Baseline Snake Species Occupancy in Madison-Area Prairie Restorations
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Introduction

Reptiles are in peril around the world. Habitat destruction caused by urban and agricultural development has been identified as a leading cause for reptile population declines (Cox et al., 2022). Wisconsin is not known for its reptile diversity, but numerous reptile species are integral to the state's native ecosystems. Snakes are the most abundant reptile taxon in Wisconsin. Of the 21 different snake species found within state boundaries, nine are species of special conservation concern and 4 are endangered. According to DNR range maps, 16 species (Table 1) are present in Dane County (Snakes of Wisconsin, n.d).

Species (alphabetical by common name)	Status
Common Garter Snake	Common
Common Water Snake	Common
Dekay's Brown Snake	Common
Eastern Fox Snake	Common
Eastern Hog-nosed Snake	Common
Eastern Massasauga	Endangered
Gopher Snake	Special Concern
Gray Rat Snake	Special Concern
Lined Snake	Special Concern
Milk Snake	Common
North American Racer	Special Concern
Plains Garter Snake	Special Concern
Red-bellied Snake	Special Concern
Smooth Greensnake	Common
Timber Rattlesnake	Special Concern
Western Ribbonsnake	Endangered

Table 1: Snake species present in Dane County according to the Wisconsin DNR (https://dnr.wi.gov/topic/WildlifeHabitat/herps.asp?mode=table&group=Snakes).

However, the presence or absence of a species at any particular location within Wisconsin has more to do with the landscape of that area than with ecologically arbitrary county boundary lines (Cagle, 2008; Cassel et al., 2019). The Madison Area is primarily an urban landscape surrounded by rural farmland. Within the urban matrix of the city, parks and restored natural spaces can act as refugia, like islands, within a sea of pavement and human infrastructure. For wild species forced to live with us in urban environments these islands of native habitat can be crucial (Grimm et al., 2008; Collas et al., 2017). This is especially true for snakes (Kjoss and Litvaitis, 2001; Zappalorti and Mitchell, 2008). Roads, pollutants, pesticides, domestic and feral animals, and human hostility combine to make human cities a perilous place for snakes, contributing to high mortality and limited mobility (Andrews and Gibbons, 2005; Andrews et al., 2008; Snodgrass et al., 2008; Gangloff et al., 2017).

The high mortality and limited mobility of snakes in urban environments make county-scale snake species range maps of little use to the land manager of a city or suburban park. The presence of a particular snake - even at a nearby site – does not immediately confirm that the species is widespread throughout an urban area. Roads and other hazards may preclude the migration of that snake from one site to another. Snakes also require adequate hibernacula (dens) on site to survive the winter. When considering restored natural spaces in urban areas, this conundrum becomes more interesting. While plant species are deliberately reintroduced during the ecological restoration of a site, it is generally assumed that animal species will recolonize a restoration on their own. With snakes in urban and otherwise fragmented landscapes, this assumption may not hold (Gangloff et al., 2017; King and Vanek, 2020). This is important to recognize

because not only are restored natural spaces crucial for snake populations in a world that is continually urbanizing, but also because snakes are an abundant predator taxon in Wisconsin's native ecosystems, and thus a crucial component in any successful native restoration. Unfortunately, as far as I am aware, no effort to characterize the snake species diversity of Madison-area urban prairie restorations has yet been attempted - even in UW Madison's own Arboretum (the birthplace of modern restoration ecology) and Lakeshore Nature Preserve. The purpose of this study is to provide preliminary data about the snake communities that exist in specific Madison-area prairie restoration sites in order to inform both site management decisions and future studies into Madison snake populations.

Methods

Field Methods and Site Information

The use of artificial cover objects (ACOs) is a commonly used passive sampling method for snakes (Graeter et al., 2008). In May of 2021, I laid a total of 100 ACOs into 10 different arrays at eight different prairie restorations in the Madison area (Table 2). The number an arrangement of ACOs in each array was standardized (Figure 1) for inter-site comparison like in King and Vanek, (2020) (Richard King, pers comm). Prairie sites were selected based on their proximity to the city for ease of travel. Half of the ACOs were 0.75x33x48" untreated plywood boards as recommended by herpetologist Robert Hay (Robert Hay, pers. comm), and the other half were ~24x24" corrugated metal sheets provided by UW Madison researchers Elizabeth Hucker and Erin Crone. ACOs were deliberately placed away from forest and trail edges when possible, in locations that 1) received full afternoon sun (level or southwest facing) and 2) were primarily grass, or a grass-heavy mix, and 3) near water or wetland boundaries when possible as suggested by herpetologist Gary Casper (Gary Casper, pers. comm). The two largest prairie restoration sites (Pheasant Branch Conservancy and Prairie Ridge Conservation Park) also had distinct high and low elevation areas, so these sites each had "high" and "low" ACO arrays (Figure 1).

Site	Prairie Restoration Size	Prairie Restoration Age	% Impervious Land Cover Within 1km
Biocore Prairie (UW Lakeshore Nature Preserve)	12 acres	24 years	18%
Greene Prairie (UW Arboretum)	20 acres	79 years	23%
Lake Farm County Park (Dane County Parks)	11 acres	44 years	1%
Overlook Prairie (UW Arboretum)	2.5 acres	53 years	7%
Owen Conservation Park (Madison Parks)	30 acres	49 years	21%
Pheasant Branch Conservancy (Dane County Parks)	125 acres	27 years	14%
Prairie Ridge Conservation Park (Madison Parks)	48 acres	29 years	25%
Turville Point Conservation Park (Madison Parks)	4 acres	26 years	38%

Table 2: Prairie restoration characteristics. Impervious land cover determined using ArcGIS and the Wisconsin DNR's Community Tree Canopy Raster Dataset.

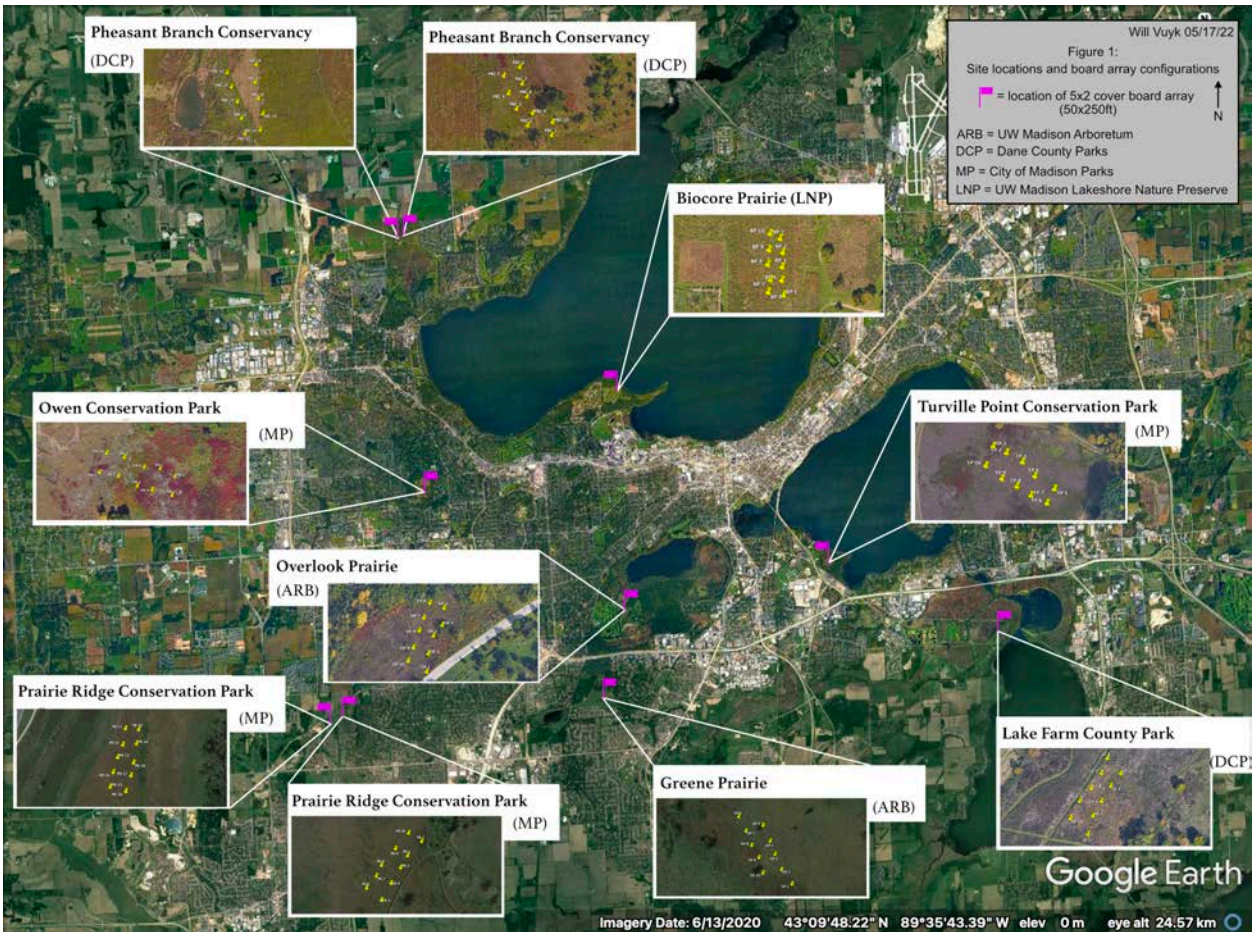

Figure 1: ACO arrays and locations in Madison. Arrays were 5x2 ACOs, alternating wood and metal. All arrays roughly 50x250ft, with ~50ft between each ACO. Pheasant Branch Conservancy and Prairie Ridge Conservation Park each had two arrays.

Data Collection

From June to October 2021, each board array was checked 10 times between 15:00 and 21:00 in accordance with protocols described in Casper, (2014). Air temperature, ground temperature, and qualitative scores of sky cover and wind speed were noted each visit. No data was collected when raining. All snakes encountered were captured, weighed and measured when possible. Captured snakes were not marked, and re-released at the site of capture, so the number of snakes found is assessed through the metric of "encounters" rather than "individuals." Only 3 recapture events were positively confirmed using unique scarring patterns.

Other Data

Snake sightings reported on iNaturalist and HerpMapper in the Madison area were used to inform experimental design and assess ACO effectiveness (iNaturalist; HerpMapper). Land cover data within 1km of each site was obtained from the Wisconsin DNR Community Tree Canopy Raster Dataset in ArcGIS (WI Community Tree Canopy).

Statistical Methods

The R package *unmarked* was used to generate snake species occupancy models using site and visit covariates and determine detection probabilities (Fiske and Chandler, 2011). Occupancy models were

ranked via QAIC using the R package *AICcmodavg* (Mazerolle, 2020). The R package *gratia* was used to fit non-linear GAM models to snake body condition index plots (Simpson, 2022).

Results

Encountered Snakes and Species Richness by Site

By the conclusion of data collection in October of 2021, I had documented 140 snake encounters, consisting of snakes from 5 different species across all prairie restorations (Table 3).

Species	Common Garter Snake	Dekay's Brown Snake	Plains Garter Snake	Milk Snake	Red-bellied Snake
# of encounters	77	50	10	2	1

Table 3: The number of snake encounters by species.

The common garter snake, Dekay's brown snake, milk snake, plains garter snake, and red-bellied snake were encountered in different frequencies and species combinations at different sites (Figure 2). My data aligned well with previously reported snake sightings at each location, and in some cases confirmed the existence of populations that had not yet been recognized (Table 4).

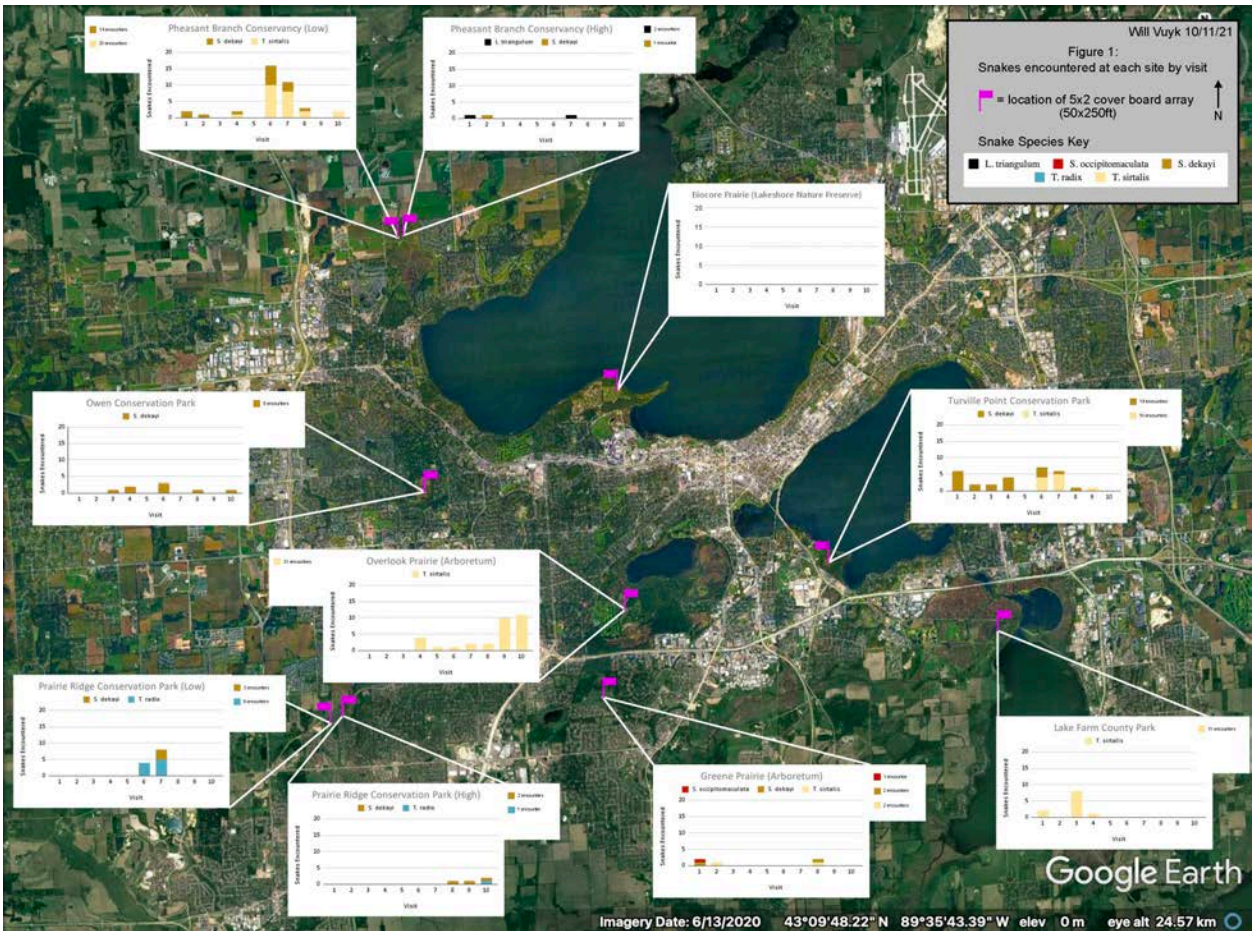

Figure 2: Snake encounters by visit for each site. Species are color coded according to key in upper right. L. triangulum = milk snake, S. occipitomaculata = red-bellied snake, S. dekayi = Dekay's brown snake, T. radix = plains garter snake, T. sirtalis = common garter snake. No snakes were encountered in the Biocore Prairie.

Site	Previously Reported Species (iNaturalist, HerpMapper)	My Cover Board Data	Anecdotal Reports
Biocore Prairie (UW Lakeshore Nature Preserve)	None	None	*In Prairie*: None *Elsewhere in Preserve*: Common Garter Snake* Eastern Fox Snake*
Greene and Overlook Prairies (UW Arboretum)	Common Garter Snake Dekay's Brown Snake Northern Water Snake Red-bellied Snake	Common Garter Snake Dekay's Brown Snake --- Red-bellied Snake	Blue Racer
Lake Farm County Park (Dane County Parks)	Common Garter Snake Dekay's Brown Snake	Common Garter Snake ---	None
Owen Conservation Park (Madison Parks)	None	Dekay's Brown Snake	None
Pheasant Branch Conservancy (Dane County Parks	Common Garter Snake Dekay's Brown Snake Milk Snake Red-bellied Snake	Common Garter Snake Dekay's Brown Snake Milk Snake ---	Garter Snake sp. Red-bellied Snake Milk Snake*
Prairie Ridge Conservation Park (Madison Parks)	None	Dekay's Brown Snake Plains Garter Snake	Garter Snake sp.
Turville Point Conservation Park (Madison Parks)	None	Dekay's Brown Snake Common Garter Snake	None

*Table 4: Comparison of snake species previously reported by the public, my data from the summer of 2021, and anecdotal reports I took note of from collaborators and passers by during the summer of 2021. * Means that the anecdotal report was confirmed with a photo.*

Snake Body Condition

Captured snakes were weighed and measured to assess age and health. Based upon size and species growth rates, the majority of snakes encountered were likely in their first or second year. The largest individual found, a 635mm, 160g common garter snake, could be 3-6 years old depending on health and sex (Ernst and Ernst, 2003). An uptick in hatchling (<3g) common garter snakes and Dekay's brown snakes was noted in August at Overlook Prairie, Pheasant Branch Conservancy and Turville Point Conservation Park, coinciding with the known hatching phenology of those species. One individual of adult length (390mm SVL) found at Pheasant Branch Conservancy was emaciated, had rough scabby scales, and extensive scabbing on the top of its head (Figure 3). Otherwise, snakes encountered appeared to be in good body condition with few injuries or scars.

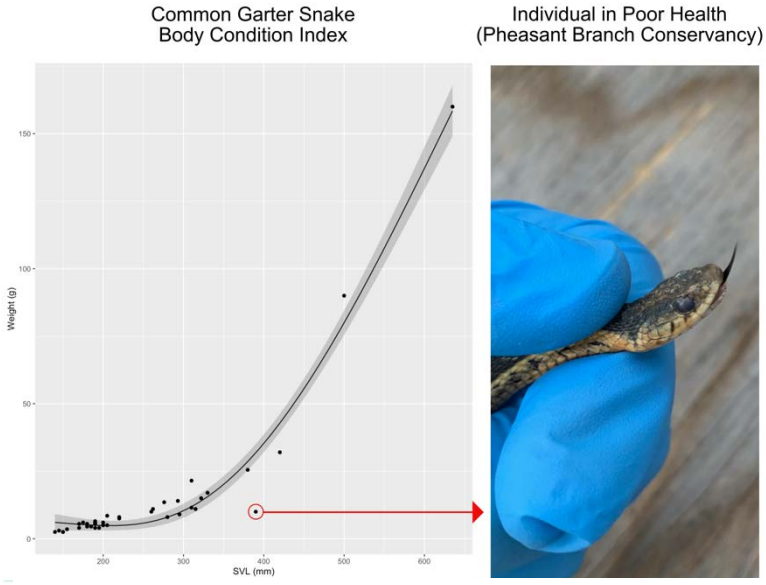

Figure 3: Captured common garter snake weight plotted over SVL (snout-vent length) and fitted using a non-linear GAM (R, gratia). A confidence interval of .975 around the fit line is marked in grey. An individual snake that was in noticeably poor health is circled in red, and an image of that individual is provided on the right.

Occupancy Models
Only common garter snakes and Dekay's brown snakes were encountered with sufficient frequency to run occupancy models. Simple models taking into account only whether a species was encountered or not at each site visit resulted in the following values for the Madison area:

Species	Occupancy probability (±SE)	Detection probability (±SE)
Common Garter Snake	0.503 ± 0.16	0.398 ± 0.07
Dekay's Brown Snake	0.709 ± 0.15	0.353 ± 0.06

Table 5: Occupancy and detection probabilities for the common garter snake and Dekay's brown snake from simple occupancy models without covariates (unmarked, R).

Models taking into account site covariates like restoration age, size, and land cover percentages with in 1km, as well as models with visit covariates like air temperature and cloud cover were all not significant for any species.

Discussion

Influence of Site and Landscape Characteristics on Snake Species Occupancy
The lack of statistical significance here is more reflective of study design than reality. It is not surprising as with only eight sites and one year of surveying, this study was severely underpowered for the sorts of analyses done by Cagle, (2008), Cassel et al., (2019) and King and Vanek, (2020). The influence of site and landscape scale characteristics in determining snake species occupancy in urban areas is a field in need of more research. Designing studies with an adequate number of sites for robust statistical analysis here is key.

More investigation into how snakes are able to navigate and migrate within urban areas is also a subject deserving more research. While it is well established that roads and other aspects of urban areas increase snake mortality and reduce mobility, snakes do nevertheless live and move within these spaces. There are several reports of snakes in Madison neighborhoods on iNaturalist, away from public natural spaces (iNaturalist). This shows that a suburban matrix between restoration islands is not completely impermeable to snakes despite heavy fragmentation and other hazards.

Species Presence and Absence
While the common garter snake, Dekay's brown snake, milk snake, plains garter snake, and red-bellied snake are all expected to exist in Dane County according to DNR range maps, the fact that no one species was found at all sites, and all five were not found at any one site, lends credence to the idea that snake species presence at the local scale is especially heterogenous in urban environments. I initially expected that both the common garter snake and Dekay's brown snake would be present at every site, as they are adaptable species more often found in urban areas (Ernst and Ernst, 2003; Gaul, Rufus W., 2008). The fact that I did not find them at certain sites is more likely due to insufficient survey effort than true absence. In the cases of Owen Conservation Park, Lake Farm County Park, and Pheasant Branch Conservancy I expect that common garter snakes, Dekay's brown snakes, and red-bellied snakes respectively would be discovered readily with continued surveys (Table 4). In other cases it may be more complicated. Not a single snake (of any species) has been seen at nearby Biocore Prairie since its initial restoration 24 years ago. Why snakes are rarely seen or reported at all in the Lakeshore Nature Preserve as a whole remains a mystery (Adam Gundlach, and Seth McGee, pers comm), especially given the presence of snakes at similar nearby sites in this study.

The plains garter snake, a species of special concern in Wisconsin, appears locally abundant at Prairie Ridge Conservation Park but – as far as we know now - that may be the only place it exists in the Madison area. Prairie Ridge (and the adjacent UW Arboretum Pasque Flower Hill site) has long

supported a “high lime” prairie ecosystem relatively unique to the Madison area. The steep slope of the site, thin soil, and limestone bedrock contribute to a dry microclimate and a vegetative community more similar to that found in arid western plains (Lang, 1976). The plains garter snake is primarily a western plains species, existing in Wisconsin on the eastern edge of its range (Ernst and Ernst, 2003). Very similar to the common garter snake in both appearance and diet, the two species have been found to occupy different thermal niches. The plains garter snake is more active in warmer, dryer conditions than its congenator (Hart, 1975). The specific success of the plains garter snake (and potential absence of the common garter snake) at Prairie Ridge is likely tied to the prairie’s dry “high lime” properties, making the site potentially a crucial refugia for this species of special concern.

Of species not found at all in this study, the Eastern fox snake is the only true surprise. Fox snakes have been reported multiple times at Cherokee Marsh in Madison, once at the Lakeshore Nature Preserve (iNaturalist; Adam Gundlach, pers comm). They have been found frequently in studies from more rural areas, it is likely that the larger size and greater mobility of the fox snake make it more susceptible to urban hazards like roads and human hostility (Andrews and Gibbons, 2008; Cagle, 2008; King and Vanek, 2020). The gopher snake, the largest species in Wisconsin, would also face these threats. Considered a species of special concern, one individual was reported on iNaturalist in a field just 5km west of Prairie Ridge in May 2021 (iNaturalist). The north American racer is another species of special concern in the state, and two Arboretum stewards told me they saw one in Greene Prairie. Whether it truly was a racer is unknown. The closest official reports of racers to Madison are around Arena, WI (iNaturalist). This study, which used artificial cover objects (ACOs) in prairies, was ill suited to detect two other snake species, the common water snake and the Eastern hog-nosed snake, because the water snake is an aquatic species and hog-nosed snakes do not often use ACOs (Graeter et al., 2008). Many water snakes have been reported in and around Madison’s lakes and wetlands, while a singular hog-nosed snake was reported east of I-90 from Madison Park’s Heritage Prairie. It was originally reported as a massasauga rattlesnake, indicating the continual threat of human violence against mis-identified harmless species (iNaturalist).

Ecological Significance

Knowledge of the snake populations that exist in urban parks and natural spaces is important for land managers because snakes are abundant meso-predators in intact native ecosystems. Generalist species like the common and plains garter snakes feed on a wide range of invertebrates, amphibians, mammals and sometimes birds. The Dekay’s brown snake and red-bellied snake specialize more on invertebrates, eating many species of slugs and worms. Larger species like the milk snake, Eastern fox snake, north American racer and gopher snake can take on larger prey, including amphibians, mammals, birds and other snakes (Mushinsky, 1987). Nearly all snakes are preyed upon by higher-order avian and mammalian predators, from bluebirds to hawks, shrews to coyotes (Ernst and Ernst, 2003).

Snakes are also unique when compared to other native predators in Wisconsin at similar trophic levels because they are exothermic (or cold-blooded). This means their metabolic rate is much lower than endothermic birds and mammals (Figure 4), and thus they convert much more of the energy they consume into biomass. Because of this, snakes have an important role in energy flow upwards through native ecosystems as more of the energy they consume is passed on to their predators. Snakes, being so energy efficient, can exist at high population densities. In one study, as many as 840 plains garter snakes were reported per hectare (Parker and Plummer, 1987). Snake biomass per hectare has been calculated to be greater than that of predatory mammals and birds, making them potentially the most massive vertebrate predator taxon in native grassland ecosystems (Iverson, 1982; Parker and Plummer, 1987).

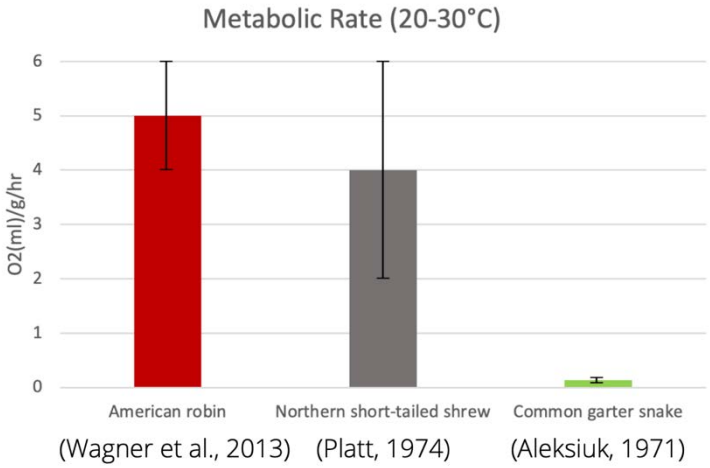

Figure 4: Reported oxygen consumption (proxy for metabolic rate) for three native Wisconsin meso-predators at ambient temperatures from 20-30°C. As reported by Aleksiuk (1971), the common garter snake requires less than 10% (0.08-0.2 ml O2/g/hr) of the oxygen required by the American robin (4-6 ml O2/g/hr) (Wagner et al., 2013) and northern short-tailed shrew (2-6 ml O2/g/hr) (Platt, 1974).

Understanding what snake species are present in a given prairie restoration is crucial to understanding the ecology of that ecosystem. This is especially relevant now as invasive *Amynthas* jumping worms are spreading across Madison. It was recently determined in the UW Arboretum that common garter snakes actively feed on these worms, with positively identified *Amynthas* remains making up 26.3% of garter snake stomach contents. Captured red-bellied snakes, while none of them had recently fed on jumping worms, were mainly full of nonnative slugs, indicating that small snakes can provide predation pressure on a wide range of nonnative invertebrates (Crone et al., 2022). While not investigated by Crone et al., (2022) it is likely that Dekay's brown snakes similarly feed on nonnative invertebrates, helping keep their populations in check. The added precarity of new invasive species in urban restorations makes the ecological function of snakes as abundant, adaptable predators even more important.

Conclusion

Despite their ecological importance, snakes are often overlooked in the field of restoration ecology. It is surprising how little is known about snake populations on the properties of Wisconsin's flagship research university and parks in its vicinity. With urban landscapes being so difficult for snakes to traverse, the assumption that snake species will recolonize urban prairie restorations spontaneously like birds and mammals is likely not to be true some of the time (Andrews and Gibbons, 2005; Gangloff et al., 2017; Cassel et al., 2019; King and Vanek, 2020). A prairie restoration without a robust snake community will not function the same as the native ecosystem it is trying to replicate, and thus snake populations should be of concern to restoration ecologists and land managers. The lack of snakes in Biocore Prairie is concerning in this respect, and worthy of further study.

The need for baseline snake population data in Madison and Wisconsin is pressing not only because of the ecological role snakes play, but also because snake populations are imperiled by urban development

and its accompanying roads, pollutants, pets, and misguided people. On top of that, snakes are in danger of contracting snake fungal disease (SFD), an emerging fungal disease that can be fatal (Lorch et al., 2016). SFD has been confirmed in Dane County, as well as other counties around the state (Snake Fungal Disease // Wisconsin DNR, n.d). The emaciated common garter snake found in this study (Figure 3), while not confirmed, showed many of the signs of SFD. The more data we can collect on snake populations in Wisconsin, the more we can understand the danger this fungal pathogen truly poses and the more we can do to protect snakes not just from SFD, but from the dangers of urbanization.

I hope not only that this study can provide a baseline for future investigations into Madison-area snake populations, but I also hope that it can bring more attention to snakes as integral components of our native Wisconsin ecosystems that deserve more attention than they currently get. Being especially susceptible to urban threats to wildlife, snakes could act as an urban umbrella taxon. If we can strive to make our urban spaces snake friendly, our urban ecosystems as a whole will benefit. The more we can learn about the snakes living in our midst, the more we can better coexist not only with them, but with all the other living beings that share the world with us.

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