RECOMMENDATIONS FOR A RESTORATION MONITORING PLAN FOR A POPULATION OF MASSASAUGA RATTLESNAKES IN THE MATTHAEI BOTANICAL GARDENS

A Master's Thesis

Presented to the

Faculty of the School for the Environment and Sustainability

University of Michigan

Ann Arbor, Michigan

In Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

By

NICOLÁS A. GUTIÉRREZ-RIERA

Committee members:

Sara Adlerstein-Gonzalez
Michael A. Kost

April 2024

Table of Contents

Acknowledgements	4
Abstract	5
Introduction	1
Methods	6
Site selection	6
Vegetation cover survey	11
Snake survey	13
Results	15
Vegetation cover	15
Snake surveys	21
Discussion	30
Vegetation Cover	30
Snake Presence	32
Conclusions & Recommendations	38
Appendix A	43
Appendix B	44
Appendix C	45
Bibliography	46

Acknowledgements

I would like to express my gratitude to Sara Adlerstein-Gonzalez, PhD, for her constant support and for her patience throughout this research project, and for guiding me through graduate school and helping me find a career path that would suit me best. I would also like to thank Michael Kost, for his constant encouragement, training and overall support, and for inculcating a love and appreciation for plants in me.

Abstract

Habitat restoration efforts are crucial for the conservation of the eastern Massasauga rattlesnake (*Sistrurus catenatus catenatus*). Populations of this endangered species have declined, in part due to habitat loss and degradation. The study assessed vegetation cover at different stages of habitat restoration and Massasauga presence at the University of Michigan Matthaei Botanical Gardens located in Ann Arbor, Michigan, where there is an active population. Three study sites were selected to assess vegetation cover at different stages of habitat restoration and Massasauga presence. Vegetation surveys utilized the line intercept method to record the cover of woody plants and thistle along transects. Snake meander surveys, following established protocols, were conducted to assess Massasauga presence and abundance between May and Octoberof 2022 and 2023. Study sites were selected based on previous Massasauga surveys and habitat quality assessments. Results revealed variations in native and invasive plant species distribution, especially in the ground layer, where invasive woody plant species dominated; native woody plant species dominated the canopy layer. On the snake surveys, a total of 20 snakes were identified; most were found in the one site under the process of restoration the longest, which has unique topographic and vegetation characteristics. Also, 42 potential hibernacula were recorded. Results highlight associations between habitat characteristics and Massasauga presence, indicating the importance of continued research and adaptive management. The prevalence of invasive species, particularly in the ground layer, underscores ongoing challenges of managing non-native plants. Promising results in habitat improvement suggest the need for targeted invasive species removal and expanded monitoring efforts to ensure long-term conservation success. Expansion of

monitoring efforts for Massasauga rattlesnakes with multiple trained observers and diverse survey methods is essential for accurate population assessments and informing adaptive management strategies to support the long-term conservation of the Massasauga rattlesnake and its habitat.

Introduction

The eastern Massasauga rattlesnake (*Sistrurus catenatus catenatus*) is native to the Midwestern region of North America and due to its key role in its ecosystem, is considered an indicator species (USFWS 2019). An indicator species, the Massasauga provides early warnings to responses to environmental impacts, indicates the cause of change, and provides a cost-effective assessment of stressors (Carignan & Villard 2002). In particular, the Massasauga is considered an important indicator species for temperate wetlands ecosystems. Because reptiles are known to be less common in temperate regions due to their needs for maintaining healthy body temperatures, reptiles common to these ecosystems can only thrive in the right environmental conditions; this species requires both low wetlands to hibernate and dry uplands to sunbathe in order to survive (Cole 2014). Thus, the eastern Massasauga is an important species for the conservation of its ecosystem. Unfortunately, populations have declined, and it is listed as endangered in the United States by the US Fish & Wildlife Service, partially due to lack of management and habitat loss (USFWS 2019). The Massasauga is a federally threatened species due to factors that include degradation and fragmentation of habitat and corresponding population declines throughout the species' range (Shafer 2018).

An important aspect of the life history of the Massasauga is the patterns of habitat use and movement. The Massasauga has been reported to inhabit a wide array of habitats that include wet prairies (Seigel 1986), fens and sedge meadows (Minton 1972; Johnson 1995; Kingsbury 1996, Kingsbury and Barlow 1999), peatlands (Johnson 1995 2000), coniferous forest (Weatherhead and Prior 1992), and meadows and old fields (Reinert and Kodrich 1982, Wright 1941, Smith 1961). However, according to the USDA (2002), it is apparent that habitat use varies regionally, and is somewhat site dependent even within a particular region. It is important to point out that Massasaugas have been noted to avoid particularly heavy wooded areas, preferring areas with open canopies and/or an open shrub layer (Wright 1941, Bielema 1973, Reinert and Kodrich 1982, Seigel 1986, Kingsbury 1996, Kingsbury and Barlow 1999). The reasoning behind this particular habitat selection is thought to be a desirable thermoregulatory mosaic and an increase in density of their most common prey (USDA 2002), which includes small mammals and snakes (Keenlyne and Beer 1973, Seigel 1986, Johnson 1995), such as voles, jumping mice, and garter snakes (USDA 2002). Within these open habitats, Massasaugas often select microhabitats close to isolated shrubs and trees, as these offer shade and protection from aerial predators, such as hawks (Bielema 1973, Johnson 1995, USDA 2002), eagles, and herons (USFWS 2019).

Another important aspect of Massasauga habitat selection is proximity to water. However, the Massasauga is not an aquatic or semi-aquatic species, and it is known to avoid open water and swimming (USDA 2002). Massasauga selecting habitat near water sources occurs throughout the species' range, such as in Missouri (Seigel 1986), Wisconsin (King 1997), Indiana (Minton 1972, Kingsbury 1996, Kingsbury and Barlow 1999), Pennsylvania (Maple 1968, Reinert and Kodrich 1982), and New York (Johnson 1995).

Massasaugas show a distinctive shift in habitat use depending on the season (Kingsbury 2002). During the summer months, the snakes tend to prefer habitats located on topographically higher and drier ground, and shift to lower ground in wet prairies and meadows during the spring and fall (Bielema 1973, Reinert and Kodrich 1982, Seigel

1986, Johnson 1995). Regardless of their preferences for higher ground during the warmer months of the year, Massasaugas move back to lower ground during the fall, in preparation for winter (USDA 2002). This is because they hibernate throughout the winter in areas where the soil is saturated but not fully inundated, which supports the reasoning behind selecting habitats near bodies of water. In these areas, the snake uses crawfish burrows (Maple 1968, Seigel 1986, Kingsbury and Barlow 1999), and to a lesser degree, sphagnum hummocks (Johnson 1995), as their hibernacula for the winter months.

An aspect of the Massasauga's life history that is important to take into account for restoration of a local population, is reproduction. Massasauga rattlesnakes are ovoviviparous and give birth to live, fully developed, young (USDA 2002) varying in number from 3 to 19 in a brood (Seigel 1986). Massasaugas mate in the late summer or fall from late July to early September (USDA 2002). However, fertilization and development do not occur until the following spring. Gravid female Massasaugas have a stronger tendency for open habitats than their non-gravid counterparts and males, as gravid females are more thermally stable (Kingsbury 2002). Gravid females also tend to move less from these locations.

In Michigan, a nearly complete assemblage of Massasauga habitats exists, making the state ideal for the proliferation of this species (USDA 2002). In the southern region of the state, Massasauga habitat is often quite like those found in nearby states, including Illinois, Indiana and Ohio, where the species is associated with wet meadows and sedge fens around lakes or rivers.

The Massasauga rattlesnake has an active population at the University of Michigan Matthaei Botanical Gardens (MBG) located in Ann Arbor, Michigan (https://mbgna.umich.edu/eastern-Massasauga-rattlesnake). Surveys of the Massasauga at MBG were conducted in 2010, 2011, 2014, 2015 & 2019 by an ecological consulting group (Anton and Mauger, 2019). These surveys accounted for the presence of the snake, description of the study sites, and provided general management recommendations, but little is known about population size, distribution, and habitat preferences. The results of these surveys showed a decline in the number of Massasaugas recorded, which was attributed to the increase in woody vegetation cover, as well as survey timing. Recommendations included removing woody brush as well as to maintain natural prairie and wetland habitats in the gardens. Manual removal and the use of prescribed burns were recommended as methods for the removal of unwanted vegetation cover, with a strong emphasis on avoiding snake mortality. On the other hand, the survey reports suggest that presence of the exotic grass species that dominate some of the areas of the MBG are beneficial for voles (*Microtus pennsylvanicus*) and meadow jumping mouse (*Zapus hudsonius*), which are important Massasauga prey, as well as provide the snakes with concealment from humans and predators, layered thermoregulation sites, and foraging habitat. These grasses dominate the uplands of an area immediately west of the main parking lot of MBG, and what Anton and Mauger (2015) defined as Search Area 5.

At Matthaei Botanical Gardens, efforts to restore the natural habitat of the Massasauga have been made throughout the years. Several methods have been used to control invasive shrub species including brush mowing, cutting by hand (manual removal), glyphosate herbicide treatments, and prescribed burns; these are documented in the MBG Invasive Shrub Management Webpage and Matthaei-Nichols Prescribed Burns Online Maps.

In this study, I selected three sites with similar habitat characteristics that have been in the process of restoration for different periods of time, ranging from several decades to two years (Michael Kost, MBGNA, personal communication). This selection was done in order to be able to compare the short and long term impacts of the restoration process on the vegetation cover as well as on the snake population. In these sites, I assessed the percent cover of invasive and native plant species and conducted surveys to determine the presence and relative abundance of the Massasauga rattlesnake. The goal of these surveys was to develop recommendations for a management plan of habitat restoration for the population of Massasauga rattlesnakes at the University of Michigan MBG. It is important to note that to restore the population of snakes, its habitat has to be restored.

Methods

The goal of this study was to craft recommendations for a habitat monitoring plan for efforts to restore a population of Massasauga rattlesnakes found at the Matthaei Botanical Gardens (MBG) by means of restoring its native habitat. To achieve this goal, I compared the vegetation cover and snake presence in three study sites located within the gardens that are at different stages of habitat restoration. Each study site has a dry upland and a wet lowland which are important components of an ideal habitat for the Massasauga rattlesnake, as they live and hibernate in the lowlands, and bask and hunt mostly in the uplands (US FWS 2022).

At each study site I conducted surveys to assess the plant community and the Massasauga population. Plant surveys evaluated the composition of the woody vegetation, and in particular, the area covered by invasive species. The plant surveys were conducted in the growing season between May and Septemberin 2022 (Table 1). The Massasauga surveys were conducted to verify the presence and relative abundance of the species in the study sites. The snake surveys included six surveys per site for a total of 18 surveys, and were conducted between May and October of 2022 and 2023 (Table 1).

Site selection

Three study sites were selected for the project. Site 1 was selected based on the findings of previous Massasauga surveys which showed this area as having the highest concentration of the snakes in MBG (Anton et al. 2010, 2011, 2014, 2015 & 2019). Sites 2 & 3 were selected based on information provided by the Natural Areas Manager and the Associate Curator of the MBG, as well as a study made by Crancer (2011), which informs that the area is known to have high floristic quality as well as residence of the threatened Massasauga. Floristic quality is an indicator of natural area significance, which can be used to identify habitats with high presence of native plants, ease comparison between sites, and monitor the progress of habitat restoration (Herman et al. 2001); this reasoning gave priority to the two first sites selected.

Site 1 is located in the MBG west-central area, near the border with Dixboro Road, north of the garden's artificial pond, Willow Pond (Figure 1). This is the control site and was selected because it showed a consistent trend of snake presence as well as presence of hibernacula throughout all the surveys performed by Anton et al. (2010, 2011, 2014, 2015 & 2019). This site was described in these reports as a mix of trees, upland grasses, rushes, sedges and lowland open shrub swamp, and it is in close proximity to the MBG Visitor Center. A hillside at the western edge of the parking lot affords some topographical relief. Adjacent standing open water is in the form of Willow Pond, built in the 1960s, and crayfish burrows in the pond's lowland margins serve as winter denning sites for snakes, including eastern Massasauga rattlesnakes.This area has been in the process of restoration for over a decade, according to the staff at the MBG, having had a mechanical invasive shrub removal as early as 2013. Furthermore, sections of this site have been treated with prescribed burns in 2006, 2008 and 2019, as well as received glyphosate herbicide treatments in 2012, 2013 and 2015 (Matthaei Botanical Gardens 2024)

Site 2, is located in the northern section of the MBG, neighboring a tennis club and Cherry Hill Road (Figure 1). This site is commonly known as Kirk Fen, which is a wetland with varying topography, and identified as a site of high conservation value by the team at the MBG. This site borders Kirk Brook, a tributary of Fleming Creek, which delineates its southern border. This area has been in the process of restoration for over a decade, according to the staff at the MBG. It was partially cleared in 2013, 2015, and 2019 (Matthaei Botanical Gardens 2018), and received partial treatments with glyphosate in 2013, 2015, 2017, as well as partial prescribed burns in 2011, 2016 and 2018 (Matthaei Botanical Gardens 2024).

Site 3, is located in the northern section of the MBG, neighboring the tennis club and Cherry Hill Road (Figure 1). This area, covered by invasive shrub species, didn't allow rattlesnakes to sunbathe until it was cleared in early-mid 2020 (Figure 2). This site is commonly known as Cummings Fen, which is a wetland with varying topography, and identified as a site of high conservation value by the team at the MBG (Michael Kost, MBGNA, personal communication). This site borders Fleming Creek, which delineates its southern border. This site began its main restoration process in 2021 with a thorough mechanical removal of invasive shrub species (Michael Kost, MBGNA, personal communication 2021). However, small treatments have occured in small sections of the site in the past, such as glyphosate treatments in 2013 and 2015, as well as a small prescribed burn in 2019 (Matthaei Botanical Gardens 2024).

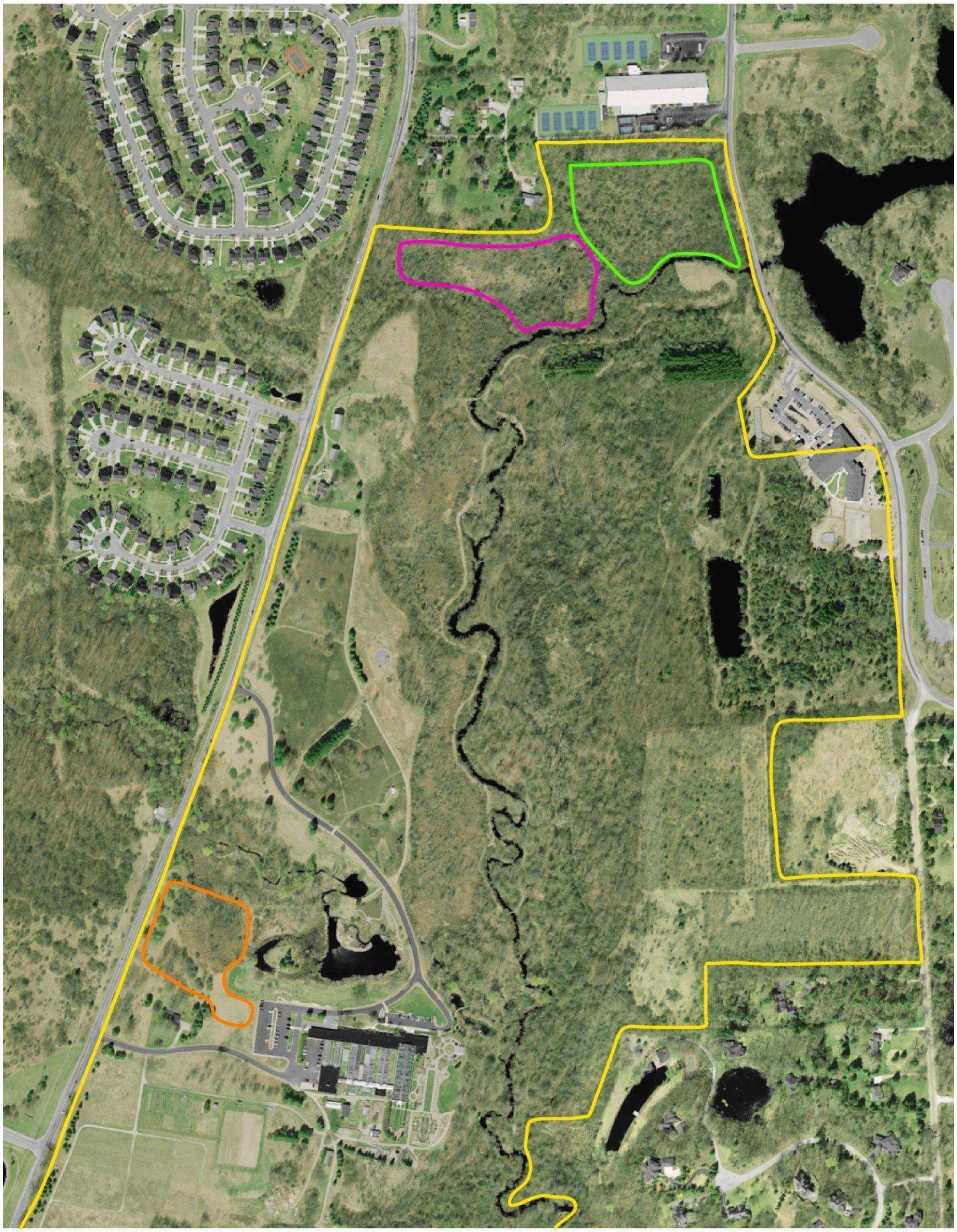

Figure 1. Aerial multispectral image of the Matthaei Botanical Gardens, at 1800 N Dixboro Rd, Ann Arbor, MI 48105 and immediate surroundings, taken in 2010. It has a one foot resolution and includes a near infrared band Yellow boundary delineates the MBG property. Study sites boundary in orange = Site 1, pink = Site 2, and green = Site 3.

Figure 2. Aerial photograph showing the approximate location of Study Site 3 within the green perimeter, before the clearing of invasive shrubs taken on September 19th, 2020 in the top, and, after the clearing of invasive shrubs taken on September 27th, 2021 (Michael Kost, MBGNA, personal communication, 2021). Image retrieved from Nearmap.

Vegetation cover survey

I conducted a vegetation cover survey protocol utilizing the line intercept method (Barbour et al. 1987). Within each study site, three 100-m transect lines were run perpendicular to the slope of the site (Figures 3, 4 and 5). The MBG natural area managers are mostly concerned and interested in knowing the current status of Canada thistle (*Cirsium arvense*) and woody invasive plants in the property, as these have had the most noticeable impact in the vegetative makeup of the habitats present (Steve Parrish and Michael Kost, MBGNA personal communication, 2021). Thus, I recorded the cover of thistle and all woody plants that intercepted the transect lines. Measurements were made to the nearest centimeter. The transect lines were placed at least 10 paces from each other (Figures 3, 4 and 5); each pace was approximately 1.5 m in length.

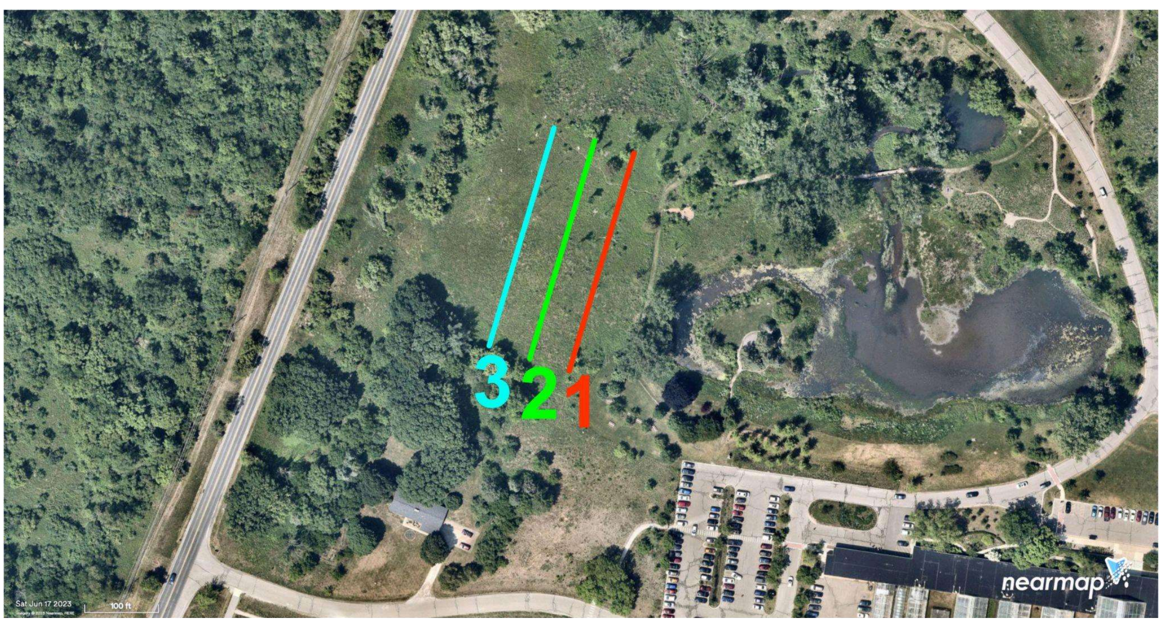

Figure 3. Aerial photograph showing the approximate location of the three transects in study Site 1. Image retrieved from Nearmap.

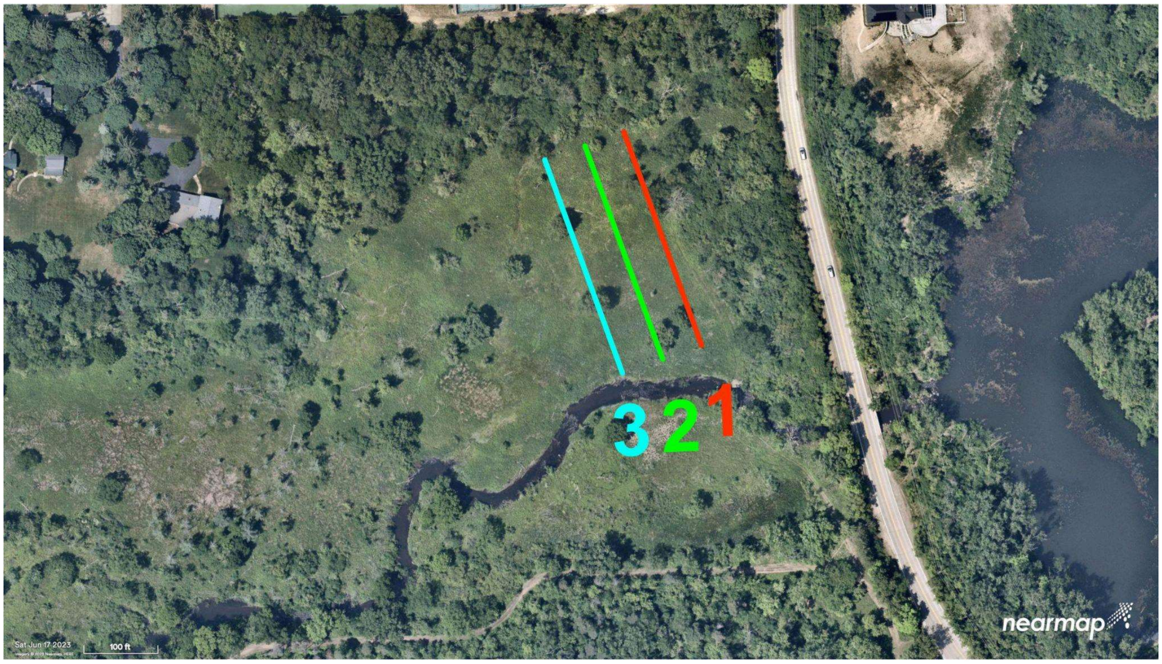

Figure 4. Aerial photograph showing the approximate location of the three transects in study Site 3. Image retrieved from Nearmap.

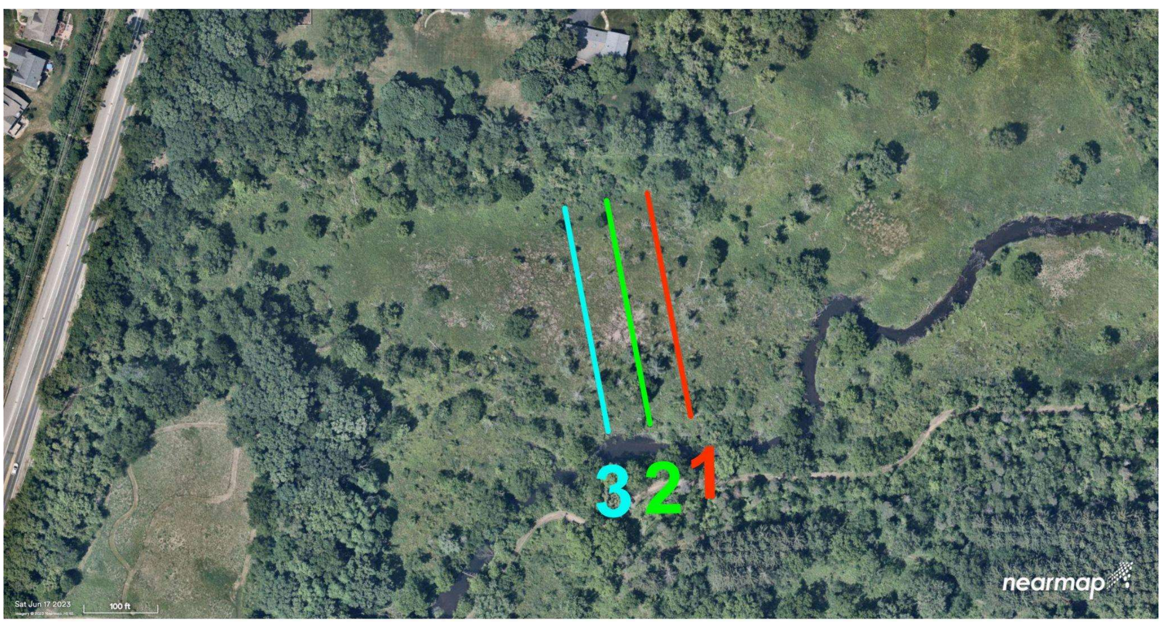

Figure 5. Aerial photograph showing the approximate location of the three transects in study Site 2. Image retrieved from Nearmap.

Woody plants and thistles that intercepted the transect line were recorded and placed in a height category, which included ground (0-1m), shrub (1-5m), and canopy (5m or more) layers. Woody plants were identified to species level and placed within native and non-native categories. Effort was focused on identifying woody plants to the species levels because the invasive species of most concern to the restoration work done in the gardens are woody plant species. These include common buckthorn (*Rhamnus cathartica*), glossy buckthorn (*Frangula alnus*), Morrow's honeysuckle (*Lonicera morrowii*), Amur honeysuckle (*L. maackii*), Tartarian honeysuckle (*Lonicera tatarica*), autumn olive (*Elaeagnus umbellata*), multiflora rose (*Rosa multiflora*), wild privet (*Ligustrum vulgare*), and border privet (*L. obtusifolium*). In all sites, the invasive Canada thistle, also of concern, was identified to species level.

Snake survey

The snake survey protocol followed the previous survey work done at the MBG by Anton et al. (2010, 2011, 2014, 2015 & 2019), which was based on the survey protocols from Casper et al. (2001). The surveys in this stud followed these protocols as closely as possible. The snake surveys were timed-meander surveys, which consisted of 120 minutes of one person walking through the study site and taking note of signs of presence of Massasauga rattlesnakes, including sightings, sound of a rattle, and presence of hibernacula. Parameters for seasonality and time of day as well as weather parameters followed as closely as possible those recommended by Casper et al. (2001) (Table 1). All other animals sighted were noted, including but not limited to Massasauga's prey and predators. The meandering route was recorded and mapped via a GPS watch. I estimated an index of snake abundance as the number of individuals observed by observer effort.

Table 1. Date, time, and weather conditions of snake surveys

# of Survey	Site	Date	Time of Day	Temperature (Cº)	Cloud Coverage
1	1	5/17/2022	11:20AM - 1:20PM	15	Mostly sunny
2	1	6/1/2022	9:52AM - 11:52AM	25	Mostly sunny
3	1	6/11/2022	1:44PM - 3:44PM	24	Mostly cloudy
4	3	6/21/2022	2:08PM - 4:08PM	33	Partially cloudy
5	3	10/15/2022	2:04PM - 4:04PM	11	Cloudy
6	3	10/22/2022	2:03PM - 4:03PM	24	Sunny
7	2	10/22/2022	4:07PM - 6:07PM	24	Sunny
8	2	10/23/2022	1:51PM - 3:51PM	24	Partially cloudy
9	2	10/23/2022	3:55PM - 5:55PM	24	Partially cloudy
10	3	5/25/2023	1:09PM - 3:09PM	18	Sunny
11	3	5/25/2023	3:15PM - 5:15PM	18	Sunny
12	3	5/25/2023	5:16PM - 7:16PM	17	Sunny
13	2	5/26/2023	2:45PM - 4:45PM	21	Sunny
14	2	5/26/2023	4:46PM - 6:46PM	21	Sunny
15	2	5/29/2023	11:33AM - 1:33PM	29	Sunny
16	1	6/5/2023	11:06AM - 1:06PM	24	Sunny
17	1	6/5/2023	1:11PM - 3:11PM	24	Sunny
18	1	6/17/2023	2:13PM - 4:13PM	26	Sunny

Results

Vegetation cover

Overall, I took note of 218 instances of plant species intercepting the transect lines. In Site 1, ground layer woody plants covered 65.41% of the extent of the three 100-m transects, while the shrub and canopy layers covered 10.44% and 24.15%, respectively (Figure 6). In Site 2, the ground layer covered 58.20% of the ground along the transect lines, the shrub layer covered 21.85%, and the canopy layer 19.95%. In Site 3, the ground layer covered 49.44% of the ground along the transect, while the shrub and canopy layers covered 14.54% and 36.02%, respectively.

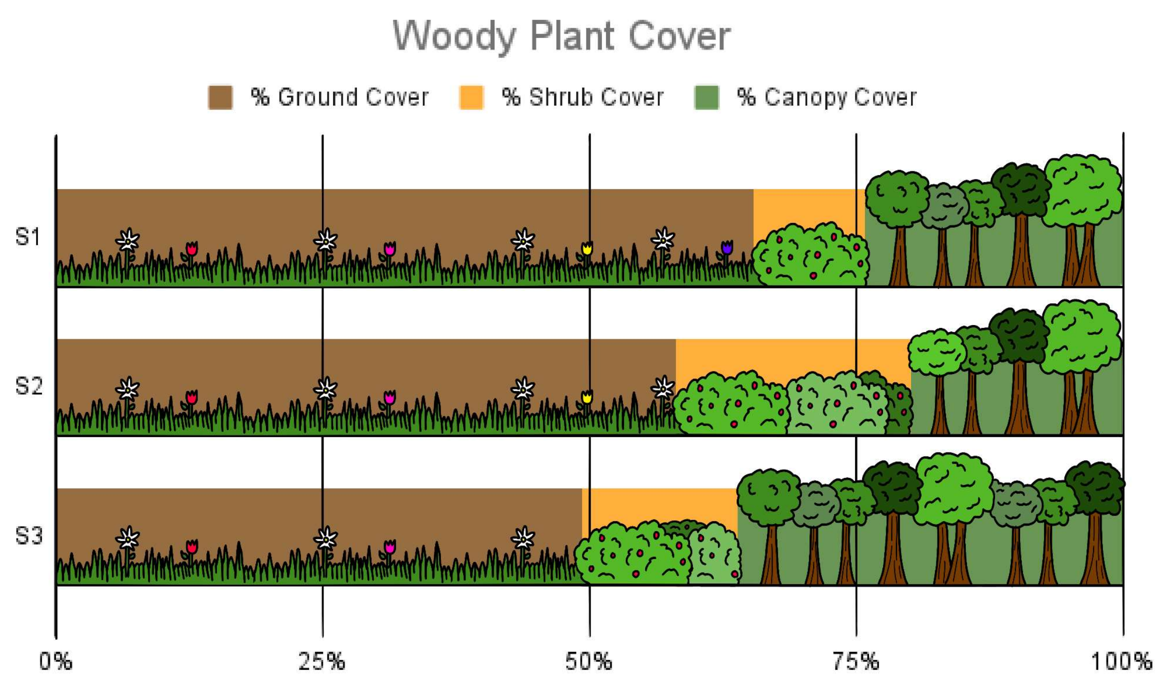

Figure 6. Pictograph representing the percentage of vegetation cover of three 100-m transects identified in each site that belongs to the ground (0-1m), shrub (1-5m) and canopy (5m or more) layer categories.

Table 2. Woody plant species and thistle (*Cirsium arvense*) identified by study site and total coverage by species (in cm) along the three 100 m transects by site. Note that Rhamnus cathartica and Frangula alnus are reported together for locations where they could not be separated in dense patches.

	Species	Site 1(cm)	Site 2(cm)	Site 3(cm)	All sites (cm)	Native / Invasive
1	Acer negundo	200	950	1960	3110	Native
2	Carpinus caroliniana	0	320	0	320	Native
3	Cirsium arvense	970	10250	15440	26660	Invasive
4	Cornus sericea	1340	0	0	1340	Native
5	Corylus americana	0	1010	0	1010	Native
6	Elaeagnus umbellata	720	0	0	720	Invasive
7	Frangula alnus	5170	250	0	5420	Invasive
8	Fraxinus americana	4241	0	280	4521	Native
9	Fraxinus nigra	0	340	0	340	Native
10	Fraxinus pennsylvanica	0	20	0	20	Native
11	Juglans nigra	200	1750	0	1950	Native
12	Juniperus virginiana	1540	1220	0	2760	Native
13	Larix laricina	1250	8340	90	9680	Native
14	Ligustrum vulgare	0	820	65	885	Invasive
15	Lonicera maackii	0	1020	110	1130	Invasive
16	Lonicera morrowii	0	760	0	760	Invasive
17	Lonicera tatarica	0	150	0	150	Invasive
18	Malus sp.	430	0	0	430	Native
19	Prunus serotina	290	0	2010	2300	Native
20	Quercus sp.	0	750	0	750	Native
21	Quercus rubra	20	0	0	20	Native
22	Rhamnus cathartica	1490	3970	22544	28004	Invasive
23	R. cathartica & F. alnus	9410	23210	0	32620	Invasive
24	Rosa multiflora	40	350	50	440	Invasive
25	Rosa palustris	0	20	0	20	Native
26	Rubus occidentalis	30	0	0	30	Native
27	Salix exigua	310	0	0	310	Native
28	Tilia americana	0	850	2030	2880	Native

29	Toxicodendron radicans	680	180	0	860	Native
30	Ulmus americana	700	1870	1170	3740	Native
31	Viburnum lentago	300	450	0	750	Native
32	Viburnum trilobum	20	0	0	20	Native
33	Vitis riparia	90	1460	1070	2620	Native
34	Zanthoxylum americanum	50	0	0	50	Native

Table 3. Woody plant and thistle species identified by study site and their coverage (% of the three 100 m transects). Note that figures for Rhamnus cathartica and Frangula alnus are reported jointly for locations where they occurred together in dense patches.

	Species	Site 1 % cover	Site 2 % cover	Site 3 % cover	Total % cover	Native / Invasive
1	Acer negundo	0.68	1.58	4.19	2.28	Native
2	Carpinus caroliniana	0.00	0.53	0.00	0.23	Native
3	Cirsium arvense	3.29	17.00	32.98	19.51	Invasive
4	Cornus sericea	4.54	0.00	0.00	0.98	Native
5	Corylus americana	0.00	1.67	0.00	0.74	Native
6	Elaeagnus umbellata	2.44	0.00	0.00	0.53	Invasive
7	Frangula alnus	17.53	0.41	0.00	3.97	Invasive
8	Fraxinus americana	14.38	0.00	0.60	3.31	Native
9	Fraxinus nigra	0.00	0.56	0.00	0.25	Native
10	Fraxinus pennsylvanica	0.00	0.03	0.00	0.01	Native
11	Juglans nigra	0.68	2.90	0.00	1.43	Native
12	Juniperus virginiana	5.22	2.02	0.00	2.02	Native
13	Larix laricina	4.24	13.83	0.19	7.09	Native
14	Ligustrum vulgare	0.00	1.36	0.14	0.65	Invasive
15	Lonicera maackii	0.00	1.69	0.23	0.83	Invasive
16	Lonicera morrowii	0.00	1.26	0.00	0.56	Invasive
17	Lonicera tatarica	0.00	0.25	0.00	0.11	Invasive
18	Malus sp.	1.46	0.00	0.00	0.31	Native
19	Prunus serotina	0.98	0.00	4.29	1.68	Native
20	Quercus sp.	0.00	1.24	0.00	0.55	Native
21	Quercus rubra	0.07	0.00	0.00	0.01	Native

22	Rhamnus cathartica	5.05	6.58	48.15	20.50	Invasive
23	R. cathartica & F.alnus	31.91	38.48	0.00	23.88	Invasive
24	Rosa multiflora	0.14	0.58	0.11	0.32	Invasive
25	Rosa palustris	0.00	0.03	0.00	0.01	Native
26	Rubus occidentalis	0.10	0.00	0.00	0.02	Native
27	Salix exigua	1.05	0.00	0.00	0.23	Native
28	Tilia americana	0.00	1.41	4.34	2.11	Native
29	Toxicodendron radicans	2.31	0.30	0.00	0.63	Native
30	Ulmus americana	2.37	3.10	2.50	2.74	Native
31	Viburnum lentago	1.02	0.75	0.00	0.55	Native
32	Viburnum trilobum	0.07	0.00	0.00	0.01	Native
33	Vitis riparia	0.31	2.42	2.29	1.92	Native
34	Zanthoxylum americanum	0.17	0.00	0.00	0.04	Native

Invasive woody plant species in the ground layer represented over 50% of the surveyed area: 57.98%, 57.58%, and 48.78% in Site 1, Site 2, and Site 3, respectively (Figure 7). The invasive species in the shrub layers of the surveyed area of Site 1, Site 2, and Site 3 composed 2.61%, 21.17%, and 8.88%, respectively. In Site 1, the invasive woody plant species in the canopy layer represented 2.54% of the total vegetation cover. In Site 2, the invasive woody plant species in the canopy layer represented 2.86% of the total vegetation cover. In Site 3, the invasive woody plant species in the canopy layer represented 8.05% of the total vegetation cover. These included common buckthorn (*Rhamnus cathartica*), glossy buckthorn (*Frangula alnus*), Morrow's honeysuckle (*Lonicera morrowii*), Amur honeysuckle (*L. maackii*), Tartarian honeysuckle (*L. tatarica*), autumn olive (*Elaeagnus umbellata*), multiflora rose (*Rosa multiflora*), wild privet (*Ligustrum vulgare*) and border privet (*L. obtusifolium*).

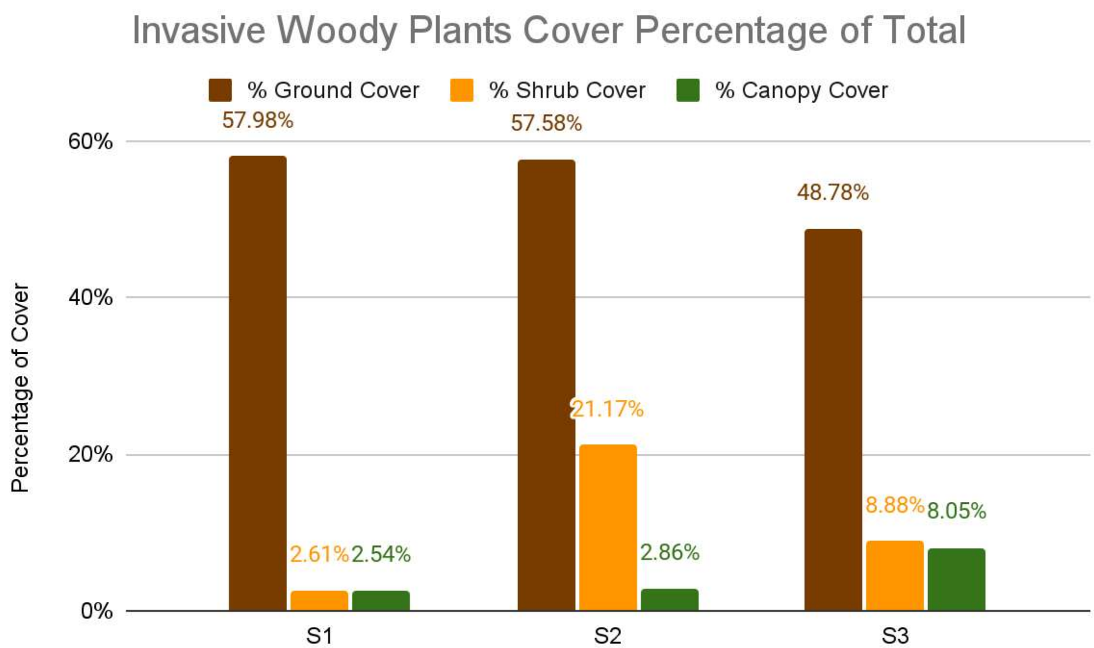

Figure 7. Percentage of the total vegetation cover of invasive plant species in ground (0-1m), shrub (1-5m) and canopy (5m or more) layer categories along the three 100m transects in each site.

Of the total vegetation cover, in Site 1 native woody plant species in the ground layer represented 7.43%, in the shrub layer represented 7.83%, and in the canopy layer represented 21.60% (Figure 8). In Site 2, native woody plant species in the ground layer represented 0.62% of the total vegetation cover, while in the shrub and canopy layers represented 0.68% and 17.09% respectively. In Site 3, the native woody plant species in the ground layer represented 0.66% of the total, in the shrub layer represented 5.66% of the total, and in the canopy layer represented 27.97% of the total vegetation cover.

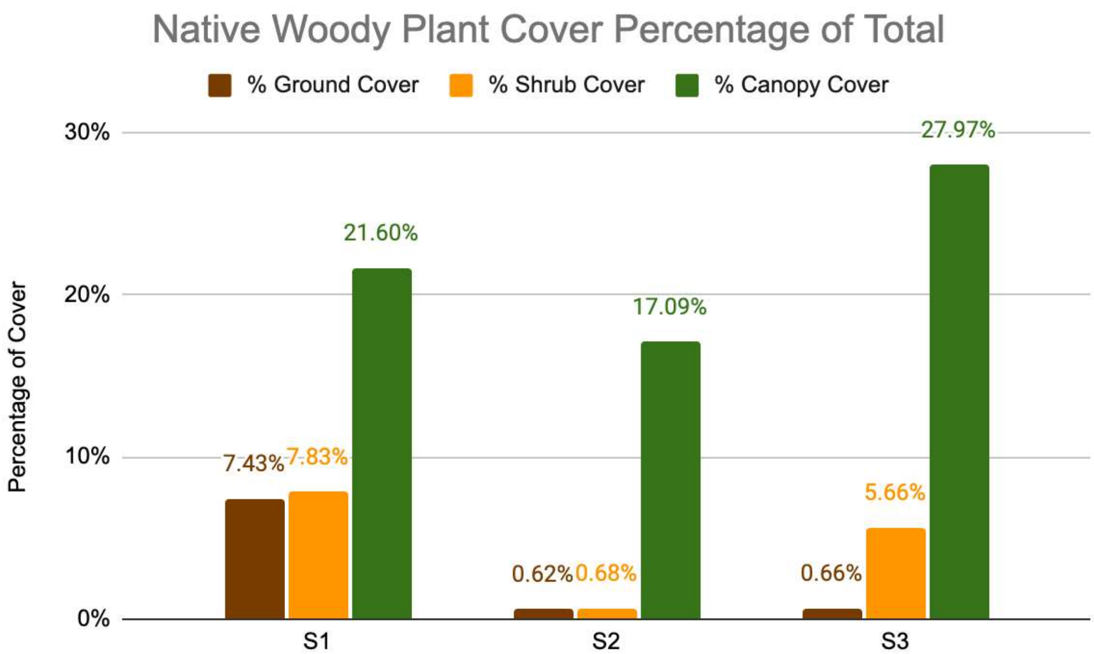

Figure 8. Percentage of the total native woody plant cover along the three 100-m transects that belong to the ground (0-1m), shrub (1-5m) and canopy (5m or more) layer categories in each study site.

Out of the total woody vegetation cover of Site 1, 63.14% were invasive species, while 36.86% were native (Figure 9). In Site 2, 65.71% of the total woody vegetation cover were invasive species while 34.29% were native. Invasive woody plant species in Site 3 represented 81.61% of the total cover while 18.39% were native.

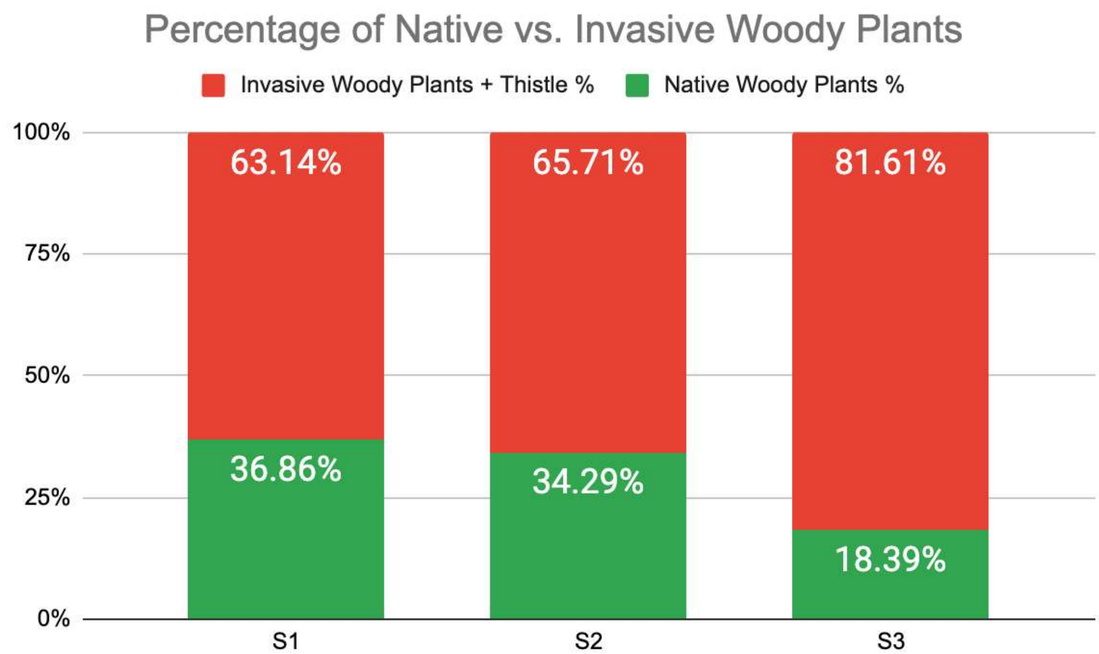

Figure 9. Percentage of invasive and native woody plant species cover along the three 100-m transects in the study sites.

The percentage of total coverage of woody plants belonging to the canopy, shrub and ground layers, in each site varied by transect (Figure 10). On average in Site 1, the ground, shrub and canopy layers covered approximately 65%, 10%, and 24% of the total. Within Site 1 by transect, these layers covered 55%, 9%, 36%; 75%, 16%, 8%; and 71%, 3%, 26% of the total respectively. On average in Site 2, the ground, shrub, and canopy layers covered 51%, 12%, and 37% of the total. Within Site 2 by transect, these layers covered 51%, 6%, 43%; 52%, 16%, 33%; and 51%, 12%, 36% of the total respectively. On average in Site 3, the ground, shrub, and canopy layer covered 58%, 22%, and 20%, of the total respectively. Within Site 3 by transect these layers covered 57%, 31%, 13%; 57%, 28%, 15%; and 60%, 10%, 30% of the total respectively..

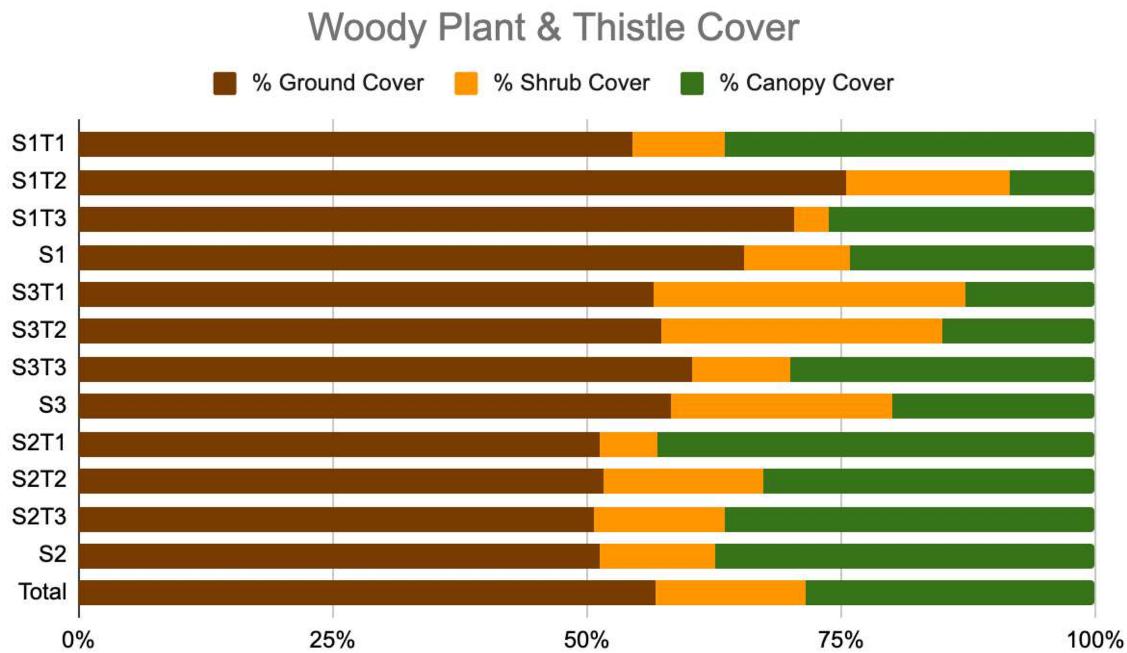

Figure 10. Percentage of vegetation cover of each of three 100-m transects identified in each site that belongs to the ground (0-1m), shrub (1-5m) and canopy (5m or more) layer categories. This includes both native and invasive species.

The coverage of invasive and native woody plants varied by site and was similar by transect within sites (Figure 11). On average in Site 1, the invasive and native plant cover was 63%, and 37% of the total, respectively and by transect they covered 61% and 39%, 68% and 32%, and 58% and 42%. On average in Site 2, the invasive and native plant cover was 66% and 34% of the total and by transect they covered 65% and 35%; 65% and 35%, and 66% and 34% . On average in Site 3, the invasive and native plant cover were 82% and 18% of the total and by transect 87% and 13%, 81% and 19%, and 76% and 24%. .

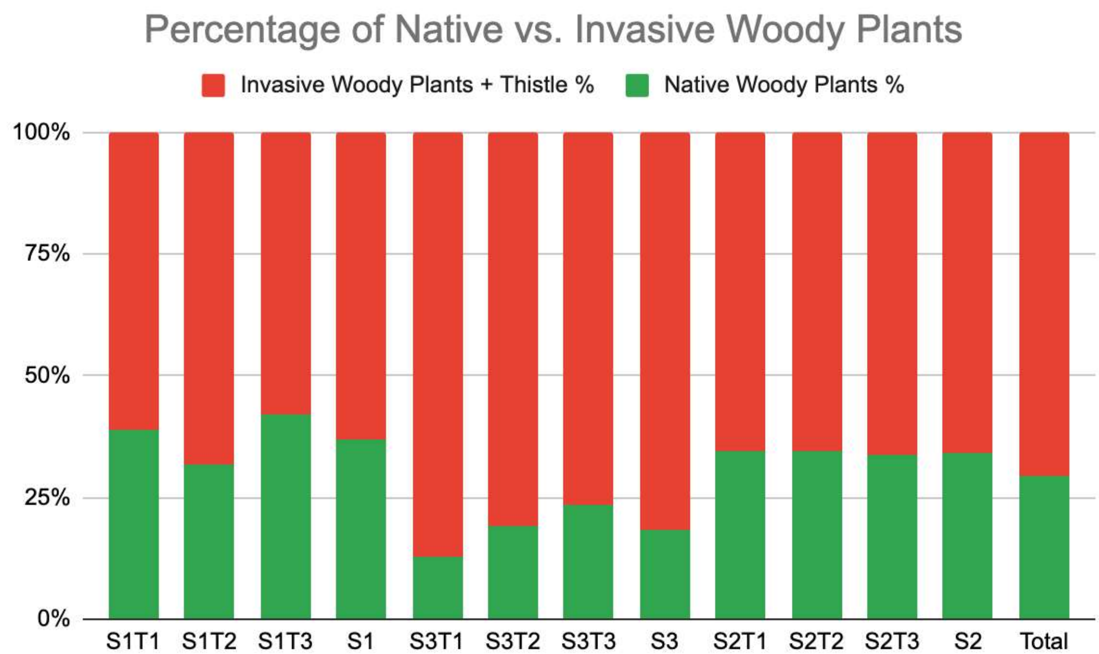

Figure 11. Percentage of invasive and native woody plant species cover along each of the three 100-m transects in each of the study sites.

Coverage of invasive woody plants, and thistle, belonging to the canopy, shrub, and ground layers varied by site and transect (Figure 12). On average in Site 1, the ground, shrub, and canopy layers covered 92%, 4%, and 4%, of the total respectively. Within Site 1 by transect the layers covered 86%, 8% and 6%, respectively; 98% and 2% and 0%, and , 92%, 1%, and 7%. On average in Site 2, the ground, shrub and canopy layers covered 78%, 9%, and 13%, of the total and by transect 75%, 5%, 20%; 79%, 4%, 17%; and 80%, 18%, 2%. On average in Site 3, the ground, shrub and canopy layers covered 70%, 26% and 4%, of the total respectively and by transect these layers covered 65%, 35%, 0%; 69%, 31%; 0%; and 78.%, 12%, 10%.

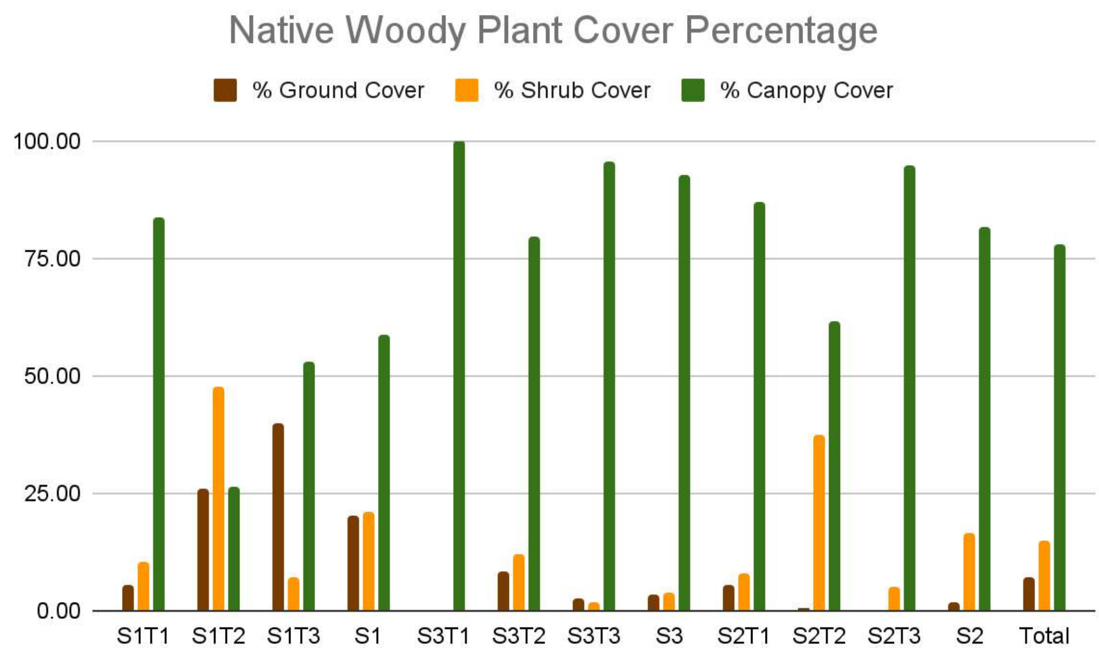

Figure 12. Percentage of the total native woody plant cover along each one of the three 100-m transects that belong to the ground (0-1m), shrub (1-5m) and canopy (5m or more) layer categories in each study site.

Coverage of native woody plants belonging to the canopy, shrub, and ground layers varied greatly by site and within transects (Figure 13). On average in **Site 1**, ground, shrub and canopy layers covered 3%, 4%, and 93% of the total and by transect the layers covered 6%,10%, 84%; 26%, 48%, 26%; and 40%,7%, 53%, respectively. On average in **Site 2**, the ground, shrub, and canopy layers covered 20%, 21%, and 59% of the total; while by transect the layers covered 5%, 8%, 87%; 1%, 37%, 62%;.and 0%, 5%, 95% of the total respectively. On average in **Site 3**, the ground, shrub and canopy layers covered 2%, 16%, and 82% of the total, while by transect they covered 0%, 0%, 100%; 8%, 12%, and 80%; and 3%, 2%, 95%.of the total respectively.

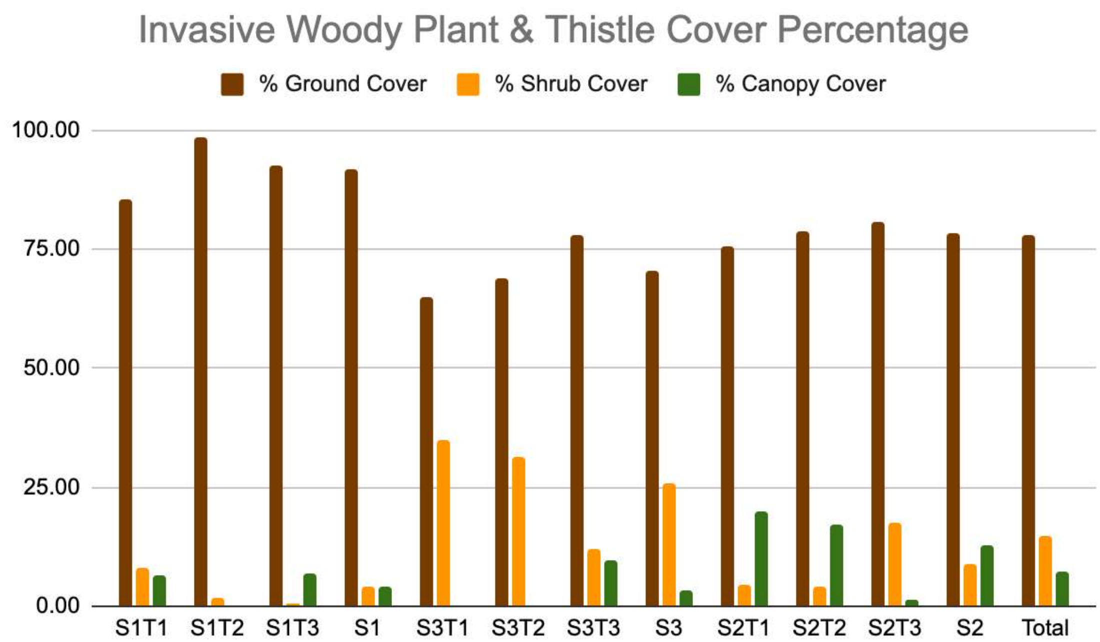

Figure 13. Percentage of the total invasive woody plant cover along each one of the three 100-m transects that belong to the ground (0-1m), shrub (1-5m) and canopy (5m or more) layer categories in each study site.

Snake surveys

The temperature during the surveys ranged from 11 to 33ºC (Table 1). Weather conditions varied: 11 out of the 18 surveys were conducted with sunny weather, 2 mostly sunny, 3 partially cloudy, 1 mostly cloudy, and 1 cloudy. The total distance walked during the surveys was approximately 40 km with a range from 1.63 km to 2.76 km. The compiled GPS survey trackings for each site are shown in Figures 12, 13, and 14.

For the 2022 surveys, the average temperature was 22.67 ºC, and the average distance covered was 2.24 km. The weather for this set was 2 sunny, 3 mostly sunny, 3 partially cloudy, and 1 cloudy, for a total of 9 surveys. For the 2023 surveys, the average temperature and distance covered was 22.2 ºC and 2.11 km, respectively. During this year, all survey days were sunny.

Of all Massasauga sightings in 2022 and 2023, 75% were in Site 1, while 15% were in Site 2 and 10% in Site 3 (Figure 14). I recorded 15 rattlesnakes in Site 1: 5 of them in 2022 and 10 in 2023 (Table 4). In Site 2, I recorded 3 snakes: 2 in 2022 and 1 in 2023. In Site 3, I did not find any snakes in 2022, and I recorded 2 snakes in 2023. Thus, the relative abundance index by survey ranged from 0 to 2 snakes/hour/observer. The average relative abundance per site was 1.25, 0.25 and 0.17 snakes/hour/observer for Sites 1, 2, and 3, respectively. Hibernacula were observed in all three sites, ranging from 10 in Site 1 and 1 in Site 3 (Table 4 & Figure 20).

Table 4. Number of Massasauga sightings (Observed) and heard (Heard) recorded by one surveyor by two hour survey effort and other observations during the study.

Site	Date	Observed	Heard	Massasauga/ (Time*observer)	Hibernacula	Notes:
1	5/17/2022	0	2	1.0	10	**4 garter snake 1 rabbit 1 squirrel 1 rodent (unidentified)**
1	6/1/2022	0	0	0.0	10	**3 garter snakes 1 deer 1 groundhog**
1	6/11/2022	1	2	1.5	10	**1 shedded snake skin**
3	6/21/2022	0	0	0.0	2	
3	10/15/2022	0	0	0.0	2	
3	10/22/2022	0	0	0.0	2	**1 garter snake**
2	10/22/2022	0	1	0.5	5	
2	10/23/2022	0	1	0.5	5	**2 deer**

2	10/23/2022	0	0	0.0	5	**5 deer**
3	5/25/2023	0	2	1.0	2	**4 deer** **1 rabbit**
3	5/25/2023	0	0	0.0	2	**1 wild turkey** **1 garter snake** **1 brown snake** **1 deer**
3	5/25/2023	0	0	0.0	2	
2	5/26/2023	0	1	0.5	5	**7 deer** **1 wild turkey** **1 brown snake**
2	5/26/2023	0	0	0.0	5	**7 deer**
2	5/29/2023	0	0	0.0	5	**1 deer**
1	6/5/2023	1	3	2.0	10	**1 garter snake** **1 rabbit** **2 small mammals (unidentified)**
1	6/5/2023	0	4	2.0	10	**1 garter snake**
1	6/17/2023	0	2	1.0	10	**1 rabbit**

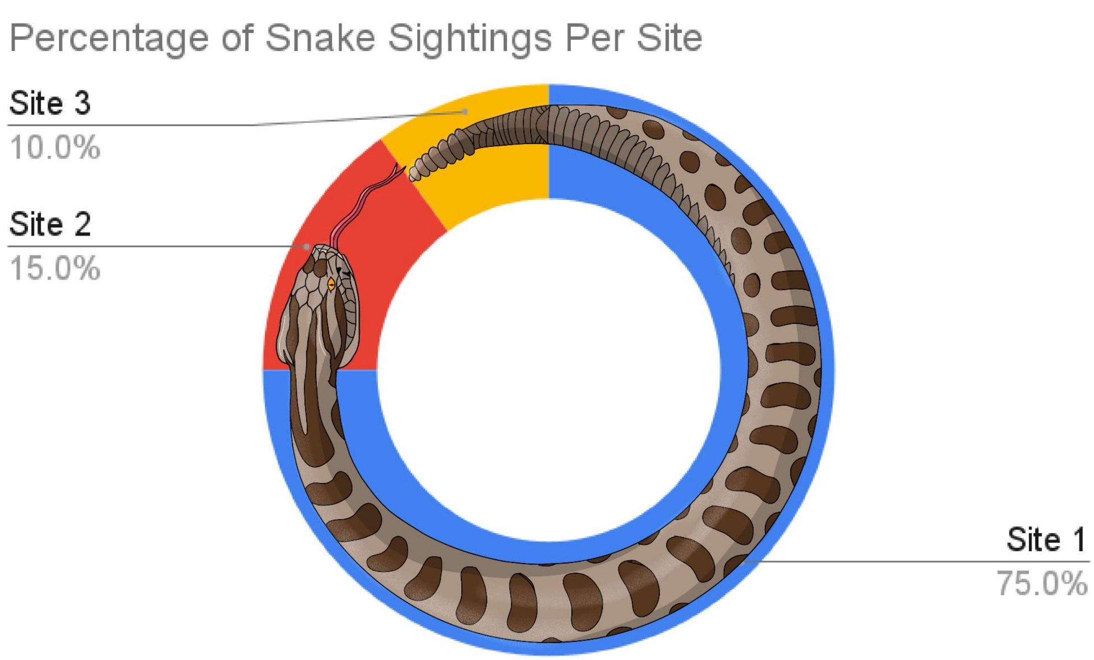

Figure 14. Donut graph representing the percentage of sightings of Massasauga rattlesnakes in each site.

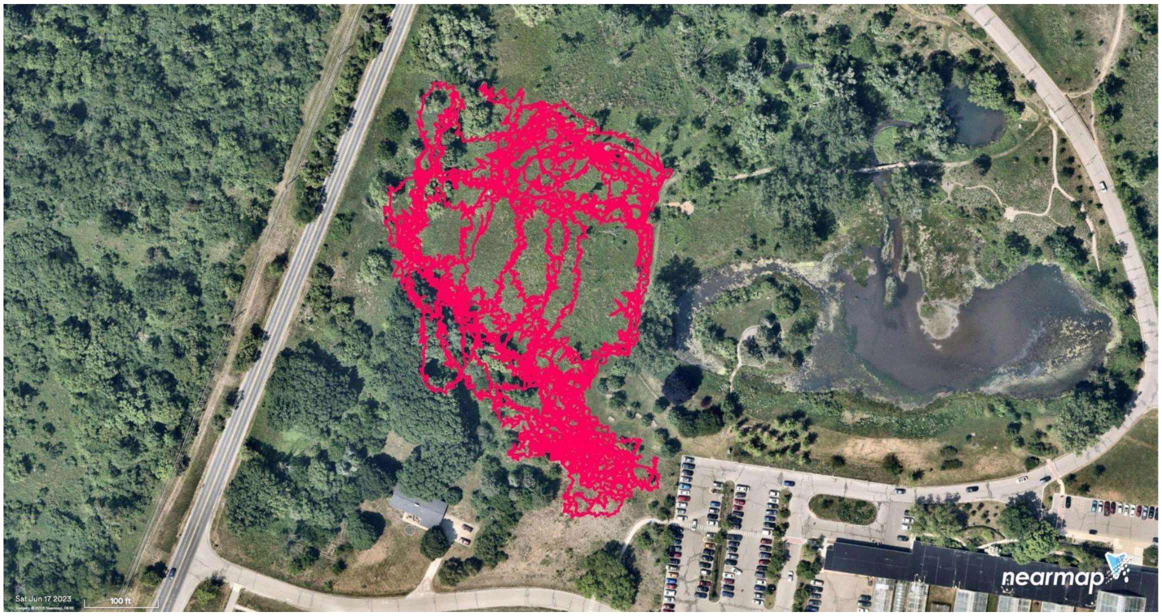

Figure 15. Compiled GPS tracking information for the six snake surveys done in Site 1, in red. Image retrieved from nearmap.

Figure 16. Compiled GPS tracking information for the six snake surveys done in Site 2 (in red). Image retrieved from nearmap.

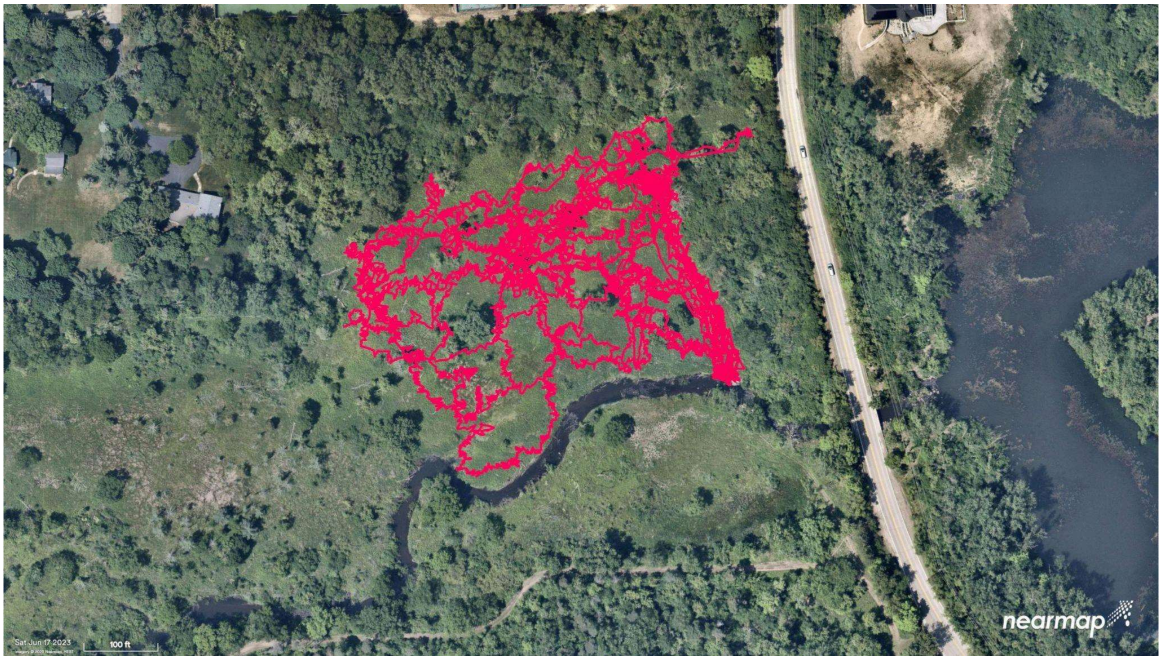

Figure 17. Compiled GPS tracking information for the six snake surveys done in Site 3 (in red). Image retrieved from nearmap.

Other fauna recorded during 2022-2023 Massasauga surveys included the following: 30 deer, 12 garter snakes, 9 small mammals, 2 brown snakes and 2 wild turkeys (Table 4) (Figures 14, 15). In Site 1, I recorded 9 garter snakes, 3 rabbits, 1 squirrel, 3 rodents, 1 groundhog, 1 deer, and 2 small mammals. In Site 2, I recorded 22 deers, 1 brown snake, and 1 wild turkey. In Site 3, I identified 1 snake, 5 deers, 1 rabbit, 1 wild turkey, 2 garter snakes, and 1 brown snake.

Figure 18: Garter snakes found on the study sites during the 2022 and 2023 study period.

Figure 19. Brown snakes found on the study sites during the 2022 and 2023 study.

Figure 20: Hibernacula found on the study sites during the study between 2022 and 2023.

Figure 21: Cattail patch found on Site 2, taken during the study between 2022 and 2023.

Discussion

Vegetation Cover

The total percent cover of invasive species among sites as estimated in 2023 ranging from 81.61% to 63.14%, decreased with the time elapsed since the restoration efforts began, nevertheless the decline seemed to plateau after some years. For Site 1, after 17 years in the process of restoration, 63.14% of the total woody vegetation cover was invasive species. For Site 2, after 10 years in the process of restoration (Matthaei Botanical Gardens, 2018), the total woody vegetation cover of invasive species was only slightly higher at 65.71%. For Site 3, after 2 years from the major clearing in 2021, 81.61% of the total woody vegetation cover was invasive species, which was notably higher than in the other sites.

In all three sites, invasive plant species (common and glossy buckthorn; Morrow's, Amur, and Tartarian honeysuckle; autumn olive; multiflora rose; and wild and border privet) were concentrated in the ground layer, while most commonly found native woody species were concentrated in the canopy layer (box elder, green ash, eastern black walnut, eastern red cedar, tamarack, black cherry, basswood, american elm, and riverbank grape). This is not surprising as all sites started their restoration process with manual removal of mature invasive woody plants (Steve Parrish and Michael Kost, MBGNA, personal communication). This means that the majority of the invasive woody plants and thistle observed at the sites were young shoots of reduced height. The two buckthorn species were the most prolific invasives. Given that buckthorns have high fecundity, bird-dispersed fruit, high germination rates, and seedling success in disturbed conditions

(Knight et. al, 2007), it has an advantage on the freshly uncovered ground layer. Canada thistle, another one of the most prolific invasive plant species found, has the ability to successfully reproduce vegetatively underground through an expanding root system, which creates expansive colonies (Moore 1975).

The shrub layer makeup differed in each site, ranging between 10.44% and 21.85% of the woody plant cover, which positively relates to the duration of restoration efforts in each site. This means that the longer one of the sites was in the process of restoration, the least shrub total coverage this site had. Buckthorn, which was the most common of the invasive species present in the sites, has a tendency to form dense stands that outcompete native plants and dominate habitats (Mascaro et al. 2007); this means that when left unchecked it turns the habitat into a homogeneous thicket of bushes.

It is imperative to ensure that vegetation surveys provide relevant information to monitor restoration efforts. tVegetation results of the percent cover of the ground, shrub and canopy layers, both native and invasive species, from each of the three 100-m transects by site , show differences between transects (Figure 10). . r. The disparity among cover of ground, shrub, and canopy layers among ransects within r sites suggests that given the habitat heterogeneity more than three transects might be required for surveys to be representative of the vegetation and assess restoration results. Moreover, this complexity is magnified when considering the distinction between invasive and native woody plant species (Figures 12 and 13). Therefore, a comprehensive understanding of vegetation cover necessitates accounting for these nuanced differences within sites.and requires further research on refining survey protocols.

Snake Presence

Survey results indicate that the site with the highest snake presence had a feature which was lacking in the other two sites. Specifically, the presence of an upland area characterized by dense grass or sedge cover was notably associated with a larger Massasauga population. This suggests that such habitat conditions play a crucial role in supporting the local Massasauga population. Therefore, the presence of upland areas with dense grass or sedge cover may be considered habitat suitable and favorable for Massasauga populations. More research is needed in this subject to fully understand what the driving factor is for this Massasauga population's habitat preference, as well as its growth.

Ideal Massasauga habitat contains a mix of open spaces and cover, which is not possible if the area is thickly covered by shrubs. Hence I believe that the effective removal and subsequent control of invasive shrubs is one of the leading causes for a higher presence of Massasauga rattlesnakes in the sites with less coverage by shrubs. Nevertheless, while Massasaugas benefit from having a heterogeneous habitat, which includes cover in the form of tall grass patches or bushes, having bushes is not necessarily an indication of a poor Massasauga habitat. Presence of native shrub patches could therefore be beneficial for the Massasauga habitat, which begs the question if it is enough to remove invasive shrubs, or would it be beneficial to encourage native shrub species to take over this niche.

The three sites selected in this study have the characteristics required for Massasauga habitat, but Site 1 with the longest history of restoration efforts had the highest number of snakes recorded. Habitat characteristics include a body of water, wet lowlands, dry higher ground, as well as a vegetation assembly dominated by plants in the ground layer, with scattered shrubs and trees. However, it is unclear if the restoration efforts are the main driver of population numbers due to the lack of demographic data on this population before the 2010 Anton et al. studies (2010, 2011, 2014, 2015 & 2019). Thus, it is hard to determine whether Site 1 had a higher Massasauga presence due to the duration and relative success of the restoration process, or if there was already a sizable population before restoration started. But, it can be said that the continued presence of Massasaugas on the site suggests that the restoration efforts are being successful.

There seems to be a negative correlation between invasive woody plant species cover and the number of Massasauga found at each site. However, based on the results, this relationship is not proportional. In Site 1, which had 63.14% of invasive woody plant cover, the snake count was 15. In Site 2, with 65.71% invasive woody plant cover, the snake count was 3, which is significantly less than in Site 1. However, in Site 3, the invasive woody plant cover was 81.61% and the snake count was just 2; this site had the least snakes and the most invasive woody plant cover. Also, the percent of shrub cover negatively correlated to the number of snakes found in the surveys.

One interesting finding of this study is that the site with the most snake sightings is also the one with the most human activity; Site 1 is bordered by a busy road on the western edge, a house and the main parking lot of the MBG to the south and south-east, and a busy trail on the east. This finding was also noted by previous reports by Anton et al. (2010, 2011, 2014, 2015 & 2019), which suggests that it was due to the presence of an upland with dense Kentucky bluegrass coverage. This is in contrast to the findings of Parent and Weatherhead (2000), which state that as disturbance increased, gravid females were less visible to observers, but the visibility of non-gravid females and males did not change. This contrasting information suggests that in MBG favorable habitat conditions out-balanced the increased disturbance, which would have caused a decrease in snake presence in the area.

Several of the Massasauga sightings in Site 1, which had the most sightings, occurred in or around a Kentucky bluegrass patch growing the dry upland of this site. However, Kentucky bluegrass (*Poa pratensis*) is not a native grass, as it comes from Eurasia, which suggests that perhaps restoring habitat function is more important for Massasaugas than restoring native habitat composition. The patches of Kentucky bluegrass offer an ideal habitat for the Massasauga even though it is not native to Michigan. Furthermore, It would be beneficial, to understand the implications of leaving areas covered by non-native grass species as-is, rather than remove for restoration purposes as they seem to well perform ecosystem functions for Massasaugas. Future studies could study the effects that they could have on the ecosystem as a whole or on other native species that live in the area.

It is important to consider the role of other fauna recorded during these surveys on the presence of Massasaugas. These include deer, wild turkeys, garter snakes (Figure 18), brown snakes (Figure 19), unidentified snakes, rabbits, squirrels, groundhogs, and small rodents. Several of these species including small mammals and snakes are common Massasauga prey. Massasauga populations thrive in locations where there is an abundance of prey. Thus, it is not surprising that Site 1, which had the most Massasauga sightings, was also the site with the most small mammal and other snake sightings. I expect that the number of Massasauga prey, including mammals and reptiles, will increase in Site 2 and 3 as time goes by and the restoration process matures. On the other hand, it is important to mention that deer are known to harm and kill Massasaugas. During the snake surveys, I saw a total of 30 deer, out of which the vast majority were located in Site 3 and the adjacent Site 2; I found no deer in Site 1 during the surveys. This suggests that a big deer population in the northern section of the MBG could be keeping the Massasauga population from expanding. However, more research is needed to evaluate the effect of deer on the MBG Massasauga population .

Massasauga sightings, which varied from 15 to 2 among the three sites, were somehow proportional to the time since the restoration efforts began in each site, however lack of data prevent evaluating the effect of restoration efforts on habitat and the snake population. In Site 1, which has been in the process of restoration for 17 years, as of 2023, thus the longest period of time, 15 snakes were sighted. In Site 2, which has been in the process of restoration for ten years, as of 2023, two snakes were recorded. Meanwhile in Site 3, which was cleared in 2021, only two snakes were sighted. However, it is not possible to attribute the number of Massasaugas found in each site to the length of restoration due to lack of supporting data; A longer, more thorough study would be required to support evaluating restoration efforts. Also, the number of snakes found in Site 1 throughout the Anton et al. studies (2010, 2011, 2014, 2015 & 2019), has remained relatively stable, which does not suggest an increase in the population of Massasaugas in this section of the gardens.

Alternative methods such as plank placement and mark and recapture have been employed alongside meander snake surveys at MBG to assess snake populations; however, challenges related to the material and utilization of planks suggest the need for reconsideration of their usage. Planks are used because, as they help snakes with thermal regulation and provide a place for cover, they make an ideal place for aggregating and finding snakes. However, the material used for the planks (metal) installed at MBG is not ideal, as it can overheat easily and potentially harm the snakes. It is recommended that planks be made of wood with lower thermal conductivity than metal, but the reason for using metal is that it is more durable and therefore requires less maintenance. It is not surprising that no surveys conducted at MBG including my own have found Massasaugas under the planks suggesting they do not use these, or use them on rare occasions. Taking into account that the maintenance requirements have precluded setting the appropriate type of planks and the lack of usage of the metal planks by the Massasaugas, removing the planks could be appropriate.

Another observation recorded during the Massasauga survey that can be useful as an indicator of Massasauga abundance is the identification of potential hibernacula. I was able to find potential hibernacula in all sites (Figure 20), however, Site 1 had the highest number. As the number of potential hibernacula was positively correlated with Massasauga abundance, monitoring the number of active hibernacula might serve as an additional abundance indicator. A recommendation from this study is to map and maintain a record of active hibernacula to complement estimates from sighting and mark and recapture surveys.

Even though the nature of meander surveys is to walk in a random fashion through an area to cover the surveyed space equally, the varied topography of some areas precluded from following this protocol. It can be noted that the path of snake surveys in Site 1 included a section in the central areas with straight vertical lines and more open spaces when compared to the rest of the site (Figure 15). This area is a wetland that proved to be harder to traverse than the rest of the site, as it was saturated with water during all the surveys. Massasaugas do not tend to spend a significant amount of time in water saturated areas, therefore this section was not prioritized during the surveys. Site 2 also contained a water saturated area. In this case however, this wetland was heavily dominated by cattails; there were no woody plants in this section, and other herbaceous species were only present in small quantities. These cattails were 5 feet tall or more, and occurred as a large dense patch (Figure 21). Prioritizing invasive woody plants and thistle in vegetation surveys resulted in omitting the report of herbaceous plants, such as cattails. With the lack of sunlight reaching the ground, as well as the presence of water, it is unlikely that this specific area is frequented by Massasaugas; this section was not prioritized during the surveys. Site 3 did not contain sections with high water saturation.

Another noteworthy feature of Site 2 is a snake exclusion fence located in the northern border of the site that indicates that the Massasauga population extends beyond MBG. This border overlaps with the northern edge of the MBG, where it meets a private residential property. In this edge, there is a metal fence put in place to exclude Massasaugas from that private residential property (Figure 22). There has been human-wildlife conflict in this area, as neighbors considered the snake as a pest (Michael Kost, MBG, Personal communication 2021). This is an indirect indicator of Massasauga presence in and beyond the site.

There are areas at MBG not covered by this study and previous surveys where it is likely that Massasaugas can be found that would be beneficial to include in future monitoring. South of Site 3, on the other side of Fleming creek, there is a section with significant sedge coverage reminiscent of the section on Site 1 with Kentucky bluegrass. This area was not part of the study due to inaccessibility as well as it not being a part of the shrub removal in Site 3. However, given the findings in Site 1, this area has the potential of being an ideal habitat for Massasauga. For future studies, I think this area should be included due to its composition as well as proximity to the other sites.

It is important to note that there were several shortcomings which might have caused an underestimate or overestimate of the snake presence in this study. First, effort was limited as the surveys were performed by a single observer during the two field seasons in 2022 and 2023. Second, the observer training was limited. Surveys by a single observer can result in snakes being counted more than once as the observer moves through the survey area. Further, inexperienced observers have difficulties in finding snakes resulting in survey underestimates. According to a study by Lock & Griffith (2022), which had two groups of inexperienced students and a single experienced observer conduct standardized snake surveys, "a single experienced observer detected more snakes than both inexperienced groups." All of this highlights the importance of training surveyors and securing funding, to obtain the necessary expertise to minimize errors and observer bias. Another limitation that is important to note is accessibility. Massasaugas spend part of their time hidden under dense vegetation, such as shrubs and tall grasses, which makes them difficult to find. It is possible that during the surveys, snakes could have been in hard to access areas with dense vegetation, which in turn can cause underestimating the number of snakes present in the area.Last, Second, meander surveys might not be optimal, as one of the best methods to estimate wildlife abundance is mark and recapture surveys (Willson et al. 2011). Nevertheless, due to the conservation status change of the snake in 2016, mark and recapture surveys were not an option due to legal restrictions.

Figure 22: Fence found on the northern edge of Site 2, during the study.

Conclusions & Recommendations

Effective invasive species management and habitat restoration are crucial for supporting Massasauga populations and maintaining the biodiversity in a given area. Continued monitoring and adaptive management strategies are essential for long-term success of both restoration of the habitat and the conservation of Massasauga rattlesnakes. Also, it is imperative to establish restoration goals and a habitat monitoring plan in order to assess the success of restoration.

Snake Presence

The extensive process of restoration being applied to natural areas in the Matthaei Botanical Gardens, seems to be improving habitat suitable for the Massasauga rattlesnake. This has been evidenced by the continued presence of the snake in different sites, correlating to restoration processes. The use of different techniques, including brush hogs, cuts, glyphosate treatments, prescribed burns and more, has proven effective in slowing the spread of invasive woody species, as well as in decreasing their coverage in the landscape, especially in the shrub and canopy layers. The overall lack of mature invasive shrubs has especially helped with the creation of ideal Massasauga habitat, as well as helped with the proliferation of native plants in the ground, shrub, and canopy layers.

Multiple well trained observers are necessary to obtain a reliable Massasauga count. Data obtained by a single surveyor in this study, as well as lack of observer training, had the potential for under- or overestimation on snake presence. Underestimation can be especially true for harder to access areas such as dense vegetation patches. This underscores the need for more comprehensive monitoring approaches.

In terms of assessing the Massasauga population, I recommend monitoring and maintaining a record of known active hibernacula to get a better understanding of the habitat preferences and the dynamics of the local population. I also recommend supplementing meander surveys with additional methods such as mark and recapture surveys, if legally permissible, to collect more accurate data regarding snake abundance and population size. A comprehensive coverage of the study areas, as well as expanding the surveys including previously unsurveyed sections with potential Massasauga presence should be ensured. Furthermore, I recommend mapping and maintaining a record of active hibernacula to complement estimates from sightings and mark and recapture surveys. Regarding planks, we recommend the replacement of metal planks with wooden ones to provide the snakes with a suitable cover without risking overheating. If this is not possible for the MBG, we recommend considering the removal of the planks if they are not being utilized by the target species, and the maintenance requirements outweigh their potential benefits.

Vegetation Cover

Despite ongoing restoration efforts invasive woody plant species have a significant presence in all study sites, particularly in the ground layer, negatively impacting the habitat quality. The high concentration of these species on the ground layer spotlights the importance of more targeted removal efforts to restore Massasauga habitat. The site with the lowest total cover of invasive species was Site 1, which has been the longest under restoration efforts. However, the relatively stable snake abundance indices throughout the years, indicates that the restoration is only keeping the population in stable conditions. It seems that the biggest contributing factor to Massasauga presence is habitat characteristics, rather than the presence of specific plant species. This is supported by the results found in Site 1, which had a mix of open spaces and cover, with Kentucky bluegrass patches providing suitable habitat despite being a non-native species.

Based on results from this study, I consider that the MBG has done a good job at removing mature invasive woody plant species, however there are few refinements that would be beneficial. I recommend implementing strategies that target the removal and control of invasive woody plant species focusing on the ground layer, where they were the most prevalent throughout this study. Another recommendation is to explore options to encourage native shrub species to occupy the niche that is being exploited by the target invasive species. From the data we know that most of the canopy layer was native woody plant species, which indicate this section is going in the right direction, however I would still encourage supporting native plants to develop into mature canopy dwellers to maintain a healthy heterogeneous habitat. I recommend continuing and encouraging restoration efforts aimed at creating a heterogeneous habitat with a mix of cover and open spaces that benefits the Massasauga rattlesnake.

In Site 1, both the duration and consistency of restoration efforts, alongside specific habitat characteristics, significantly influenced the Massasauga population. Consequently, I advocate for the replication of these practices and habitat features not only in the other two study sites but also in additional sites not covered by this study. Site 1 has a history of prescribed burns, which is documented to dramatically increase rattlesnake occurrence (Dovčiak et al. 2013); Site 3 has been the site with the least controlled burns (Matthaei-Nichols Prescribed Burns Map). Thus, the use of controlled fires in sites, such as Site 3, might be an appropriate approach in order to more effectively restore them into a Massasauga habitat.

Based on observations during the surveys, areas outside the study sites seem to have similar characteristics than the area with the most snakes found in Site 1; this site had an upland with dense grass cover. Therefore, I recommend expanding survey areas beyond the immediate boundaries of the Matthaei Botanical Gardens. Specifically, surveys could be conducted along Fleming Creek east of Cherry Hill Road, extending beyond the eastern border of Site 3. Similarly, exploration along Kirk's Brook and Parker Brook, west of Sites 2 and 1 respectively, beyond Dixboro Road, could provide valuable insights into snake populations and habitat dynamics beyond the property. By extending survey efforts to these adjacent areas, a more comprehensive understanding of Massasauga rattlesnake distribution and habitat preferences can be obtained, aiding in more effective conservation and management strategies.

Including more areas with tall grasses in future studies would provide valuable information on Massasauga demographics as these were the areas with the most sightings during this study. Some sections of the gardens include a larger coverage of tall grasses, both native and non-native, and given the results from this study, it is expected that more Massasauga activity could be found in these areas. A further recommendation is investigating the effects of non-native grasses on ecosystem function as well as Massasauga habitat suitability, and if replacing them with native grass species would be appropriate.

Moving forward, I recommend the MBG to continue to apply diverse techniques to remove invasive woody plant species to restore habitat for the resident Massasauga population. Priority should be given to areas with known presence of the Massasauga rattlesnake. Areas with characteristics to become habitat for this species should also be given priority, as these could become new grounds for the population to expand.

Management Plan

An overall recommendation from this study is to create and implement a comprehensive monitoring plan for the population of Massasauga rattlesnakes as well as its habitat. Based on our findings, and the Environmental Assessment Division Argonne National Laboratory's (2004) template, such a plan should include the following:

1. Design a monitoring plan
   a. Establish vegetation restoration goals
   b. Identify data needs
      i. Identify data necessary to evaluate outcome of the restoration process
      ii. Determine previous site conditions and reference sites
         1. E.g.: Use past data from previous studies
   c. Select sites
      i. Prioritize sites that contain a heterogeneous habitat with a mix of cover and open spaces
         1. Expand to include areas that resemble previous sites with the largest know Massasauga communities
            a. E.g.: Areas with dry uplands with tall grass cover
   d. Determine vegetation and Massasauga data collection methods and data analysis
      i. Data collection methods
         1. Vegetation surveys
            a. Determine the number, length and location of distinct parallel transects
            b. Record all plant species found within the transects
               i. Categorize height layer: ground, shrub or canopy cover
               ii. Categorize whether it is a native, invasive, or non-invasive exotic species
               iii. Use topography to inform transect selection

                1. Include uplands and lowlands
        2. Snake surveys
            a. Prioritize enlisting multiple experienced surveyors to under and over estimation
                i. If not possible, extensively train surveyors in Massasauga identification
            b. Prioritize mark and recapture surveys
                i. If not possible, use meander surveys
            c. Take notes of any wildlife observed
            d. Include hibernacula
                i. Determine whether hibernaculum or crayfish burrow
        3. Analysis methods
            a. Vegetation surveys
                i. Determine if distribution of species is random, uniform, or clumped
                ii. Calculate dispersion and plant species composition
                    1. E.g.: Subsample data and determine 10 "plots" in each transect by selecting a random 1-m section of every 10 meters within the 100m total.
        4. Determine uncertainty and error
    e. Establish restoration schedule based on existing data
    f. Determine data quality objectives
    g. Determine decision rules
        i. Determine how findings would inform decision making
2. Data collection and Results
    a. Collect and analyze data
    b. Assess and optimize the plan
    c. Evaluate analytical results
        i. How does the data relate to the project objectives?
        ii. Does the data adhere to data quality objectives?
        iii. Does the data support the decision rules?
    d. Address if data deviates from the expected
        i. Is it natural variability?
        ii. Evaluate the restoration project
        iii. Evaluate the monitoring plan
3. Management decisions
    a. General management decisions
        i. Is the restoration project:
            1. successful?
            2. trending towards success?
            3. unsuccessful?
    b. Decision making

i. Implementing annual monitoring reports

Conclusion

In conclusion, the restoration efforts undertaken at Matthaei Botanical Gardens have shown promising results in improving habitat conditions for the Massasauga rattlesnake. The implementation of various techniques, including brush hogs, prescribed burns, and glyphosate treatments, has effectively slowed the spread of invasive woody species and fostered the proliferation of native plants. However, despite these efforts, invasive species still pose a significant threat to habitat quality, particularly in the ground layer. Furthermore, while Site 1 has demonstrated success in maintaining stable snake populations, there is a need for more targeted invasive species removal efforts to further enhance habitat suitability. Monitoring efforts for Massasauga must be expanded, employing multiple trained observers and diverse survey methods, to ensure accurate population assessments and inform adaptive management strategies. Moving forward, it is crucial to continue prioritizing invasive species management, habitat restoration, and comprehensive monitoring of both vegetation cover and Massasauga population to support the long-term conservation of the Massasauga rattlesnake and its habitat. Additionally, the establishment of a comprehensive habitat and Massasauga monitoring plan, as outlined in this study, will be instrumental in guiding future management decisions and evaluating restoration success.

Bibliography

1. Anton, T., & Mauger, D. (2015). The Eastern Massasauga (Sistrurus catenatus) at Matthaei Botanical Gardens: 2015 Report. The Ecological Consulting Group, LLC Winnetka, Illinois 60093
2. Anton, T., Casper, G.S., Lee, Y.M., Mauger, D. (2010). An Assessment of the Eastern Massasauga, Sistrurus c. catenatus, at the Matthaei Botanical Gardens: Preliminary Survey Results and General Management Recommendations. The Ecological Consulting Group, LLC Winnetka, Illinois 60093
3. Anton, T., Casper, G.S., Lee, Y.M., Mauger, D. (2011). Matthaei Botanical Gardens Eastern Massasauga Study: 2011 Survey Report. The Ecological Consulting Group, LLC Winnetka, Illinois 60093
4. Barbour, M.G., Burk, J.H., & Pitts, W. D. (1980). Terrestrial Plant Ecology. Benjamin/Cummings Publishing Company, Menlo Park, CA.
5. Carignan, V., & Villard, M.-A. (2002). Selecting indicator species to monitor ecological integrity: A Review. Environmental Monitoring and Assessment. Retrieved October 15, 2021, from https://link.springer.com/article/10.1023/A:1016136723584#citeas.
6. Casper, G.S., T.G. Anton, R.W. Hay, A.T. Holycross, R.S. King, B.A. Kingsbury, D. Mauger, C. Parent, C.A. Phillips, A. Resetar, & R.A. Seigel. (2001). Recommended standard survey protocol for the eastern Massasauga, Sistrurus catenatus catenatus. U.S. Fish & Wildlife Service Region 3.
7. Cole, J. (2014). The effect of urban sprawl & suburbanization on Eastern Massasauga rattlesnake populations in northeastern Illinois. DSpace Home.

Retrieved March 1, 2022, from
https://dspace.carthage.edu/handle/20.500.13007/474

8. Crancer, C.J. (2011). RESTORATION AND VEGETATION RESPONSE IN KIRK FEN, A PRAIRIE FEN IN ANN ARBOR MICHIGAN (dissertation).
9. Dovčiak, M., Osborne, P., Patrick, D., & Gibbs, J. (2013). Conservation potential of prescribed fire for maintaining habitats and populations of an endangered rattlesnake sistrurus C. catenatus. Endangered Species Research, 22(1), 51–60. https://doi.org/10.3354/esr00529
10. Environmental Assessment Division Argonne National Laboratory (2004). GUIDANCE FOR HABITAT RESTORATION MONITORING: FRAMEWORK FOR MONITORING PLAN DEVELOPMENT AND IMPLEMENTATION. https://exwc.navfac.navy.mil/Portals/88/Documents/EXWC/Restoration/er_pdfs/gpr/navfacesc-ev-ug-2061-env-monitorhabitat-200408.pdf?ver=mMj78GmzcQx8tPLsyERwZg==&timestamp=1651709831441
11. Ernst, C.H. & Barbour, R.W. (1989). Snakes of Eastern North America. George Mason University Press, Fairfax, Virginia. 282 pp.
12. Frost, D.R., Hammerson, G.A. & Santos-Barrera, G. (2007). Sistrurus catenatus. The IUCN Red List of Threatened Species 2007: e.T64346A12772707. Retrieved October 15, 2021, from https://dx.doi.org/10.2305/IUCN.UK.2007.RLTS.T64346A12772707.en.
13. Hammerson, G.A. (1999). Amphibians and reptiles in Colorado. Second edition. University Press of Colorado, Boulder, Colorado.

14. Hermans, K.D., Masters, L.A., Penskar, M.R., Resnizek, A.A., Wilhelm, G.S., Brodovich, W.W., & Gardener, K.P. (2001). FLORISTIC QUALITY ASSESSMENT WITH WETLAND CATEGORIES AND EXAMPLES OF COMPUTER APPLICATIONS FOR THE STATE OF MICHIGAN REVISED, 2ND EDITION – OCTOBER 2001. https://www2.dnr.state.mi.us/publications/pdfs/huntingwildlifehabitat/fqa.pdf

15. Invasive Shrub Management Web Map. MBGNA. (2018). https://mbgna-umich.hub.arcgis.com/maps/umich::invasive-shrub-management-web-map/about

16. Joint Nature & Conservation Committee. (2010). Handbook for Phase 1 habitat survey: A technique for environmental audit. Retrieved October 15, 2021, from https://data.jncc.gov.uk/data/9578d07b-e018-4c66-9c1b-47110f14df2a/Handbook-Phase1-HabitatSurvey-Revised-2016.pdf.

17. Jones, P.C., King, R.B., Bailey, R.L., Bieser, N.D., Bissell, K., Campa, H., Crabill, T., Cross, M.D., Degregorio, B.A., Dreslik, M.J., Durbian, F.E., Harvey, D.S., Hecht, S.E., Jellen, B.C., Johnson, G., Kingsbury, B.A., Kowalski, M.J., Lee, J., Manning, J.V., … Yagi, A. (2012). Range-wide analysis of eastern Massasauga survivorship. The Journal of Wildlife Management, 76(8), 1576–1586. https://doi.org/10.1002/jwmg.418

18. Knight, K.S, Kurylo, J.S, Endress, A.G, Stewart, J. Ryan, & Reich, P.B. (2007). Ecology and ecosystem impacts of common buckthorn (Rhamnus cathartica): a review. Biological invasions, 9, 925-937. doi: 10.1007/s10530-007-9091-3

19. Lock, M.M.G., & Griffiths, R.A. (2022). PDF 02.detectability of reptiles in standardised surveys: A test using grass snake natrix helvetica models. The Herpetological Journal, 32(4), 183–189. https://doi.org/10.33256/32.4.183189

20. Marshall, J.C., Manning, J.V., & Kingsbury, B.A. (2006). Movement and macrohabitat selection of the eastern Massasauga in a fen habitat. Herpetologica, 62(2), 141–150. https://doi.org/10.1655/04-12.1

21. Mascaro, J., & Schnitzer, S.A. (2007). Rhamnus cathartica L. (common buckthorn) as an ecosystem dominant in southern Wisconsin forests. Northeastern Naturalist, 14(3), 387–402. https://doi.org/10.1656/1092-6194(2007)14[387:rclcba]2.0.co;2

22. MBGNA. (n.d.). *Eastern Massasauga Rattlesnake*. Eastern Massasauga Rattlesnake | Matthaei Botanical Gardens & Nichols Arboretum. https://mbgna.umich.edu/eastern-Massasauga-rattlesnake

23. Michigan Natural Features Inventory. Sistrurus catenatus (Eastern Massasauga) - Michigan Natural Features Inventory. (n.d.). https://mnfi.anr.msu.edu/species/description/11519/sistrurus-catenatus

24. Moore, J.A., & Gillingham, J.C. (2006). Spatial ecology and multi-scale habitat selection by a threatened rattlesnake: The Eastern Massasauga (sistrurus catenatus catenatus). BioOne Complete. Retrieved February 15, 2022, from https://doi.org/10.1643/0045-8511(2006)6[742:SEAMHS]2.0.CO;2

25. Moore, R.J. (1975). The Biology of Canadian Weeds.: 13. cirsium arvense (L.) SCOP. Canadian Journal of Plant Science, 55(4), 1033–1048. https://doi.org/10.4141/cjps75-163

26. Parent, C., & Weatherhead, P.J. (2000). Behavioral and life history responses of eastern Massasauga rattlesnakes (sistrurus catenatus catenatus) to human disturbance. Oecologia, 125(2), 170–178. https://doi.org/10.1007/s004420000442

27. Seigel, R.A. (1986). Ecology and conservation of an endangered rattlesnake, Sistrurus catenatus, in Missouri. Biological Conservation 35: 333-346.

28. Shaffer, S.A. (2018). Eastern Massasauga Rattlesnake Population and Habitat Ecology in Southern Michigan (Order No. 10932019). Available from ProQuest Dissertations & Theses Global. (2100026242). https://proxy.lib.umich.edu/login?url=https://www.proquest.com/dissertations-theses/eastern-Massasauga-rattlesnake-population-habitat/docview/2100026242/se-2

29. Szymanski, J. (1998). Status Assessment for Eastern Massasauga (Sistrurus c. catenatus). U.S. Fish & Wildlife Service. Retrieved October 15, 2021, from https://training.fws.gov/Pubs3/statusass/easternMassasauga.pdf.

30. Tennant, A. (1984). The Snakes of Texas. Texas Monthly Press, Austin, Texas. 561 pp.

31. U.S. Fish and Wildlife Service. (2019). Eastern Massasauga Rattlesnake Sistrurus catenatus Fact Sheet. Official Web page of the U S Fish and Wildlife Service. Retrieved October 15, 2021, from https://www.fws.gov/midwest/endangered/reptiles/eama/eama-fct-sht.html.

32. U.S. Fish and Wildlife Service. (2019). Eastern Massasauga Rattlesnake. U.S. Fish and Wildlife Service Midwest Region Endangered Species. Retrieved October 15, 2021, from https://www.fws.gov/midwest/endangered/reptiles/eama/conserve.html.

33. U.S. Fish & Wildlife Service. (2022). *Species profile: Eastern Massasauga (rattlesnake) (Sistrurus catenatus)*. ECOS. https://ecos.fws.gov/ecp/species/2202

34. Willson, J.D., Winne, C.T., & Todd, B.D. (2011). Ecological and methodological factors affecting detectability and population estimation in elusive species. The Journal of Wildlife Management, 75(1), 36–45. https://doi.org/10.1002/jwmg.15