Within the matrix, higher numbers denote higher priority for treatment, such that 8–9 are highest priority (shaded in red), 6–7 are moderate priority (7 shaded in gold; 6 shaded in yellow), and 5–0 are lower priority (no shading). Source: Gover 2016, Perles 2021.

HMZ Name	Adams Creek	Dingmans Falls	Toms Creek	Conashaugh	Raymondskill	Hackers	Hornbecks	Mill Creek	Ridgeline Trail	Childs Park	Tumbling Waters Trail
Shrub Honeysuckle	0	0	0	4	8	0	0	0	0	0	0
Wineberry	0	8	0	4	0	0	0	0	0	7	0
Tree-of-Heaven	0	0	0	4	7	0	0	7	0	0	7
Chinese Wisteria	0	7	0	4	7	0	0	0	0	0	0
Oriental Bittersweet	0	7	0	4	7	5	6	0	6	6	0

Table 2. Summary of Hemlock Areas Evaluated for Invasive Plant Control.

Surveyed Area	Acres Surveyed	Previous Hemlock Treatment	Included in Treatment *
Adams Creek	28.12	Yes	Yes
Childs Park	24.53	Yes	Yes
Conashaugh Creek	31.16	No	No
Dingmans Creek	44.07	Yes	Yes
Hackers Trail	49.36	No	Yes
Hornbecks Creek	22.43	Yes	No
Mill Creek	2.76	No	No
Raymondskill Creek	22.82	Yes	Yes
Ridgeline Trail	96.54	No	No
Toms Creek	38.61	Yes	Yes
Tumbling Waters Trail	64.06	Yes	No

* Reason for treatment selection is based on the rating scale from the "Invasive Species/Habitat Management Prescription Workbook" in addition to hemlock dominance greater than 40% canopy cover, abundance of sunspots with greater than 30% canopy openings, previous hemlock treatment, hemlock health, percent invasive cover, and effort to fully clear invasives.

Treatments

Invasive plant control was achieved by two methods, cut stump treatment and mechanically, depending on the species. In year one of this project, invasive exotic plants/shrubs (e.g., oriental bittersweet, Japanese barberry, multiflora rose, wineberry (*Rubus phoenicolasius*), Japanese knotweed (*Reynoutria japonica*), Chinese wisteria (*Wisteria sinensis*), tree of heaven, shrub honeysuckle, etc.) were hand clipped between two and six inches from the ground with a pair of handheld snippers and then the stumps were promptly treated with a 25%–30% solution of Rodeo herbicide (EPA registration number: 62719-324, Figure 2). Invasive annual grasses like Japanese stiltgrass (*Microstegium vimineum*) were timely mowed with a weed whacker just before they were able to seed (Figure 3).



Figure 2. Cut stump treatment of Japanese barberry (*Berberis thunbergii*) applied with hand-held sprayer**. NPS photo.**



Figure 3. Timely mechanical control of annual Japanese stiltgrass (*Microstegium vimineum)* just prior to seeding using weed whacker. NPS photo.

Additional invasive plants including garlic mustard (*Alliaria petiolata*) and mugwort (*Artemisia vulgaris*) were often present on the perimeters of hemlock areas and were not treated, as the first treatment season began after these plants had already seeded. Thus, treatment would not have been effective. At each treatment site, GPS data and herbicide totals were collected and later added to the geodatabase (Appendix A).

Table 3. Treatment acreage and amount of Rodeo (53.8% Glyphosate† N-(phosphonomethyl) glycine, isopropylamine salt active ingredient) herbicide used for cut stump treatment in downed hemlock areas.

Location	Area in Acres	Amount of Rodeo Used (Liters)
Adams	20.35	1.00
Childs Park	6.23	1.00
Dingmans	18.48	1.00
Hackers	19.44	0.50
Raymondskill	12.74	2.50
Toms Creek	21.59	1.00
Totals	**121.26**	**7.00**

Results and Discussion

In the second year of treatments, the previously treated areas were resurveyed for invasive plants, and follow up treatments were completed. Compared to the initial pre-treatment survey assessments in year one, showing an average of 23% invasive plant cover; year two pre-treatment surveys revealed a much-reduced invasive plant coverage of 4% in the previously treated areas (Table 4). Treatments were determined to be effective based on these data.

Table 4. Summary of Change in Invasive Plant Cover in Treated Areas.

Treatment Area	Acres Treated	Average Invasive Cover Before Treatment *	Average Invasive Cover Second Year (Before Second Treatment) *	Percent Change in Invasive Cover
Adams Creek	20.35	21%	3%	−18%
Childs Park	6.23	26%	7%	−19%
Dingmans Creek	18.48	23%	4%	−19%
Hackers Trail	19.44	17%	1%	−16%
Raymondskill Creek	12.74	29%	3%	−26%
Toms Creek	21.59	22%	5%	−17%
Average *		**23%**	**4% approx.**	**−19%**

* Average invasive cover is calculated by adding the sum of sample locations' invasive cover values and dividing it by the total sample locations collected:

$$Average\ Invasive\ Cover = \frac{\sum Invasive\ Cover\ per\ Sampling\ Location}{Total\ Sampling\ Locations}$$

Overall, the hemlock areas in DEWA do not appear to be very healthy. There were many openings in hemlock stands, and many trees are in poor condition. The advance of HWA and EHS along with the further degradation caused by storm events have adversely affected hemlock stand viability. While this project does not represent a comprehensive forest health review, in general, affected hemlock stands show poor recovery. Even in areas noted as the healthiest areas in DEWA (Estruth et al. 2013), there were not many young hemlocks. Treefall gaps were often repopulated by earlier successional plants like birch spp. or maple. It appears that once the hemlocks lose a large swath of ground, they do not readily reclaim it. There are a few areas with highly degraded habitat, and one, Conashaugh, is degraded with heavy invasive plant infestation to the point that it was deemed beyond the scope of this project to try and rehabilitate it.

Two areas however appear to be doing relatively well—Adam's Creek and Childs Park. Childs Park seems to be the best candidate for further management projects. Although there are invasive plants bordering the hemlock areas (the bulk of our treatments), it was rare to find any in the openings that

had formed. With continued management, invasive plants can most likely be kept out of hemlock areas, especially with continued early detection and control.

This project focused on ecologically important declining hemlock stands/habitat and avenues by which invasive species become established. These areas were identified, quantified and successfully treated. Invasive species have been reduced in the remaining stands providing an avenue for hemlock regeneration.

Literature Cited

Estruth, A.K., R.A. Evans, J.J. Battles. 2013. Patterns and predictors of survival in *Tsuga canadensis* populations infested by the exotic pest *Adelges tsugae*: 20 years of monitoring. Forest Ecology and Management (305)195–203

Gover, A. 2016. Introduction to the Habitat and Invasive Species Management Planning Process. Pennsylvania State University Wildland Weed Management. (https://plantscience.psu.edu/research/projects/wildland-weed-management).

Perles. S. 2021. Triaging Invasive Plants: Strategic Planning Drives Success. Park Science: 35(1). https://www.nps.gov/articles/000/triaging-invasive-plants-strategic-planning-drives-success.htm

Ross, R. M., Bennett, R. M., Snyder, C. D., & Young, J. A. (n.d.). Influence of eastern hemlock (Tsuga canadensis L.) on fish community structure and function in headwater streams of the Delaware River basin. *Ecology of Freshwater Fish*, *2003*(12).

Snyder, C. D., Hitt, N. P., & Young, J. A. (2015). Accounting for groundwater in stream fish thermal habitat responses to climate change. *Ecological Applications*, *25*(7). https://doi.org/10.1002/eap.2015.25.issue-7

Stone, W. E., & Wolfe, M. L. 1996. Response of Understory Vegetation to Variable Tree Mortality following a Mountain Pine Beetle Epidemic in Lodgepole Pine Stands in Northern Utah. *Vegetatio*, *122*(January), 1–12.

U.S. Army Corps of Engineers. 2012. Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Eastern Mountains and Piedmont Region (Version 2.0). Wetlands Regulatory Assistance Program ERDC/EL TR-12-9(20–21).

Appendix A. Surveyed and Treated Areas.

The following maps (A1–A17) illustrate the sites that were surveyed and treated for invasive species in this project.

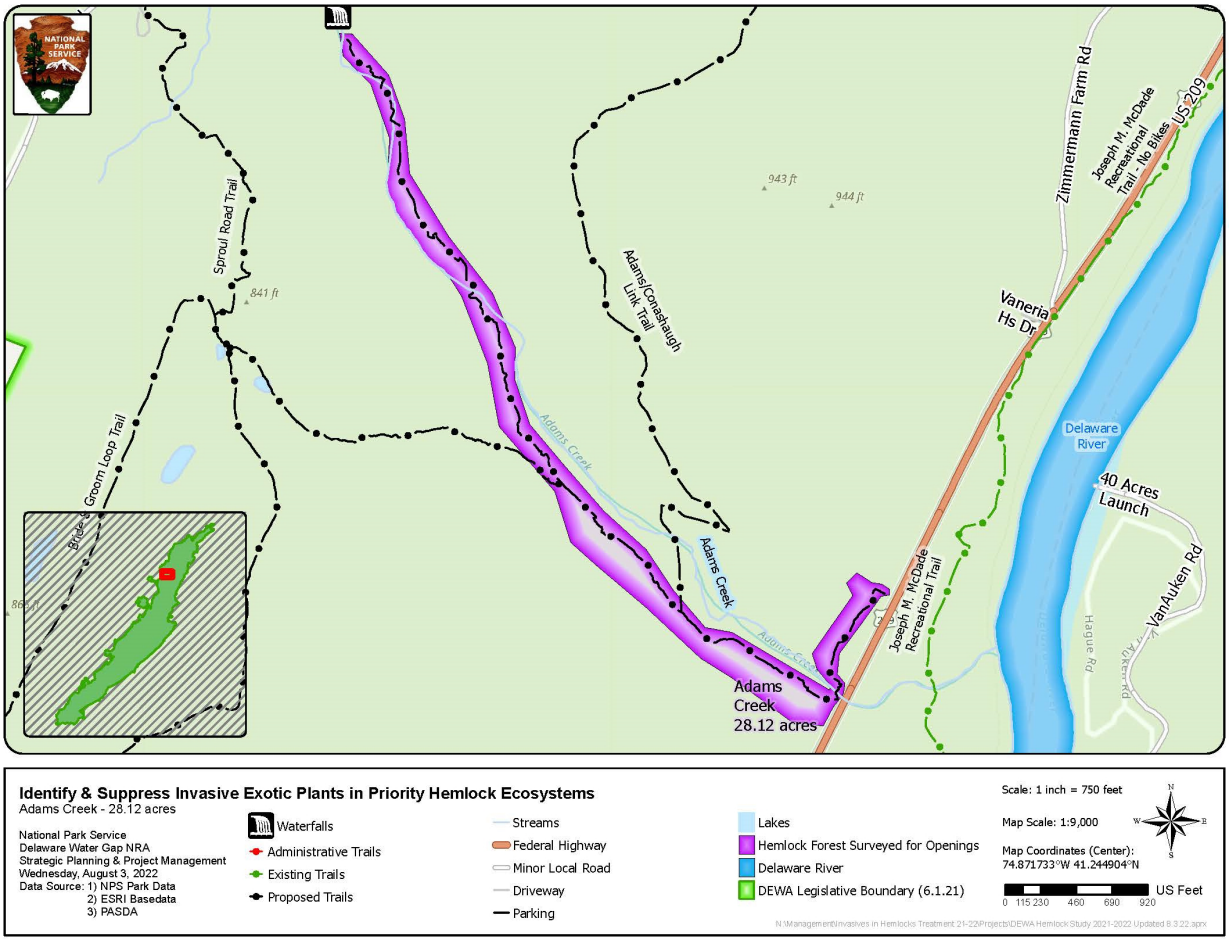


Figure A-1. Adams Creek survey area.

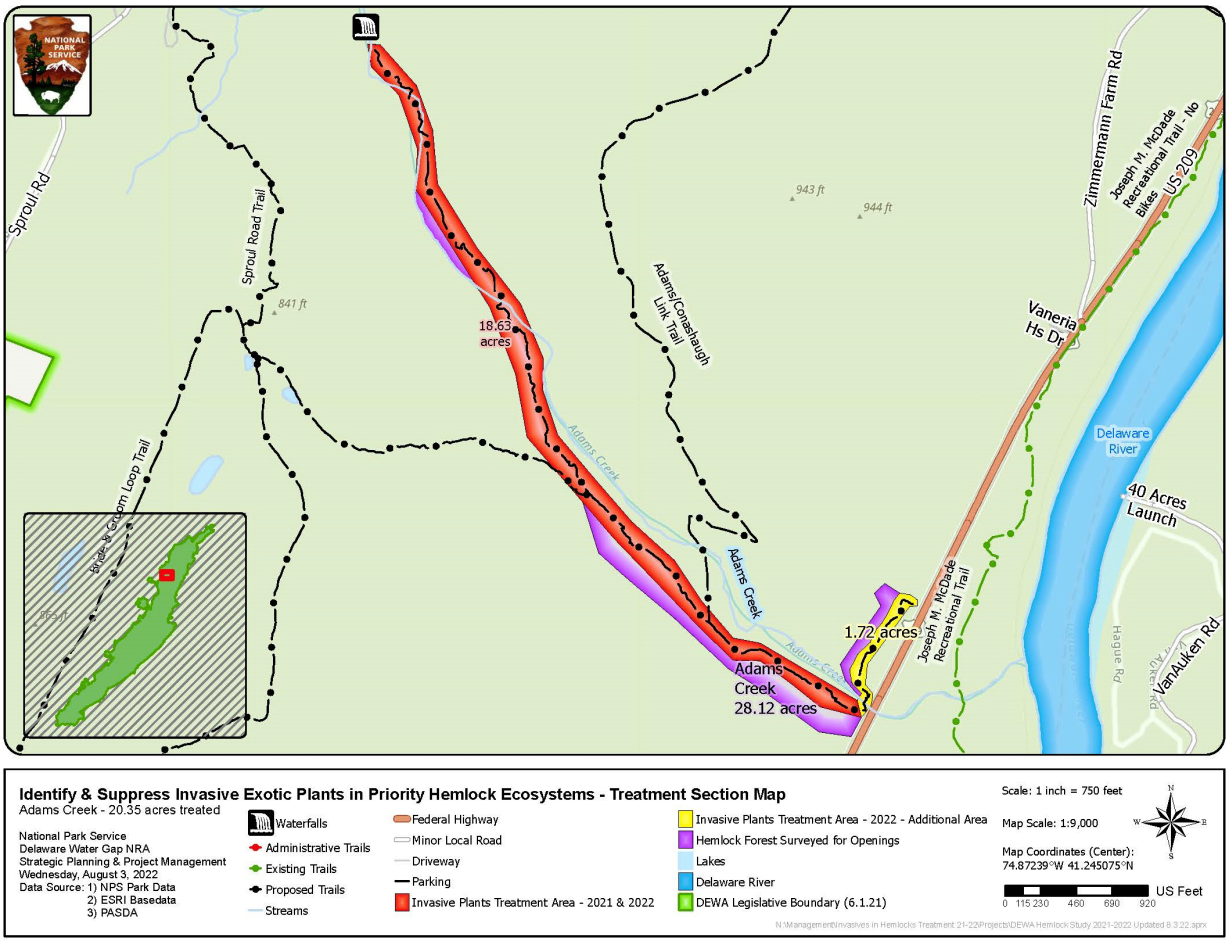


Figure A-2. Adams Creek treatment area.

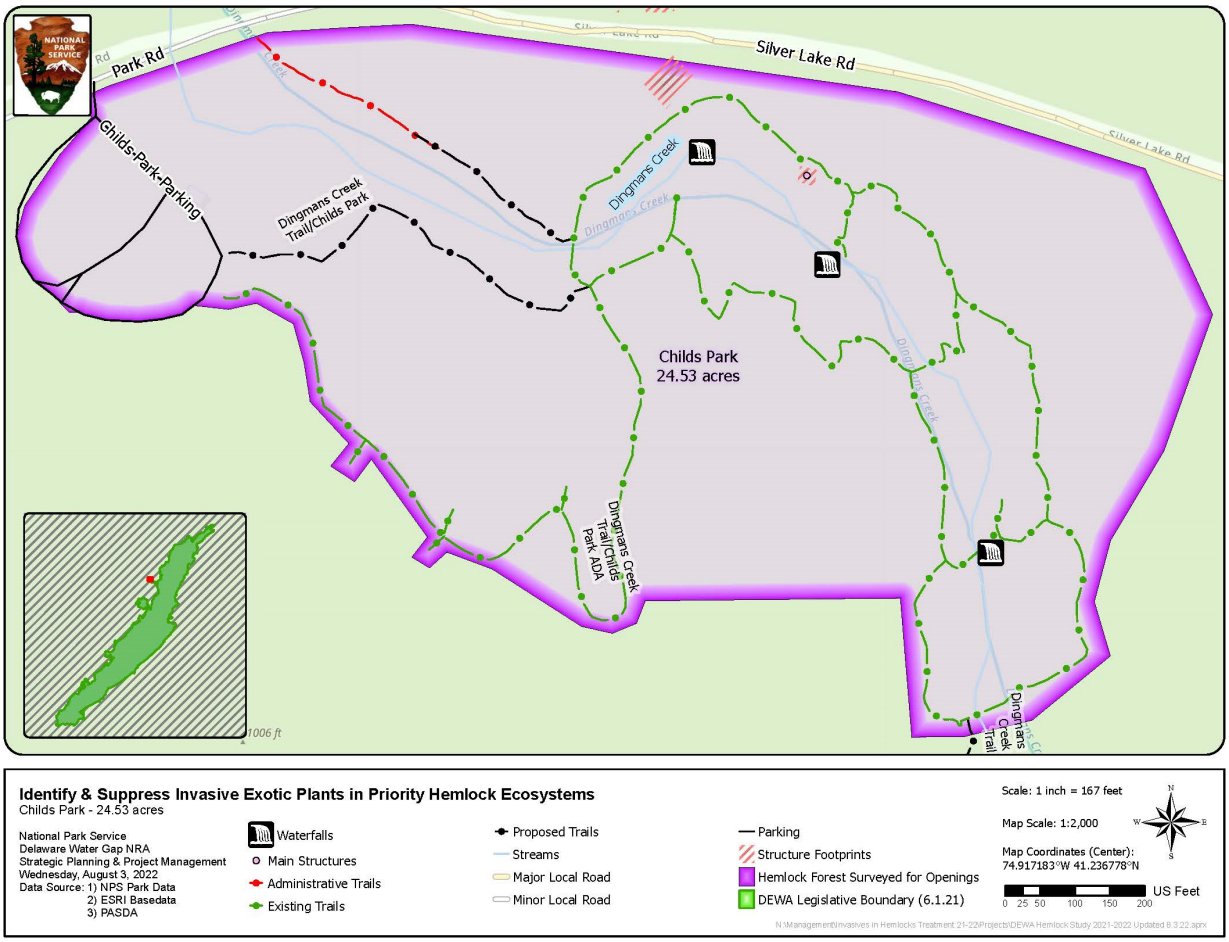


Figure A-3. Childs Park survey area.

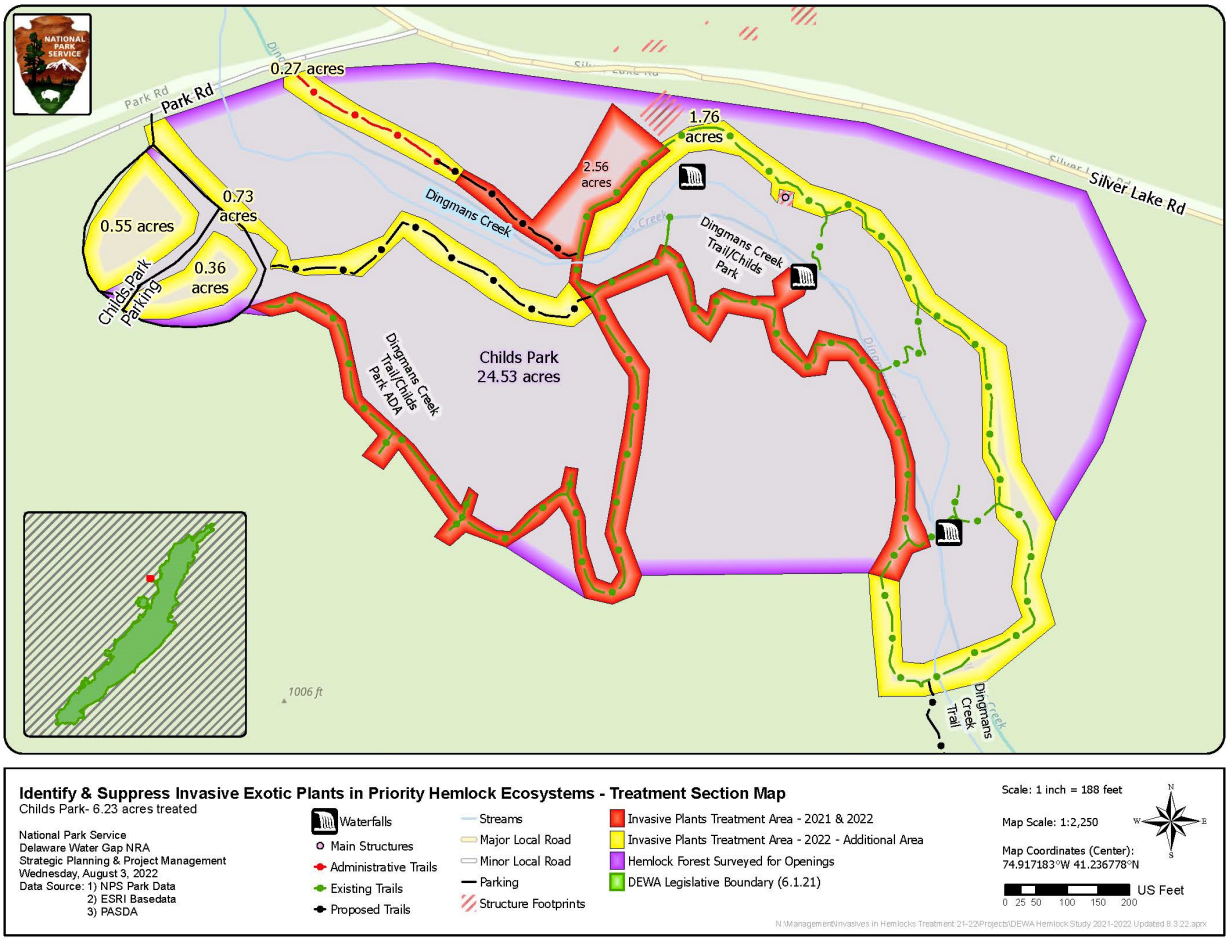


Figure A-4. Childs Park treatment area.

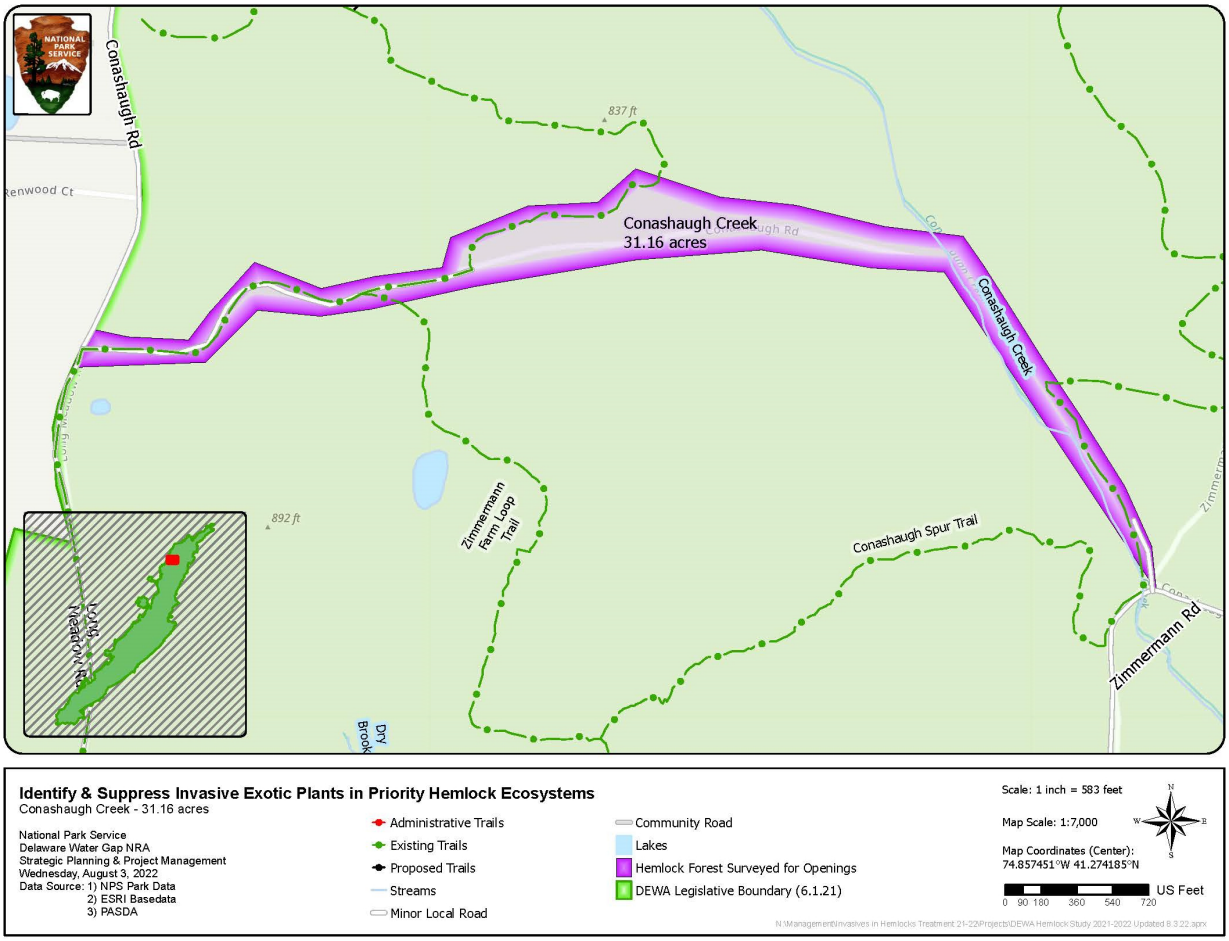


Figure A-5. Conashaugh Creek Survey area.

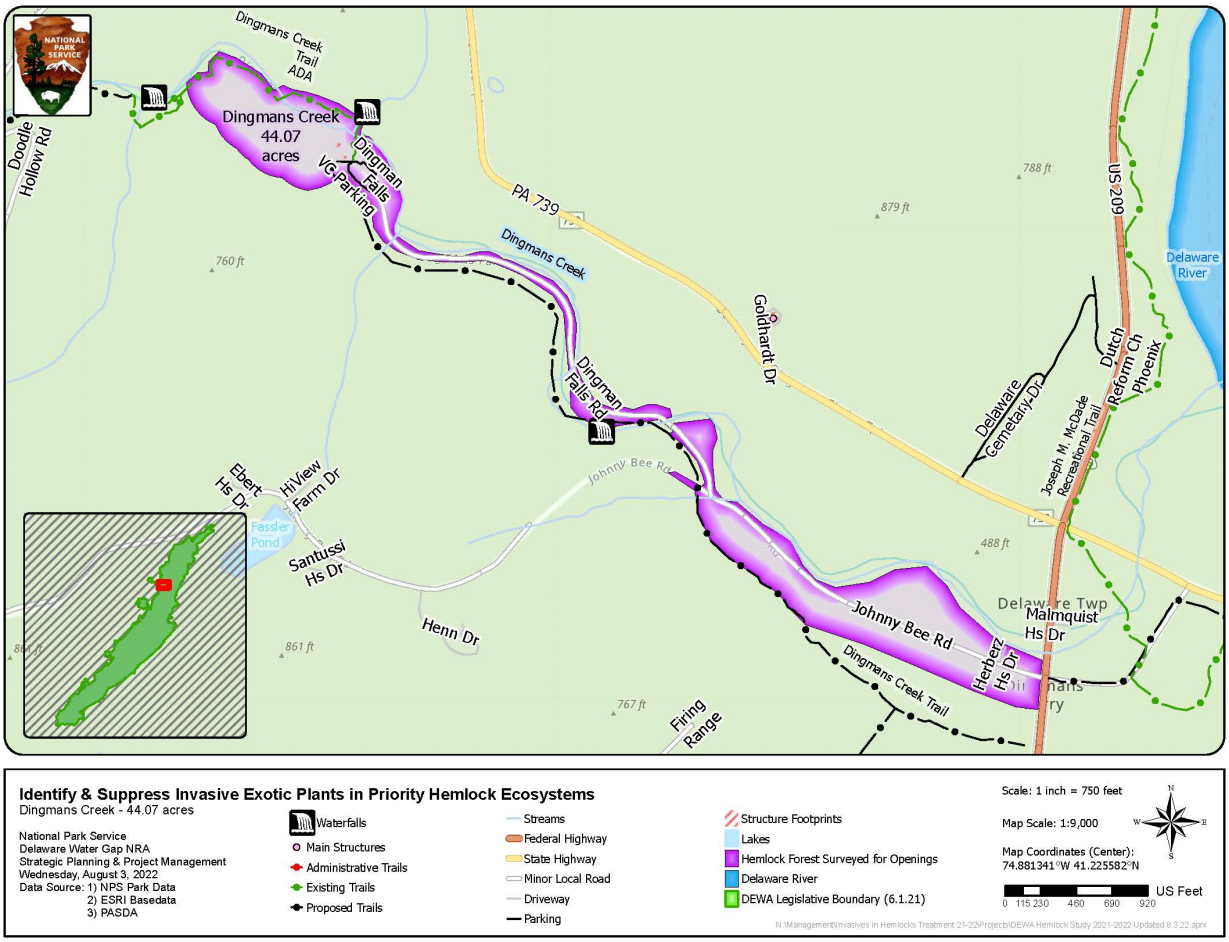


Figure A-6. Dingmans Creek survey area.

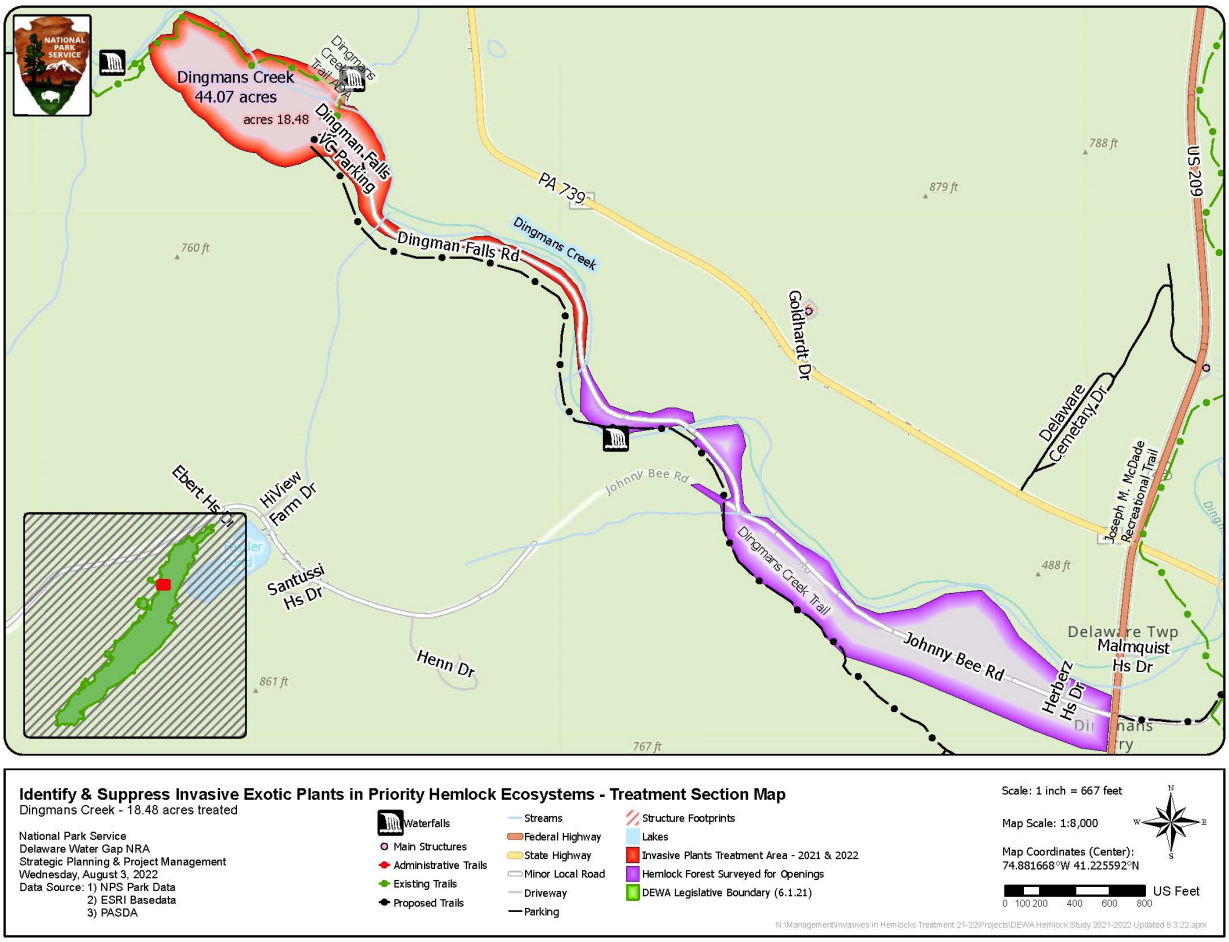


Figure A-7. Dingmans Creek treatment area.

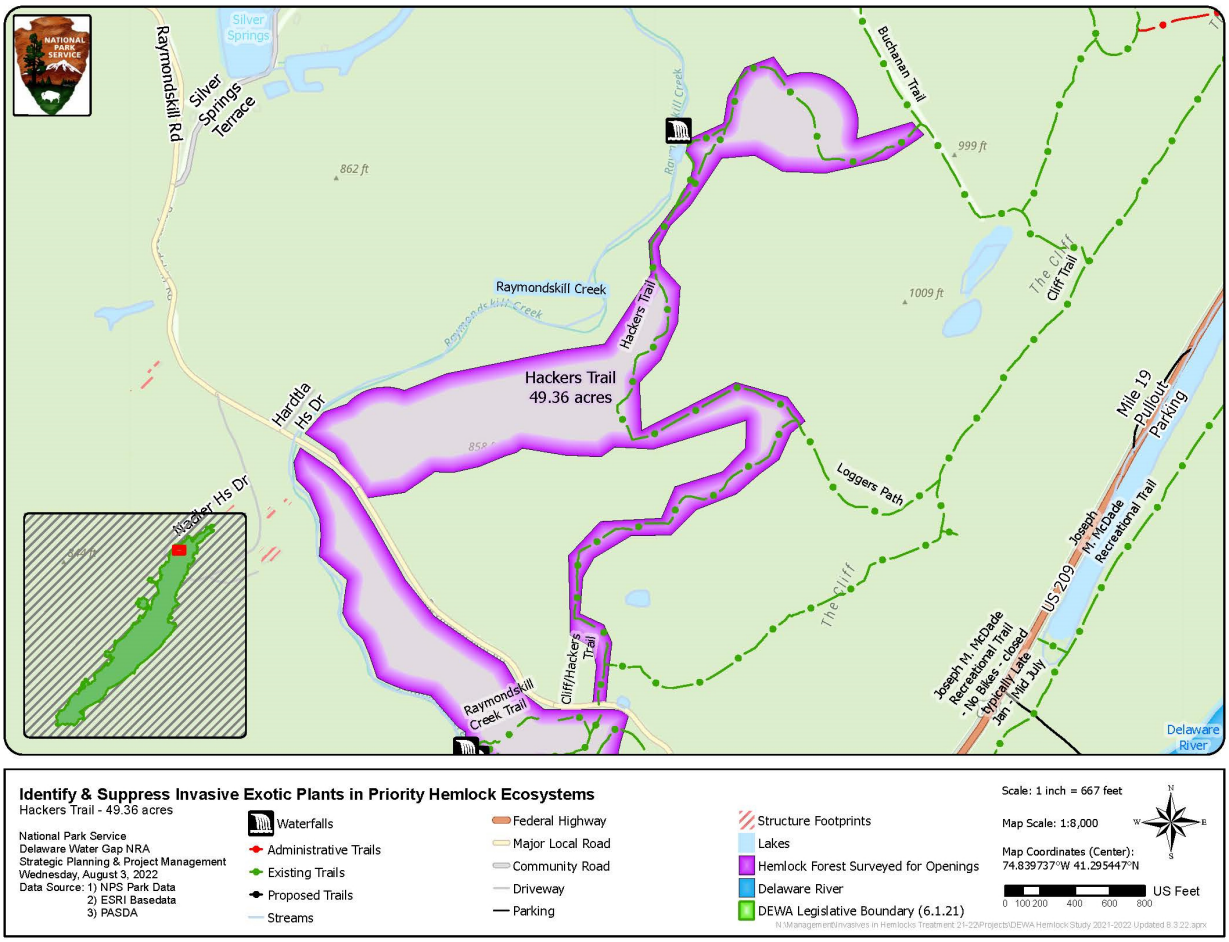


Figure A-8. Hackers Trail survey area part a.

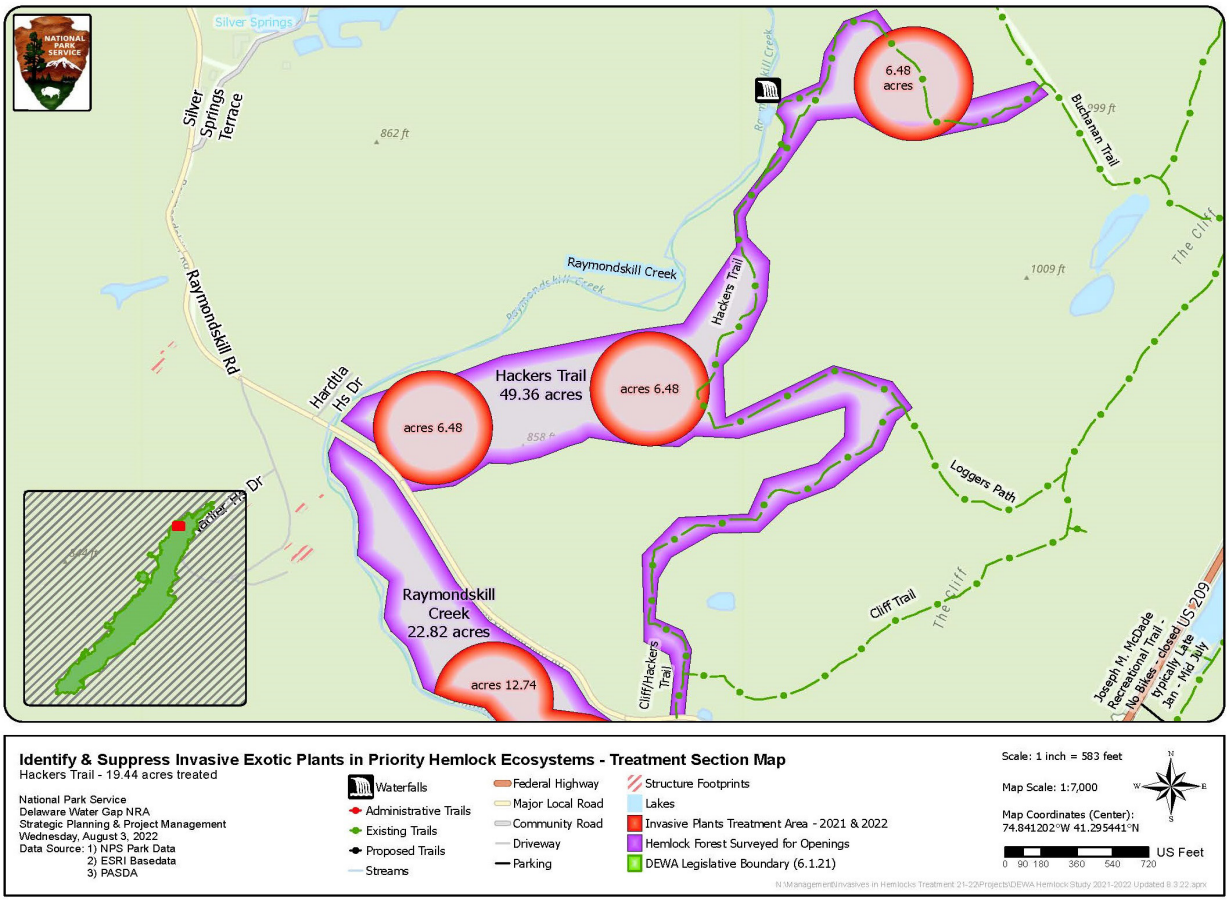


Figure A-9. Hackers Trail treatment area part b.

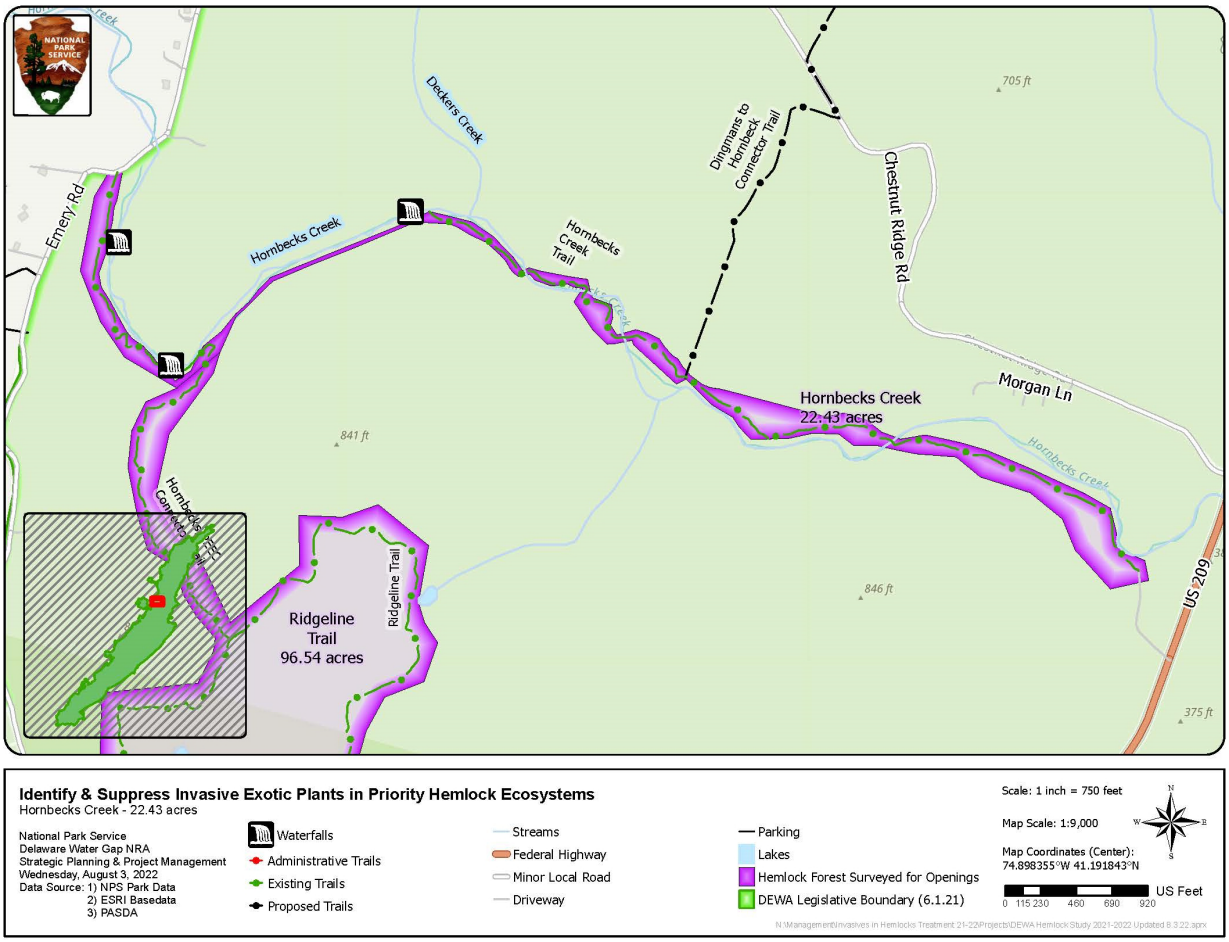


Figure A-10. Hornbecks Creek survey area.

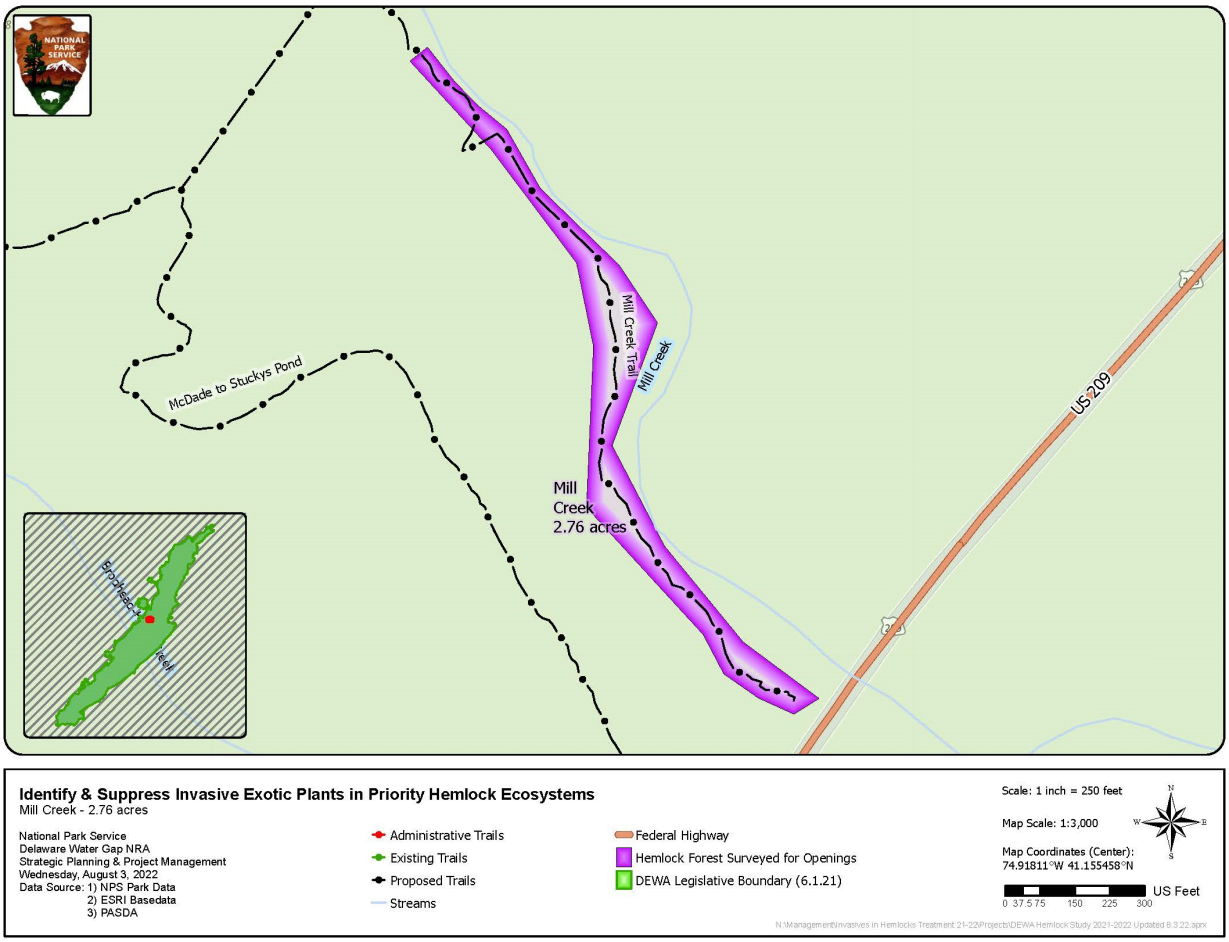


Figure A-11. Mill Creek survey area.

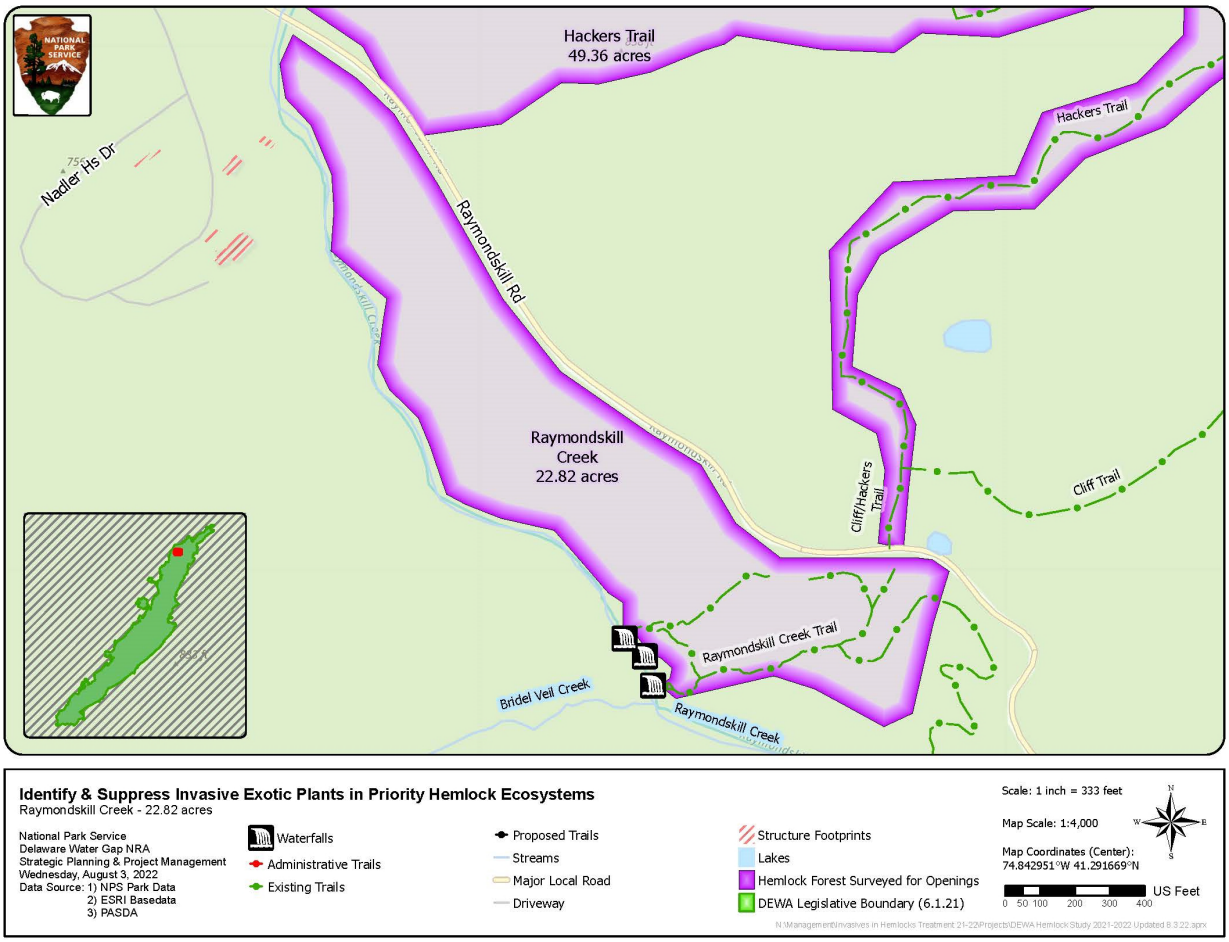


Figure A-12. Raymondskill Creek survey area.

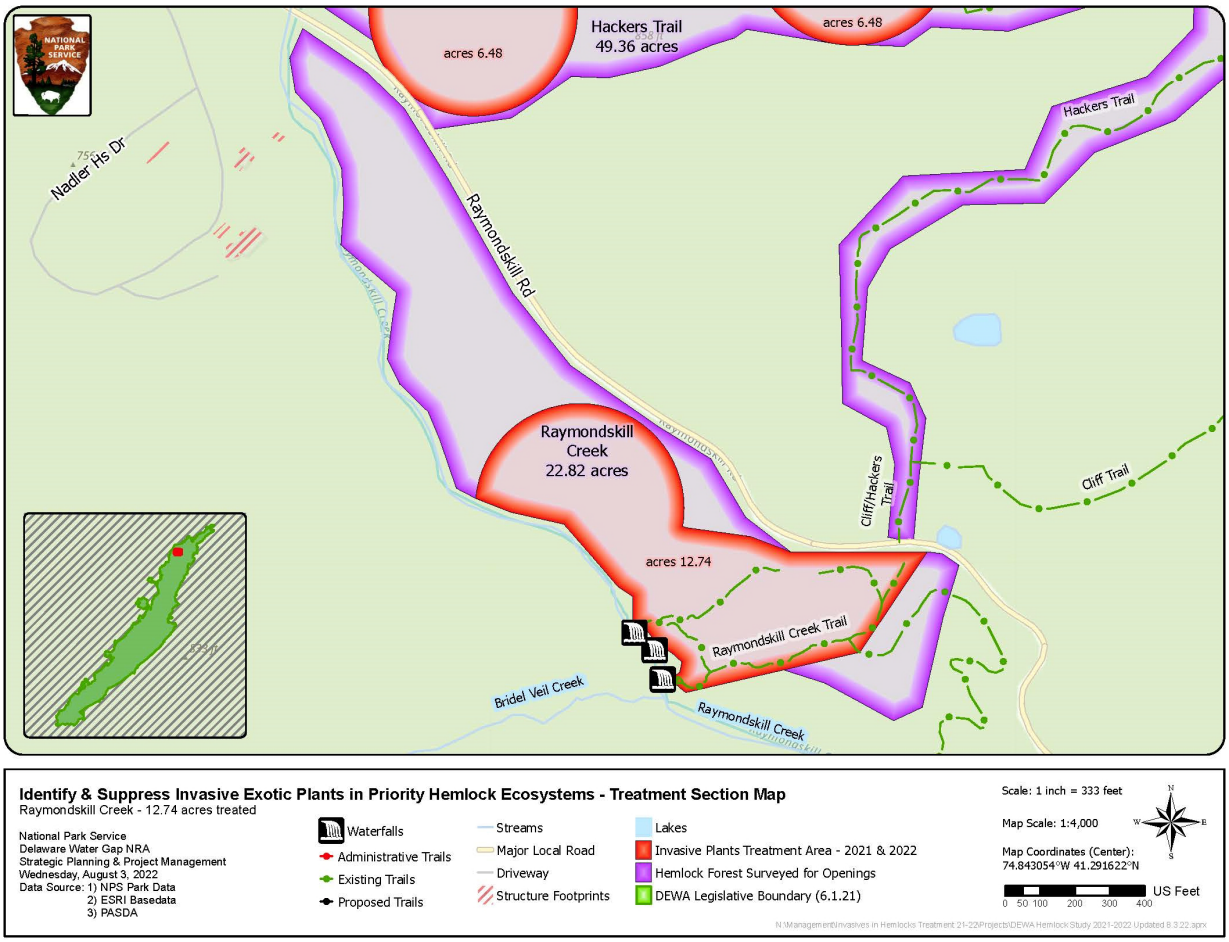


Figure A-13. Raymondskill Creek treatment area.

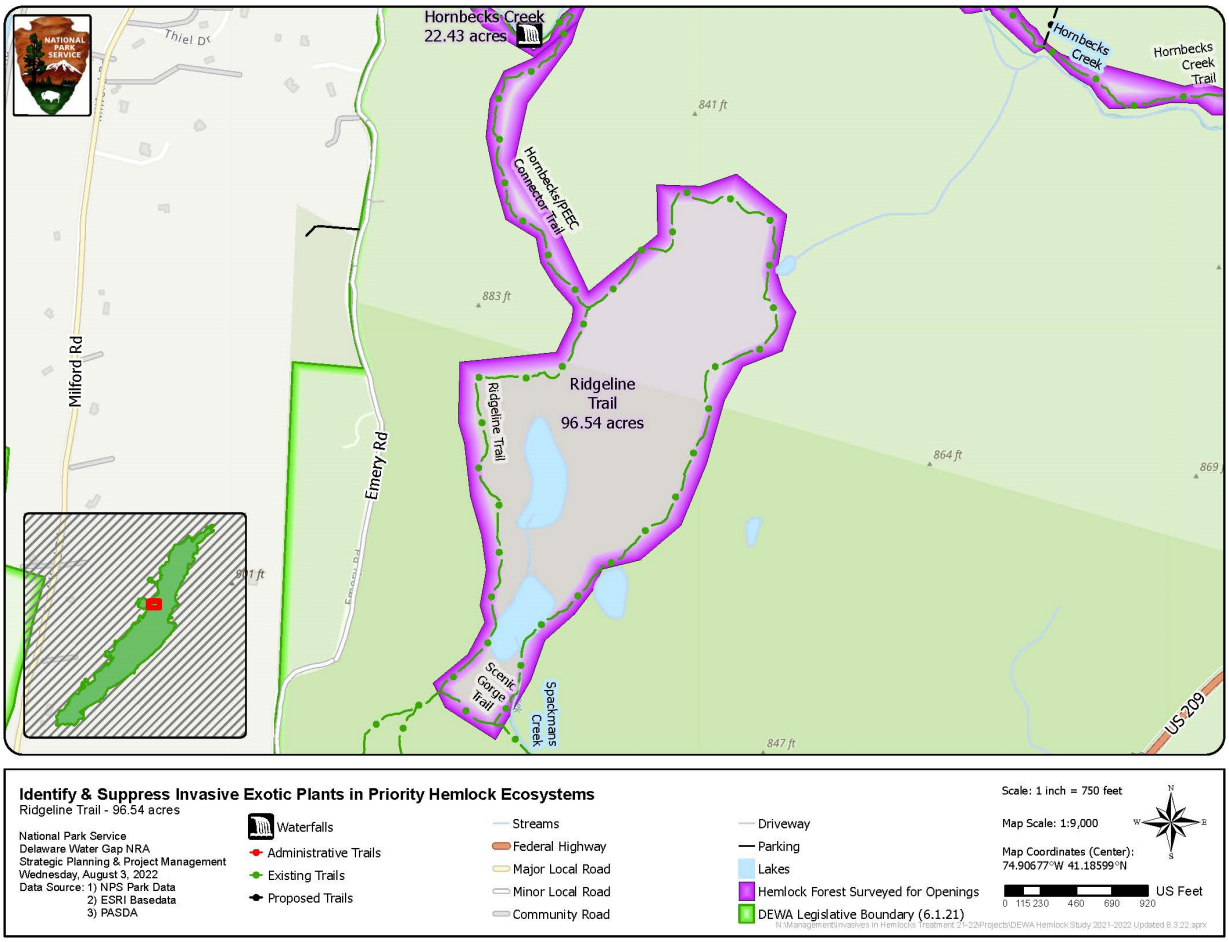


Figure A-14. Ridgeline Trail survey area.

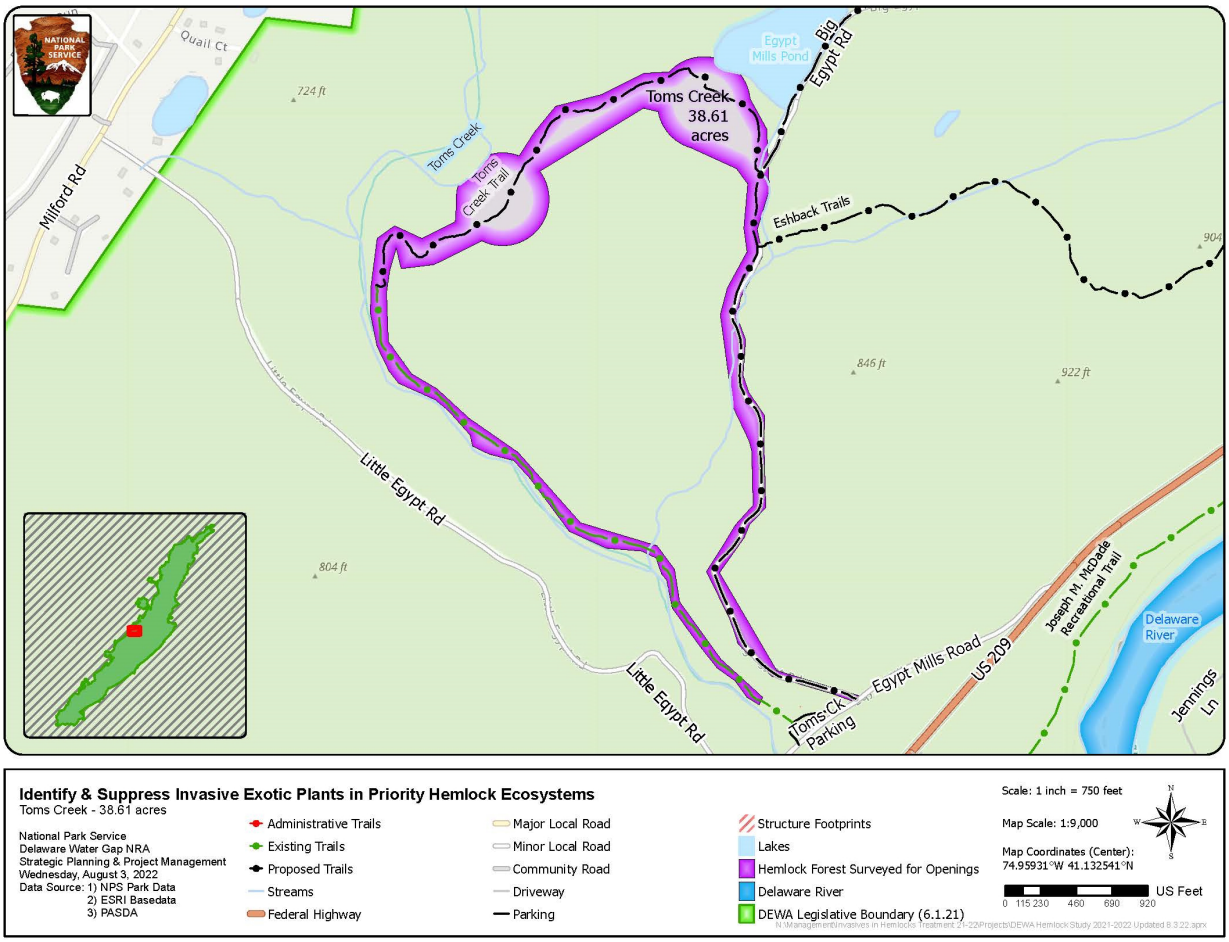


Figure A-15. Toms Creek Survey area.

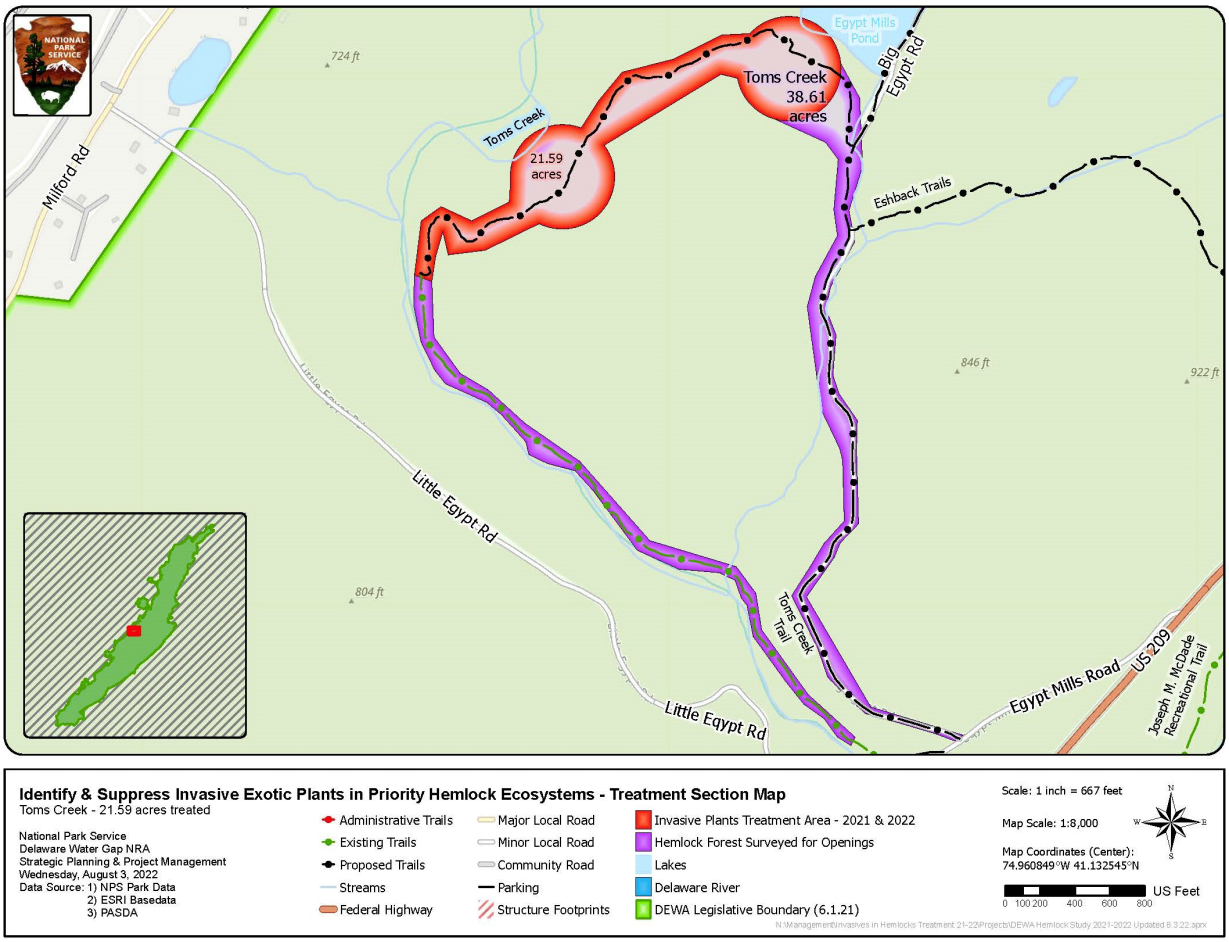


Figure A-16. Toms Creek Treatment area.

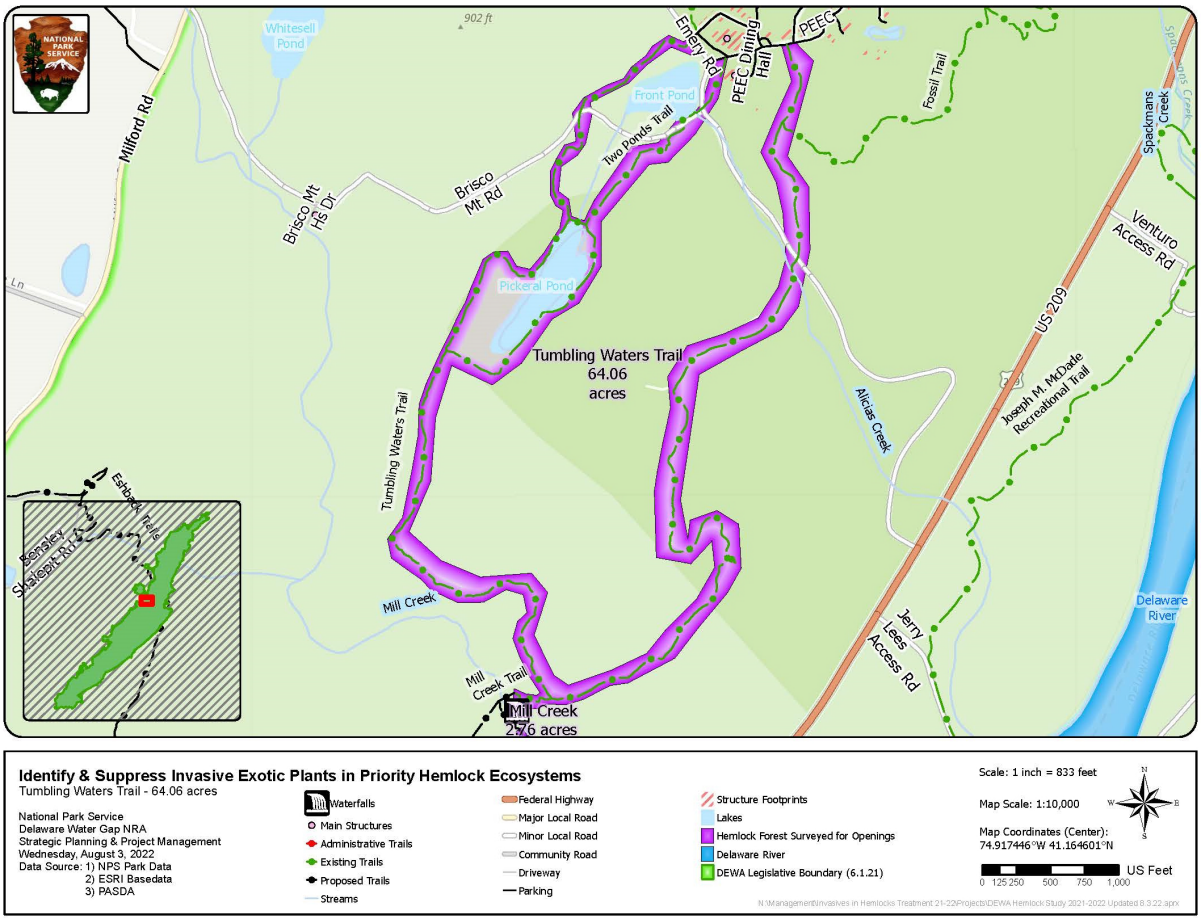


Figure A-17. Tumbling Waters Trail survey area.

The Department of the Interior protects and manages the nation’s natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 620/188091, April 2023

National Park Service
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