Status of Karner Blue Butterfly on State Lands in Michigan

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We collectively acknowledge that Michigan State University occupies the ancestral, traditional, and contemporary Lands of the Anishinaabeg – Three Fires Confederacy of Ojibwe, Odawa, and Potawatomi peoples. In particular, the University resides on Land ceded in the 1819 Treaty of Saginaw. We recognize, support, and advocate for the sovereignty of Michigan's twelve federally recognized Indian nations, for historic Indigenous communities in Michigan, for Indigenous individuals and communities who live here now, and for those who were forcibly removed from their Homelands. By offering this Land Acknowledgement, we affirm Indigenous sovereignty and will work to hold Michigan State University more accountable to the needs of American Indian and Indigenous peoples.

Cover: A female Karner blue butterfly (*Plebejus samuelis*) observed during surveys at Muskegon State Game Area in July 2024. Photo: H. Weigold.

EXECUTIVE SUMMARY

The Michigan Department of Natural Resources (MDNR) funded the Michigan Natural Features Inventory (MNFI) to continue occupancy-based surveys for the Karner blue butterfly (*Plebejus samuelis;* Karner blue) at Allegan, Flat River, and Muskegon State Game Areas in 2024. Surveys conducted in 2024 were designed to address multiple goals: 1) determine occupancy status of habitat patches to inform regulatory and management decisions; 2) track population status to evaluate progress toward recovery plan goals; and 3) evaluate the response to management actions. In addition to surveys, MNFI was tasked with developing a long-term monitoring framework for Karner blue and its habitats and creating an ArcGIS web application to facilitate sharing of spatial and survey data between MDNR and MNFI. A draft monitoring framework was shared with MDNR along with this report and MNFI will work with MDNR staff to refine the framework based on their feedback prior to surveys planned for 2025. We also presented the ArcGIS web application to MDNR and made it available to land managers and decision makers.

We built upon our existing occupancy-based sample design and survey methods developed for Karner blue and implemented between 2015-2023 (Monfils and Cuthrell 2015, 2018, Monfils et al. 2021, Cole-Wick et al. 2023). The protocol consists of two visits to all sites during the second Karner blue flight during which we collected geospatial data for all Karner blue observations. In 2024 we added additional fields to collect data on nectar choice and ant mound abundance. These data can help inform land managers of nectar resource planting priorities and determine if active ant mounds may be a limiting factor for Karner blues.

In 2024 we completed 129 surveys at 66 sites and detected Karner blues at 30 (45%) sites, with 2,582 individuals observed across all site visits. Our maximum season count was 1,985 individuals, which represents the sum of the greatest single visit count from each site. We now have seven years of data gathered on Karner blue populations between 2015 and 2024 using a consistent sample design and protocol. When considering sites surveyed every year, the recent downward trend was interrupted in 2024. Although still comparatively low for the monitoring period, the proportion of occupied sites remained unchanged from 2023, whereas abundance increased to its highest level since 2018. While still much lower than the peak values observed in 2016-2018, results of 2024 surveys suggest an improvement in Karner blue populations at these sites relative to recent years. Continued monitoring will help to assess whether this represents normal variation in population parameters or the start of a positive trend.

In the discussion we present potential actions to improve habitat for the Karner blue on state lands in Michigan, focusing on sites occupied by Karner blue in 2024. These recommendations are based on site characterization data collected during surveys, our knowledge of the sites from multiple visits across years, and an understanding of habitat requirements. Considering results from nectaring observations collected for the first time in 2024, we urge land managers to enhance Karner blue habitat with native nectar sources most used by the Karner blue: horse mint (*Monarda punctata*), butterfly-weed (*Asclepias tuberosa*), and whorled milkweed (*A. verticillata*). We hope our recommendations can serve as a quick reference to help land managers prioritize management locations and actions.

ACKNOWLEDGEMENTS

Funding for this project was provided through the Michigan State Wildlife Grants program in cooperation with the U.S. Fish and Wildlife Service, Wildlife and Sport Fish Restoration Program. We thank the following Michigan Department of Natural Resources staff for their advice, assistance, and support: Chris Hoving, Mark Mills, Jennifer Kleitch, Amy Derosier, James Miller, Don Poppe, Jake Crawford, Fahimeh Baziari, Greg Hochstetler, Cade Bush, Hannah Weigold, and Sarah McGrath. The following MNFI field technicians and AmeriCorps members assisted with surveys: Brianna Hukill, Grace Forthaus, Anna Slocum, Arcanae Clark, Emma McCarthy, and Izzy Wejrowski. Dave Brown, Talus Rutgers, and Ronda Spink joined us for surveys, and we thank them for their help. Administrative support was provided by Ashley Adkins, Sarah Carter, and Deb Richardson. Thank you to David Johnson (Muskegon County Resource Recovery Center) and Andrew Bacon (Michigan Nature Association) for permission to survey their organization's properties.

Sundial lupine (*Lupinus perennis*) blooming in May 2024 in Karner blue habitat at Allegan State Game Area. Photo: A. Cole-Wick

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INTRODUCTION

The Karner blue butterfly (*Plebejus samuelis*; Karner blue) is found in oak-pine barrens and oak savannas in Michigan where its only host plant, sundial lupine (*Lupinus perennis*; lupine), thrives on sandy soils. Once found throughout the upper Midwest and southern Canada, this rare butterfly's range is now likely restricted to Michigan, New Hampshire, New York, New Jersey, and Wisconsin, with most of the remaining populations in Michigan and Wisconsin. The Karner blue was listed as Federally Endangered by the United States in 1992 and is listed as State Threatened in Michigan (Clough 1992). A bivoltine species, the first generation of adults fly late May to June and the second flies July into August, then overwintering as eggs (Savignano 1990, Swengel and Swengel 1999). To thrive, the Karner blue needs sufficient nectar sources, a balance of lupine growing in both sun and shade, and ants, with which the butterfly has a facultative mutualism. Declines in Karner blue populations are driven by the loss of barrens and savanna systems by conversion to agriculture, development, and vegetative succession due to a lack of disturbance (USFWS 2003).

To maintain habitat for the Karner blue, regular disturbance is needed to set back succession of barrens and savanna to forest. Research shows that mechanical thinning of woody vegetation and prescribed fire together restore oak savanna better than fire alone (Bassett et al. 2020). Intact barren and savanna habitats in Michigan have become increasingly fragmented and isolated. Population declines, habitat fragmentation, and the Karner blue's low dispersal capacity (Knutson et al. 1999) results in limited genetic exchange between subpopulations and an increased risk of inbreeding. These factors have resulted in comparatively low genetic diversity within Karner blue populations and evidence of inbreeding depression in many populations, including those located in Allegan, Muskegon, and Flat River State Game Areas in Michigan (Zhang et al. 2024), which are the subject of our study. Fragmentation also negatively impacts the butterfly's host plant, with lupine populations in Michigan exhibiting potentially lower levels of genetic diversity relative to other populations (Partridge et al. 2023). The net result is diminished resiliency and adaptive capacity of both Karner blue and lupine populations, increasing their vulnerability to disturbance events and impending threats, like more frequent and longer droughts associated with climate change.

Long-term monitoring of Karner blue populations is necessary for planning management and reporting, but is challenging due to multiple survey objectives, limited resources, and dynamic ecosystem conditions (e.g., succession). In 2024, the Michigan Department of Natural Resources (MDNR) funded the Michigan Natural Features Inventory (MNFI) to continue occupancy-based surveys for this rare butterfly at Allegan, Flat River, and Muskegon State Game Areas (hereafter referred to as Allegan, Flat River, and Muskegon). The purpose of our work is to provide data to the MDNR to address multiple goals: 1) determine occupancy status of habitat patches to inform regulatory and management decisions; 2) track population status to evaluate progress toward recovery plan goals; and 3) evaluate the response of Karner blues to management actions. The MNFI worked with the MDNR in 2014-2015 to develop an occupancy-based survey that expanded beyond sites traditionally monitored with distance sampling (Monfils and Cuthrell 2015). We have since implemented this survey in 2015-2018

(Monfils and Cuthrell 2018), 2021 (Monfils et al. 2021) and 2023 (Cole-Wick et al. 2023). Results have provided information to MDNR staff responsible for planning and implementing management and tracking progress toward recovery goals. In 2024, we updated our sample design and survey methods to better meet land managers' goals and survey more potentially suitable habitat. We added new sites and started collecting data on nectar source use and ant mound abundance to help address management questions.

Consistent monitoring over space and time is crucial for effective management and compliance with U.S. Fish and Wildlife Service regulations. These data also enable MDNR biologists to assess the status of the species and make necessary adjustments to conservation activities. In 2024 we implemented the occupancy-based survey consistent with methods used in previous years (Monfils and Cuthrell 2015, 2018, Monfils et al. 2021, Cole-Wick et al. 2023) to provide the data to local, State, and regional partners working to recover Karner blue populations. Conducting surveys at the same sites over time allows for the evaluation of the long-term effects of management efforts on Karner blue occupancy and abundance.

Oak-pine barrens habitat in Allegan State Game Area containing a large population of sundial lupine, the host plant of the Karner blue butterfly. Photo: A. Cole-Wick

METHODS

Sample Design

We built upon our existing occupancy-based sample design and survey methods developed for the Karner blue and previously implemented between 2015 and 2023 (Monfils and Cuthrell 2015, 2018, Monfils et al. 2021, Cole-Wick et al. 2023). Potential sites were originally identified using a combination of Karner blue element occurrences (MNFI 2024), lupine areas, and digitized non-forested upland openings occurring on state lands. We based our surveys off of the same sample frame of sites used for surveys conducted during 2016-2018 and in 2021, which consisted of areas occupied by Karner blue during pilot occupancy surveys conducted in 2015, unoccupied sites connected to or within 200 m of sites occupied in 2015, four previously occupied sites surveyed using distance sampling in the past, and occupied sites located on private lands for which the MDNR has provided management assistance. Given that lupine populations change over time in response to competition from herbaceous and woody plants, we re-evaluated our sample frame prior to 2023 surveys. This process resulted in the removal of 10 sites due to a lack of lupine presence and/or woody plant succession and the addition of eight new sites (Cole-Wick et al. 2023).

Prior to 2024 surveys, we once again re-evaluated our sample frame to achieve one or more of the following objectives: 1) determine occupancy status at additional habitat patches requested by MDNR staff; 2) assess the status of previously occupied patches lacking contemporary survey effort; and 3) document new populations. We identified additional potential sites through discussions with MDNR staff and by locating Karner blue and oak-pine barrens element occurrences (MNFI 2024) not included in the existing sample frame. We also searched for suitable habitat at the Muskegon County Resource Recovery Center due to previous records of Karner blues and proximity to Muskegon. Preliminary surveys conducted in spring 2024 during peak lupine bloom helped to identify suitable habitat. We visited these areas and used the DAFOR scale to rank the relative abundance of lupine as dominant, abundant, frequent, occasional, or rare (see Appendix A). Areas with dominant, abundant, or frequent lupine and suitable habitat structure (≤ 60% canopy cover) were added as new sites, with coordinates of site boundaries recorded using Field Maps (ESRI 2024). This process resulted in the addition of eight new sites at Allegan (Figure 1), two each at Muskegon and the Muskegon County Resource Recovery Center (Figure 2), and one new site located on private lands in Newaygo County. Our sample frame remained unchanged at Flat River (Figure 3). While our primary objective was to survey sites located on state lands, we attempted to visit private sites when schedules, weather, and landowner permission allowed.

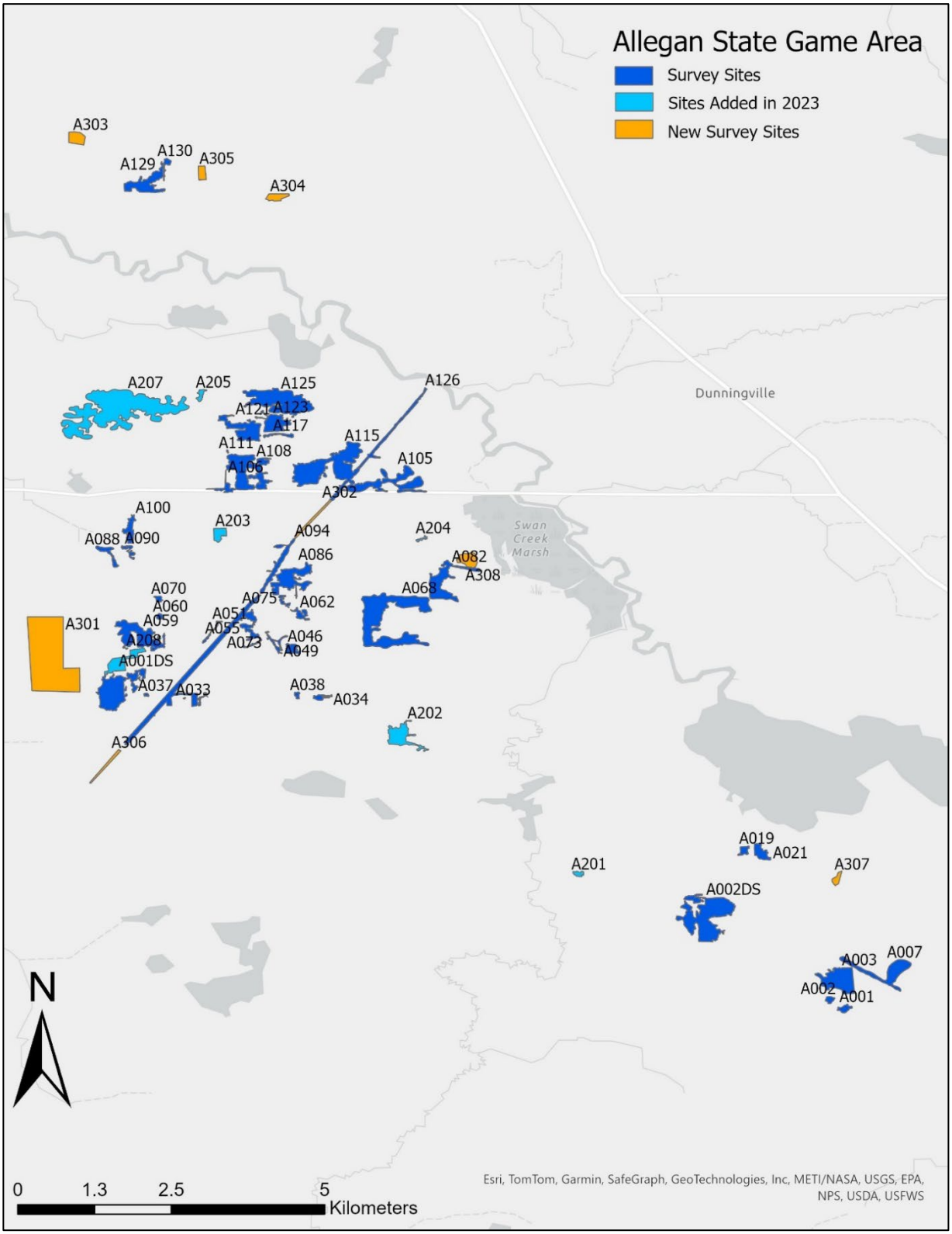

Figure 1. Existing Karner blue survey sites (blue), sites added in 2023 (light blue), and newly added sites (orange) in Allegan State Game Area visited in 2024.

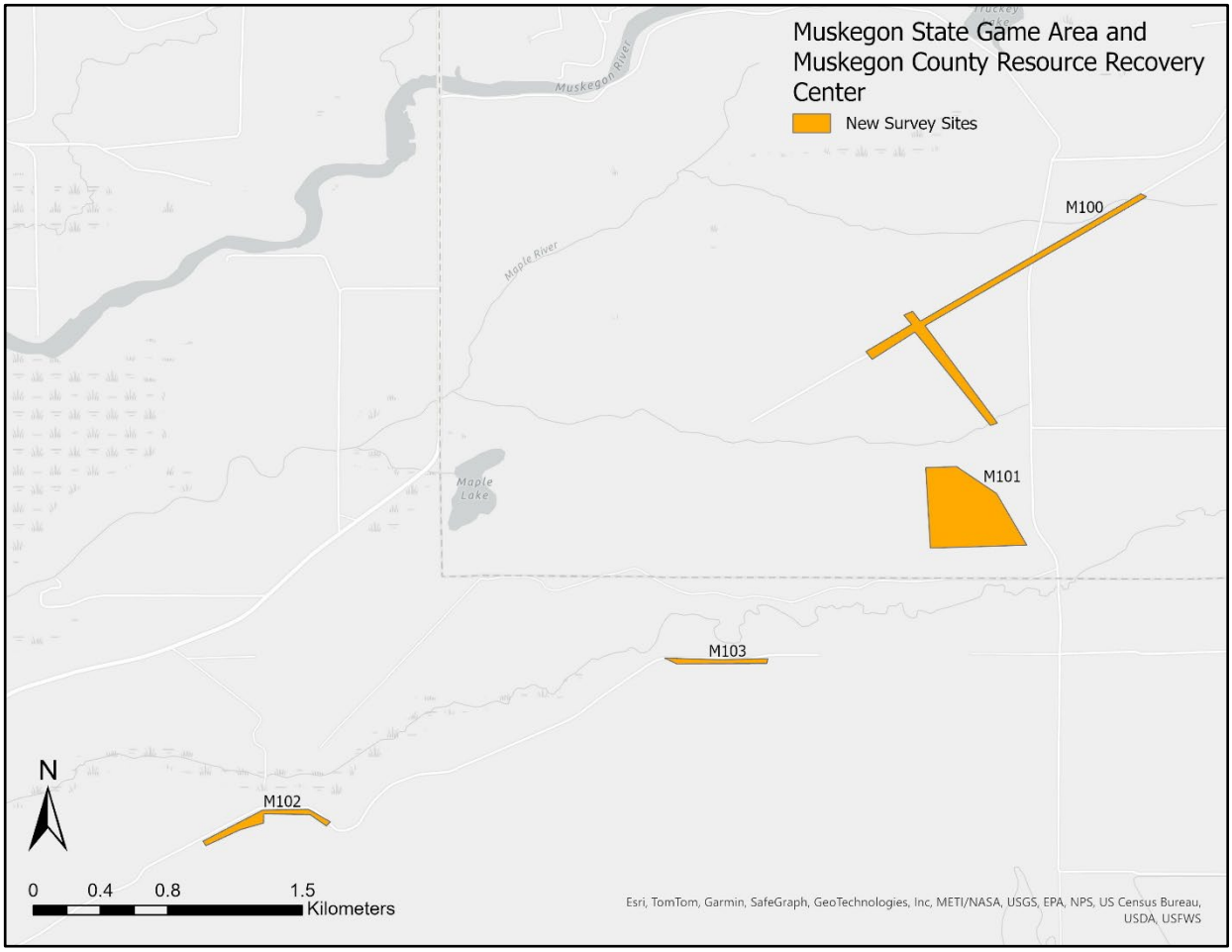

Figure 2. Newly added Karner blue survey sites in Muskegon State Game Area (M100, M101) and the Muskegon County Resource Recovery Center (M102, M103) visited in 2024.

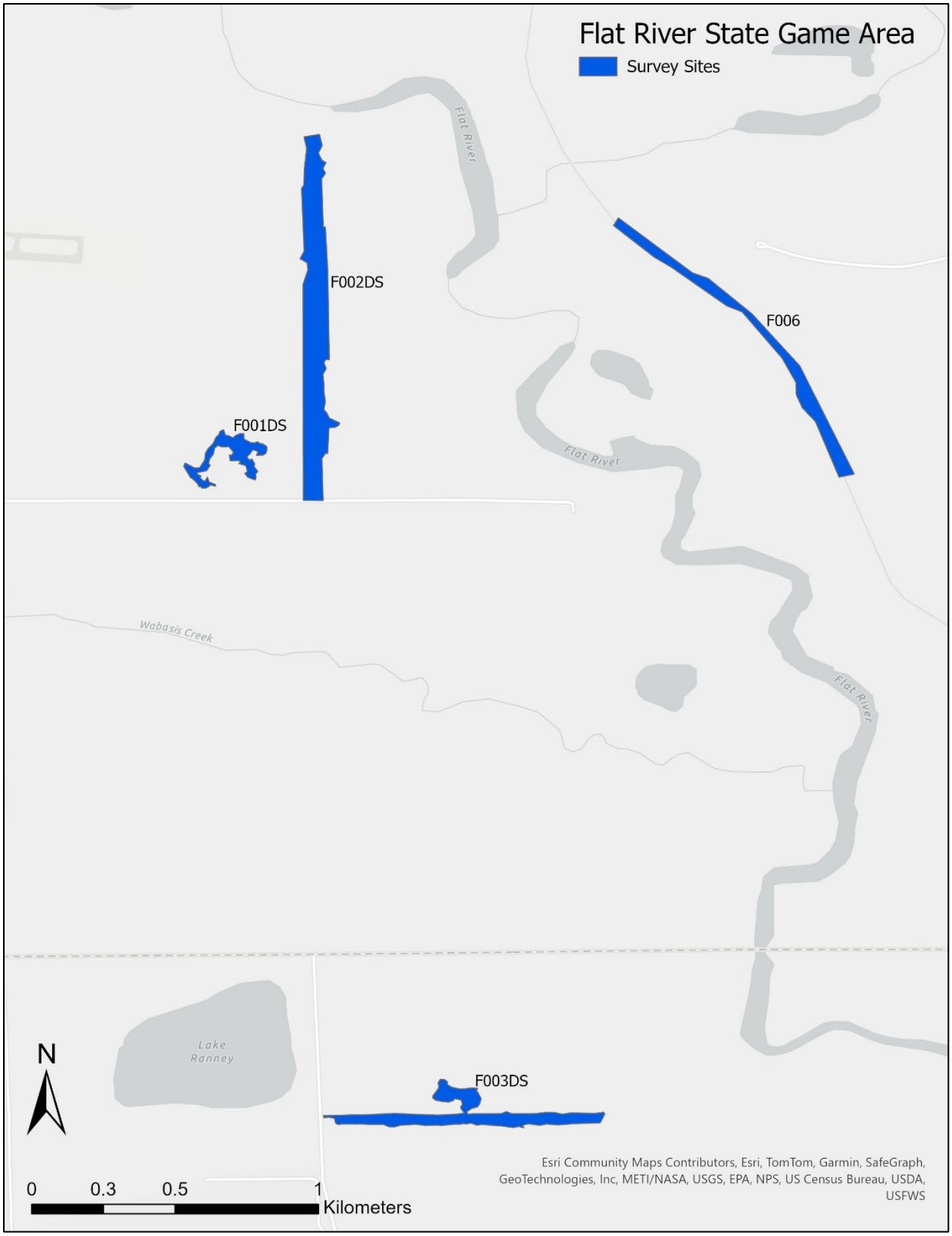

Figure 3. Karner blue survey sites in Flat River State Game Area visited in 2024.

Butterfly Survey Methods

We generated maps of the 2024 survey sites with ArcGIS Pro and Field Maps (ESRI 2024) and uploaded them to smart devices (i.e., tablet computers, smartphones) to assist surveyors as they navigated among and within sites. We focused surveys on areas having ≤ 60% tree canopy cover (Grundel et al. 1998). Areas within the polygons having one or more of the following conditions were excluded from the survey: 1) > 60% tree canopy cover; 2) > 75% bare soil and no lupine; and 3) planted crops or ground cover (e.g., grassland, lawn) lacking lupine and nectar sources. Areas of potential habitat (i.e., ≤ 60% canopy cover with lupine/nectar sources) located immediately outside of the identified polygons were added to the survey. In addition to navigating through the sites using Field Maps, surveyors recorded their tracks to document which areas were surveyed.

Once in the field, surveyors collected habitat and butterfly occurrence data in a Survey 123 form created for this project (ESRI 2024). The occupancy-based survey method we have used for Karner blue since 2015 requires two visits to each site during the second flight (mid-July to early August). Observations (presence/absence) of other butterfly species, including the monarch butterfly (*Danaus plexippus*), were recorded during both visits. We limited surveys to periods when the temperature was above 15° C (60° F), there was no rain, and when winds were ≤ 25 km/h (15 mph). If temperatures were 15 - 21° C (60 - 70° F), surveys were only conducted when cloud cover was ≤ 50%. There was no cloud cover restriction if the temperature was above 21° C (70° F). If weather conditions deteriorated during a visit, we terminated the survey and resurveyed the entire site on a suitable day. Surveys were conducted between 9 AM and 6 PM.

We conducted modified Pollard-Yates (Pollard and Yates 1993) surveys in which we followed a series of transects paralleling the outer boundary of the survey site polygon (Figure 4). The first transect began 5 m inward from the outer edge of the patch, with one surveyor slowly walking along the first transect until the entire periphery of the site was surveyed. A second transect was located 10 m inward from the first transect and was surveyed in the same manner. Additional transects were added until the entire patch of suitable habitat was surveyed. At large sites, two or more people conducted the survey together, with transects spaced 10 m apart. Observers looked for and counted Karner blue butterflies within an area 5 m to either side of the transect, 5 m forward along the transect, and 5 m above the transect (10 m x 5 m x 5 m, rectangular survey area). Surveyors walked at a steady, slow speed of approximately 35 m/min. If butterflies flew ahead of an observer, they were ignored if the surveyor was certain the individual was already counted. To facilitate an accurate count of the Karner blue and understand their distributions within and among sites, we collected geospatial information for each butterfly. We collected GPS coordinates in the Survey123 form for each Karner blue observed; however, in the case that butterflies were grouped together, we took one point for a group and recorded the number of individuals in that group. For example, if five butterflies were seen on one nectar source, one point was collected at the location for the five individuals. Observers avoided disturbing or flushing butterflies when collecting data.

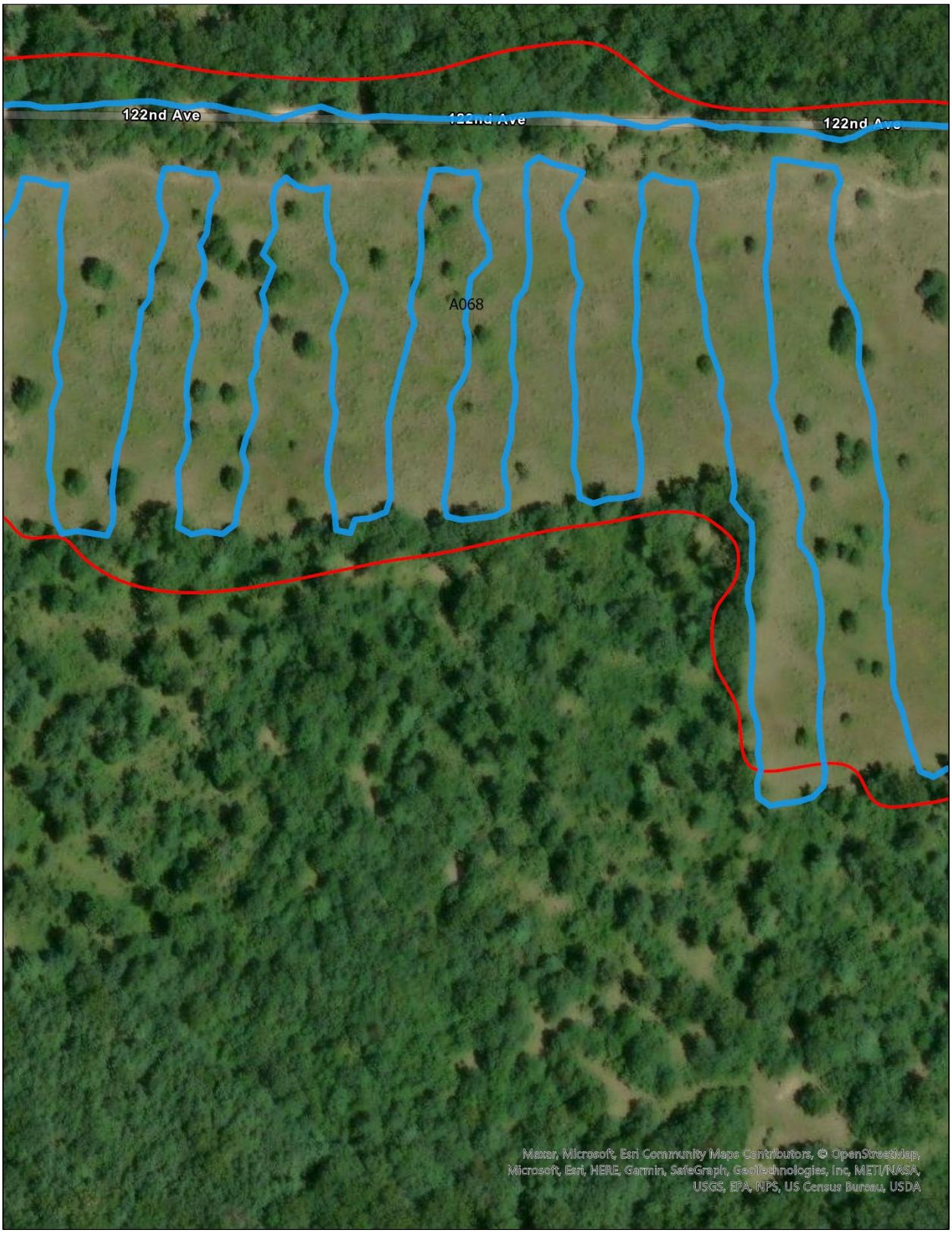

Figure 4. Survey tracks (blue) from an MNFI surveyor exemplifying how a series of parallel transects were followed until all suitable habitat (red outline) had been surveyed.

We recorded sex (male, female, unknown), wing wear (a scale from 1 to 5), and activity (perched, flying, nectaring, copulating) of each adult Karner blue. In 2024 we added a data field for recording the plant species used for nectaring, when that activity was selected. We recorded all other butterfly species detected during surveys on a checklist for each site. However, to avoid distracting surveyors from collecting essential Karner blue data, we did not attempt to estimate relative abundance for non-target species.

We characterized environmental and habitat characteristics at each site by collecting information on variables that may influence Karner blue detection and occupancy, as well as those that could be included in models used to estimate population parameters. At the start and end of a survey, we recorded the temperature (°C), percent relative humidity, cloud cover (expressed as the % of sky occluded), and maximum wind speed (km/h). Surveyors collected general information about potential threats to Karner blue and their habitats and ranked the relative abundance of lupine, nectar sources, and invasive plant species. We used the DAFOR scale to rank the relative abundance of lupine, nectar sources, and invasive species as dominant, abundant, frequent, occasional, or rare (see Appendix A). We also recorded the total number of active and inactive ant mounds observed at each site.

RESULTS

Karner Blue

In 2024 we surveyed 64 sites at three state game areas (Allegan, Flat River, and Muskegon), as well as two sites on private lands. We surveyed 95% of the sites twice, with all but one site on state lands having two visits. We detected Karner blues at 30 (45%) of the 66 sites surveyed and recorded 2,582 Karner blues across all site visits. We observed Karner blues at 24 out of 56 sites at Allegan (Figure 5), one out of four sites at Flat River (Figure 6), three out of four sites at Muskegon (Figure 7), and at both sites surveyed on private lands (Table 1). Three of the sites where we found Karner blues had not been previously surveyed. Our maximum season count was 1,985 individuals, which we calculated by taking the sum of the maximum number of Karner blues observed during a single visit to each site. Out of the 30 occupied sites, 47% (14) had maximum counts of fewer than five individuals and 27% (8) had maximum counts of just one individual. The highest abundance at a single site was recorded at the Karner Blue Nature Sanctuary, a private site managed by Michigan Nature Association, with a maximum count of 553 individuals. Three sites at Allegan – A001DS (Horseman's Campground), A059 (North of Horseman's Campground), and A073 (the main stretch of pipeline located between 122nd and 118th Ave) – accounted for 63% of the maximum season count recorded on state lands.

We documented Karner blues at six of the 13 new sites added in 2024. Abundance was low at most new sites (Figures 5-7), with a maximum season count of seven individuals at M102 (Muskegon County Resource Recovery Center), four individuals at A301 (Allegan – located between Horseman's Campground and 52nd St), and just one individual each at A306 (Allegan – southwestern stretch of pipeline near 51st St), M101 (Muskegon – Fitzgerald Barrens), and Brooks Oak Pine Barrens (Michigan Nature Association). Only M100 (Muskegon – Powerline) had a sizeable population with a maximum count of 39 individuals.

Table 1. Number of sites surveyed, number of surveys completed, and number of sites occupied by Karner blue during the second flight in 2024.

	Sites	Surveys Completed	Occupied Sites
Allegan State Game Area	56	111	24
Flat River State Game Area	4	8	1
Muskegon State Game Area	4	8	3
Private	2	2	2
Total	66	129	30

We implemented the same methods and protocol used to survey Karner blues in 2015-2023, allowing us to compare our 2024 results to previous years. Thirty-eight sites were surveyed in all seven years (2015-2018, 2021, 2023-2024; Appendix B). At these sites, naïve occupancy (i.e., proportion of sites occupied) matched 2023 for the lowest of the monitoring period and raw density (i.e., Karner blues per hectare) was lower than all previous years, yet maximum abundance was the highest since 2018 and the fourth highest overall (Table 2). The lower raw density value was driven primarily by a dramatic decrease at a small, 0.24-hectare site in Allegan (A073). Density at this site fell to approximately 96 Karner blues per hectare, down from the average of 190 recorded between 2015-2023 (Appendix B). For all sites surveyed across the seven years, 2024 had the lowest recorded naïve occupancy and matched 2015 for the lowest raw density; however, lower values for these parameters were anticipated due to the addition of 13 new sites to the sample frame, most of which were not known to be occupied by Karner blues. Maximum abundance was higher than recent years but still considerably lower than the numbers recorded in 2016-2018 (Table 2).

Table 2. Naive occupancy (proportion of sites occupied), maximum abundance (sum of greatest single visit count from each site), and raw density (Karner blues per hectare) of Karner blues by year for all sites surveyed and a subset of sites surveyed every year (n = 38).

	Naïve Occupancy		**Maximum Abundance**		**Raw Density**	
Year	**All Sites**	**Sites Surveyed Every Year**	**All Sites**	**Sites Surveyed Every Year**	**All Sites**	**Sites Surveyed Every Year**
2015	0.47	0.58	658	650	4.2	5.8
2016	0.67	0.71	4,986	1,606	25.4	21.4
2017	0.67	0.76	4,867	1,573	19.6	15.7
2018	0.69	0.68	5,384	1,028	24.2	11.1
2021	0.49	0.53	1,808	657	8.9	8.8
2023	0.46	0.47	859	609	5.6	7.9
2024	0.45	0.47	1,985	817	4.2	4.7

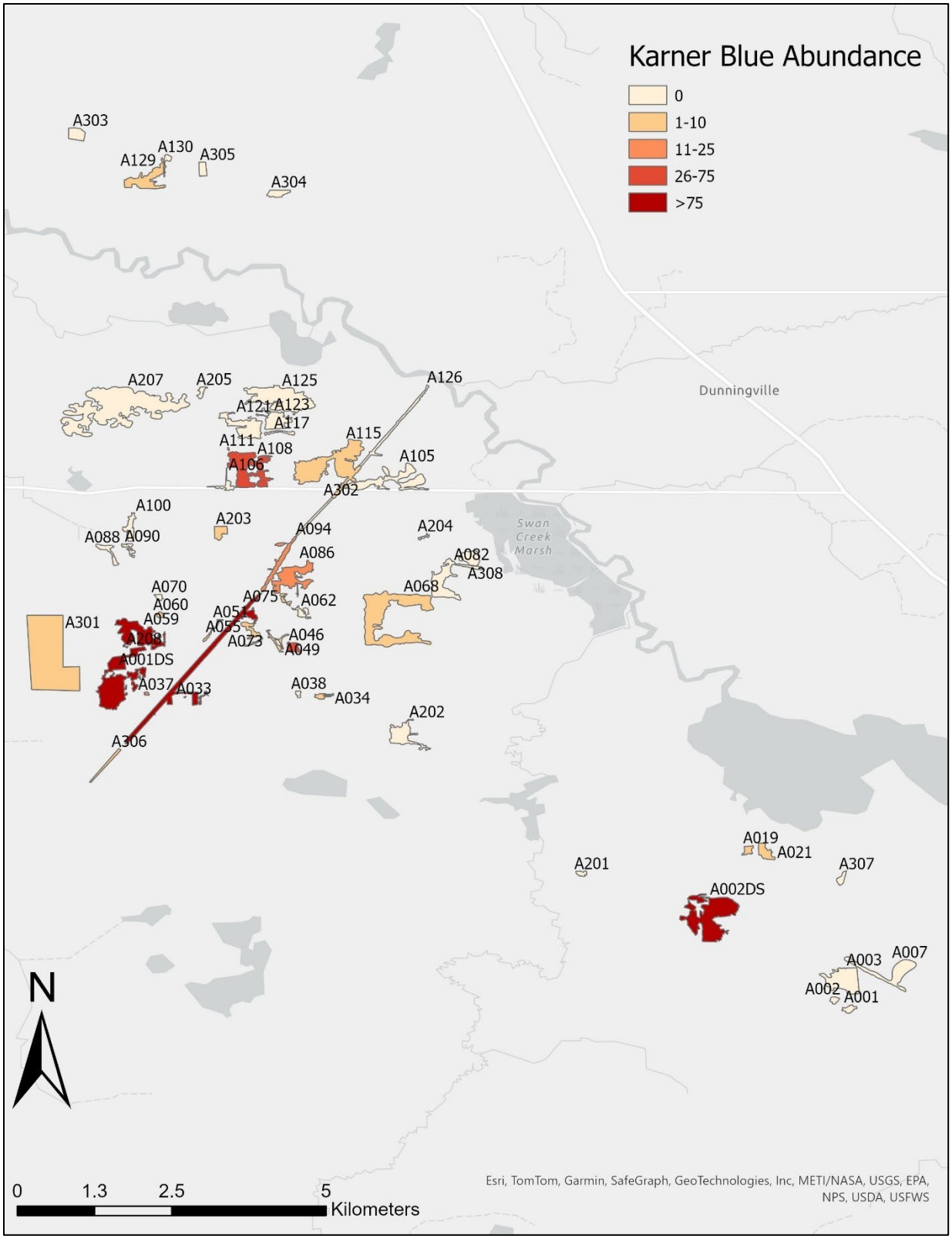

Figure 5. Number of Karner blues by site during 2024 surveys at Allegan State Game Area.

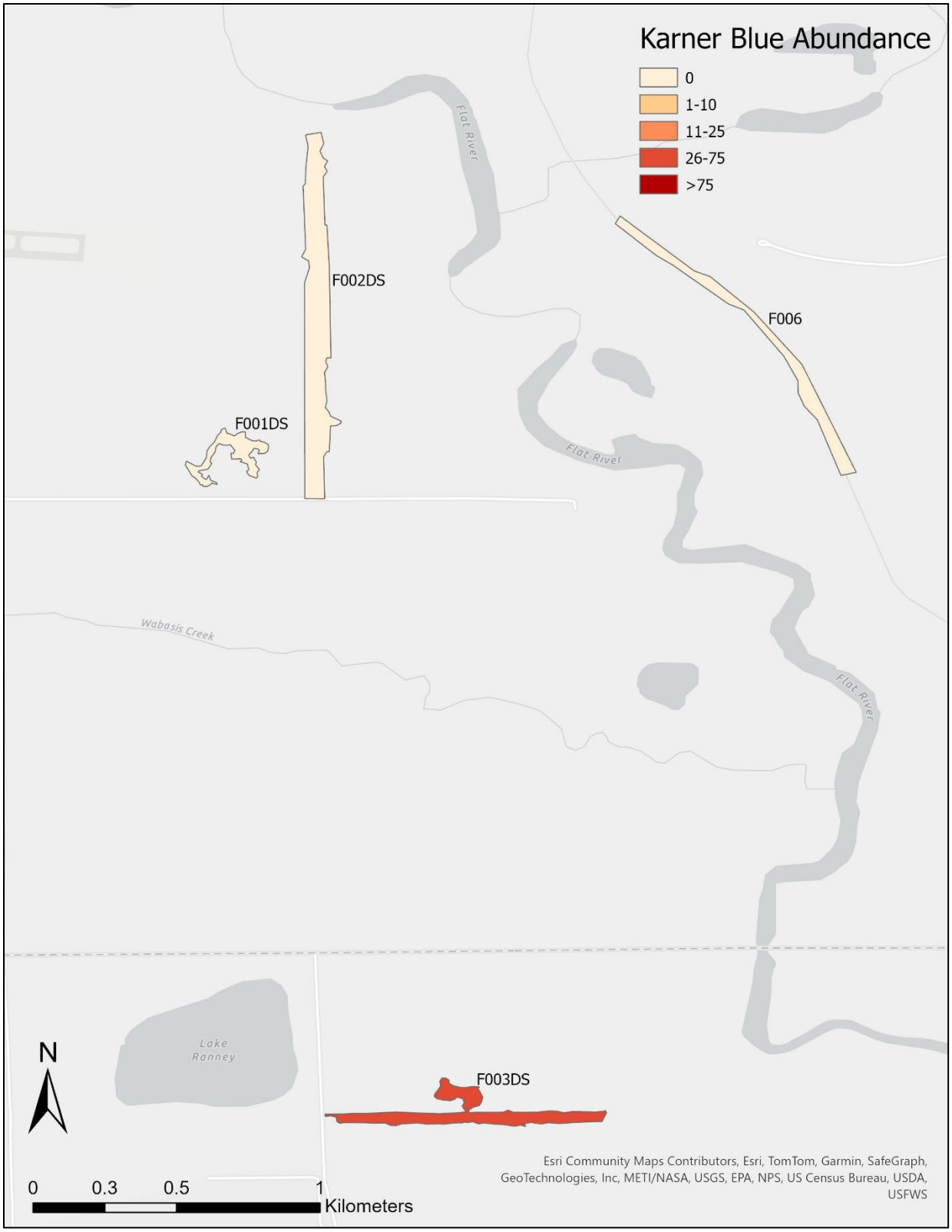

Figure 6. Number of Karner blues by site during 2024 surveys at Flat River State Game Area.

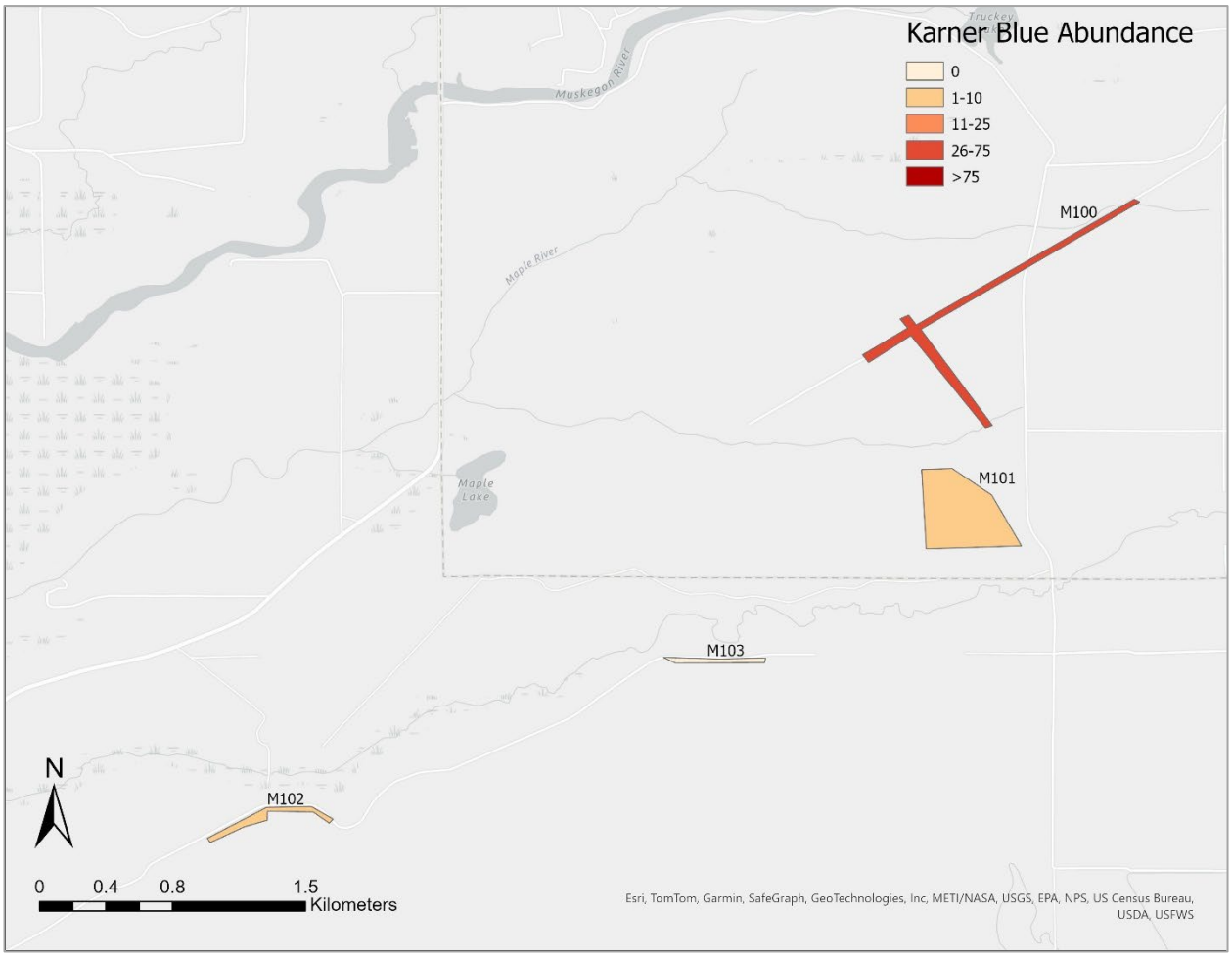

Figure 7. Number of Karner blues by site during 2024 surveys at Muskegon State Game Area and the Muskegon County Resource Recovery Center.

Fifty-three sites were surveyed in both 2023 and 2024. At these sites, total maximum abundance increased in 2024 by 1,070 individuals. Mean abundance of the 53 sites increased by approximately 20 individuals (Mean ± SE: 20.189 ± 10.612), with 16 sites (30%) increasing in abundance and 10 sites (19%) decreasing (Appendix C). Notable increases in abundance were observed at the private Karner Blue Nature Sanctuary (+497 individuals) and at three sites in Allegan – A059 (+176 individuals), A001DS (+162 individuals), and A208 (+147 individuals) – all located off 120th Ave near Horseman's Campground. For the first time since 2018, abundance at the single occupied site in Flat River (F003DS) increased from the previous year (+37 individuals). The largest declines in abundance were recorded at A037 (-35 individuals) and A094 (-22 individuals), located in Allegan off 120th Ave and between 122nd and 123rd Ave, respectively.

Site Characterization

We documented threats to Karner blue at all survey sites in 2024. Woody plant encroachment was the most prevalent, listed as a threat at 54 sites (82%). Pennsylvania sedge (*Carex pensylvanica*) was similarly pervasive, classified as a threat (i.e., frequent or higher DAFOR rank) at 47 sites (71%), all of which were in Allegan. Off-road vehicle (ORV) damage, which poses a direct threat to both Karner blues and their habitat, was identified as a threat at 31 sites (47%). Equestrian damage, car and tractor damage, roadside herbicide, bracken fern cover, and dumping of trash were identified as additional threats, although these were present at only a small number of sites (Appendix D). Spotted knapweed was the most abundant invasive plant, receiving a relative abundance rank of at least frequent at 14 sites (21%). No other invasive plants received a frequent or higher rank at any site.

Oak savannas managed for Karner blue face a variety of threats, including too much or too little canopy cover. This site contains a good balance of lupine in sun and shade, but small trees will soon begin to shade out the herbaceous layer as they grow. Photo: A. Cole-Wick

We recorded 192 observations of 356 Karner blues nectaring on 21 different plant species during 2024 surveys. Many observations included more than one butterfly on a nectar source, usually on native flowers. Site-level DAFOR ranks for each nectar source visited by Karner blues

were converted to numeric values (1-5), and relative abundance rankings were determined by summing these values across all sites surveyed. Common St. John's-wort (*Hypericum perforatum*), spotted knapweed (*Centaura stoebe*), and flowering spurge (*Euphorbia corollata*) were the most abundant of the nectar sources visited by Karner blues, whereas whorled milkweed (*Asclepias verticillata*), butterfly-weed (*Asclepias tuberosa*), and spotted knapweed were visited by the greatest number of Karner blues. Whorled milkweed was heavily utilized despite being one of the least abundant nectar sources. In contrast, common St. John's-wort was the most abundant nectar source and was used by fewer than 10 individuals (Figure 8).

To further describe the condition of our survey sites, we ranked the prevalence of lupine and ant mounds. Lupine was classified as frequent or higher at 48% of all sites surveyed and at 70% of occupied sites. The average number of active ant mounds at occupied sites was approximately 58 (Mean ± SE: 58.429 ± 16.272), considerably greater than the average of approximately eight (Mean ± SE: 8.194 ± 2.131) at unoccupied sites. These results can be viewed by site in Appendix D.

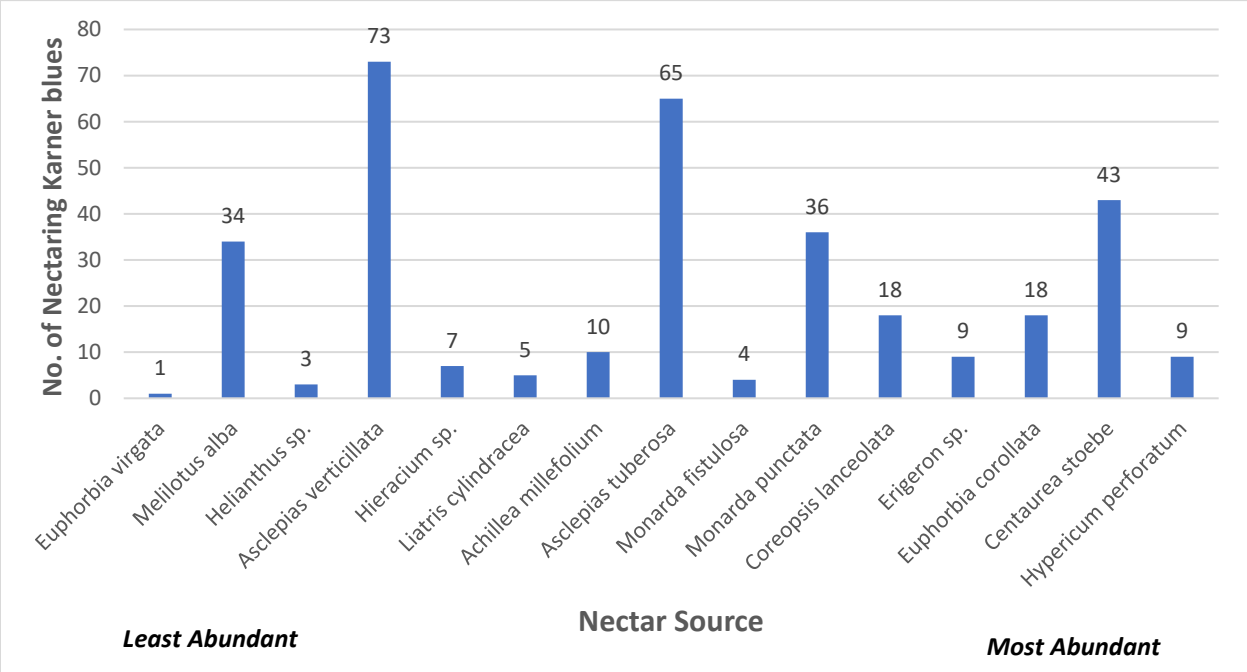

Figure 8. Nectar source utilization in relation to availability for the 15 nectar sources with corresponding relative abundance data. Nectar sources displayed in increasing order of relative abundance. Preferred nectar sources are those characterized by high utilization despite low availability (e.g., *Asclepias vertillicata*).

DISCUSSION

The purpose of Karner blue population monitoring is to assess progress toward recovery goals, evaluate response to management, and assist land managers in making the difficult decisions about where and when to conduct habitat management. A standardized sample design allows us to assess trends in population parameters across years. Understanding occupancy patterns and habitat patch abundance can aid land managers in prioritizing management locations and in establishing connectivity between occupied sites. At a finer scale, site characterization data can be used to identify management needs for individual habitat patches.

After completing surveys in 2024, 38 sites have now been monitored during all seven years. Results of 2021 and 2023 surveys indicated a possible downward trend in Karner blue occupancy and abundance since 2018, with progressively lower values for both parameters. Despite matching 2023 for the lowest value of the monitoring period, naïve occupancy stabilized in 2024, possibly indicating an end to the downward trend observed in recent years. Meanwhile, abundance increased, with the highest value recorded since 2018. Although values for these parameters are still much lower than those recorded in 2016-2018, results of 2024 surveys indicate a potential improvement in population status relative to recent years. Continued monitoring of these sites will help us determine if these values indicate the start of a positive trend for populations in southwest Michigan, or if they are merely the result of normal annual variation.

Drought, which has been correlated with substantial declines and local extinction of Midwest populations (Patterson et al. 2020, Walsh 2017), was put forth as a possible explanation for the lower number of Karner blues observed in Michigan (Cole-Wick et al. 2023) and Wisconsin (Weinzinger 2023) in 2023. If indeed the case, populations at our sites appear to be recovering, with total abundance exceeding the pre-drought level observed in 2021, despite a June-August 2024 that were a combined about 0.2° F (0.1° C) warmer globally than any other summer on record (NASA 2024). Consistent monitoring over space and time permits a better understanding of how extreme weather events such as drought influence population parameters, while also providing a mechanism to measure population recovery in subsequent years. These data are increasingly valuable as biologists work to recover Karner blue populations in the face of climate change.

In 2024 we added 13 new sites to provide patch-level data in areas requested by MDNR staff, determine the status of historically occupied sites that were not surveyed in recent years, and document Karner blues in areas that have not been surveyed to our knowledge. We documented Karner blues at two sites added within Muskegon, including one area that had been restored back to barrens by DNR staff over the past nine years. We observed Karner blues in new sites added in 2024 at the Muskegon County Resource Recovery Center, which borders the SGA to the south. According to the Natural Heritage Database (MNFI 2024), these represent the first observations at the county property since 2004. Additionally, we documented the rare butterfly at three sites lacking historical occurrence records (MNFI 2024): two in Allegan and one site recently acquired by Michigan Nature Association (Brooks Barrens). While the lack of

historical records at these sites may simply be the result of limited survey effort, they are located near occupied sites, and 2024 observations may therefore represent recent colonization events.

We noted ORV and vehicle use as a threat to the Karner blue and its habitat at 47% (31) of sites (Appendix D). Under Section 9 of the Endangered Species Act (ESA; US 1973), it is illegal for any person subject to the jurisdiction of the United States to take a federally endangered wildlife species without a permit. The Endangered Species Act defines take as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct". The Service further defines “harm” to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering. This means that under the ESA, it is illegal to take Karner blue butterfly without a permit. One way take can occur is to kill the butterfly by crushing or otherwise destroying eggs. Karner blue butterfly overwinter as eggs, which are tiny, about 0.7 mm in diameter. Use of ORVs, such as snowmobiles, through occupied habitat in a manner that crushes eggs, caterpillars, or adults would be considered take and would be illegal under the ESA. Reducing this threat on state lands would likely increase winter survivorship of the federally endangered Karner blue.

MANAGEMENT CONSIDERATIONS

The Habitat Conservation Plan for the Karner blue specifies that land managers in Michigan should continue barrens restoration projects with emphasis on connectivity between subpopulations, expansion of existing sites, and enhancement of habitat attributes within sites (MDNR 2009). Below we present some opportunities for management based on our observations from 2024 field efforts, and we identify areas to prioritize for increasing connectivity. A list of all sites is available in Appendix D, where we present data on lupine abundance, active ant mound abundance, and threats (e.g., ORV, Pennsylvania sedge, shrub encroachment, and invasive species) for all state lands we surveyed in 2024.

Enhancing Habitat at Occupied Sites

Managing for an endangered species is one of the most important charges of a land manager, but also rife with complexities, and it is our hope that habitat attribute data we collected will assist land stewards with the careful work of prioritizing and implementing management in occupied sites. Sundial lupine is inextricably linked to the Karner blue, but it is only one of the critical habitat factors necessary for its survival. In some cases, we observed sites that contained a high density of lupine, yet a low density of nectar sources or ant mounds, or vice-versa. When lupine and nectar sources are spatially separated, adult Karner blues can face a tradeoff between maximizing foraging and reproductive success (Scheirs and De Bruyn 2002). Indeed, Karner blue densities in Wisconsin were lowest in occupied habitats containing high densities of either resource but low densities of the other and highest in habitats where both resources were present in approximately equal ratios (Chau et al. 2020). Local Karner blue populations may benefit from management focused on increasing habitat that contains both resources in approximately equal proportions.

Karner blue butterflies nectaring on whorled milkweed (left) and butterfly-weed (right). Photos: A. Cole-Wick

We urge land managers to enhance Karner blue habitat with the native nectar sources most used by the Karner blue: horse mint, butterfly-weed, and whorled milkweed. Increasing these nectar sources in barrens and savanna systems will also meet goals for conservation of the

increasingly imperiled monarch butterfly. Common milkweed (*Ascelpias syriaca*) is often used in restorations and plantings, and many often overlook the value of the 11 other species of milkweed that occur in Michigan. Butterfly-weed and whorled milkweed thrive in the sandy soils of barrens and savannas in western Michigan and provide nectar that coincides with the second flight of the Karner blue. Increasing these sources will benefit these two butterflies, and myriad other species. Our nectar observations were all recorded during the second flight of the Karner blue in July. Ample resources during the first flight of the Karner blue in May are also necessary, but we suspect that nectar sources are more limited during the second flight. We have incidentally observed first flight Karner blues nectaring on sundial lupine, northern dewberry (*Rubus flagellaris*), birdfoot violet (*Viola pedata*), and common evening primrose (*Oenothera biennis*).

We noted shrub encroachment as a threat at 82% of sites surveyed in 2024 (Appendix D). Holding back succession with a combination of mechanical removal of woody vegetation, judicious herbicide application, and prescribed fire is necessary to maintain Karner blue habitat in these areas. However, it is important to maintain 30-60% canopy cover in these sites, as the Karner blue requires landscapes with heterogeneous canopy cover that enhance microclimatic diversity, and lupine population viability benefits from heterogeneous microscale temperature, moisture, shade, and soil conditions (Pavlovic and Grundel 2009). Management focused on maintaining shade heterogeneity within occupied habitats will benefit Karner blue populations by ensuring the presence of unshaded, shaded, and partially shaded lupine. This is likely to become an increasingly important consideration as climate change continues to increase the frequency of extreme weather events such as droughts. Aggressive shrub and tree removal can result in Karner blue extirpation when shaded lupine is no longer present.

Creating and maintaining natural environments that provide essential habitat to the endangered Karner blue is essential for the species' continued survival. The current HCP directs barrens restoration projects to emphasize on connectivity between subpopulations, expansion of existing sites, and enhancement of habitat attributes within sites (MDNR 2009). However, as early successional communities, these systems sometimes change from ideal habitat to shrubby, young forests within decades. Therefore, it is imperative that adult butterflies can find nearby habitat patches as their homes become unsuitable. And, even in the best of cases, where a single patch/site is ideal, genetic exchange within metapopulations is necessary to ensure their fitness for future generations. Based on our data and observations, we highlight opportunities for land managers to improve Karner blue viability at the following sites:

Horseman's & Pipeline Population (Allegan State Game Area)

Many of the Karner blues in Michigan call Allegan home, in particular these butterflies are concentrated in the central portion of the State Game Area between Horseman's Campground and the natural gas pipeline. This central portion of the Allegan metapopulation is essential for this rare butterfly's continued existence in southwest Michigan. We have worked with the Allegan DNR field staff to provide data for which management actions can improve Karner

habitat in this area. Continuing to work on building connectivity between the pipeline and neighboring sites will allow for gene flow between the subpopulations.

Monroe Population (Allegan State Game Area)

Karner populations south of Lake Allegan, located along 42nd Street (A002DS), Monroe Road (A019, A021), and Tryst Barrens (A307) represent a population that is spatially separated from the central Horseman's population. Most of the butterflies are concentrated along 42nd Street, and while Karner abundance this year improved over numbers from 2023, this site contains a fraction of the butterflies it once had. Lupine cover is suppressed at this location due to the prevalence of shrubby oaks in the western and southeastern portions of this site, and by Pennsylvania sedge in the northeast portion of the site. Karner blues persist in the small openings, which are being kept open in part by large ant mounds, but management is needed to maintain these rare butterfly populations.

Fitzgerald Barrens (Muskegon State Game Area)

The Karner blue populations at Muskegon include the restored Fitzgerald Barrens (M101), Muskegon County Resource Recovery Center, and Consumers Energy powerlines. In 2015, Muskegon field staff began the restoration of what is now called the Fitzgerald Barrens after MNFI ecologist, Jesse Lincoln, documented remnant barrens indicator species. At the time, the area was forested, and Muskegon staff began restoring the forested parcel through a combination of mechanical woody removal and prescribed fire. Without seeding, the Fitzgerald barrens now contains a carpet of lupine with dappled sunlight filtering through the thinned canopy, providing an ideal amount of canopy cover needed for Karner blues and healthy lupine in late season. In 2024, we documented one Karner blue in the Fitzgerald Barrens, which likely colonized from the nearby powerline right-of-way. We recommend that the Muskegon staff continue to implement prescribed fire in combination with manual removal of woody species and expand this site towards the powerline to facilitate the movement of Karner blues. We also observed a lack of ant mounds at this site and recommend translocating ants to Fitzgerald Barrens.

Ramney Road Barrens (Flat River State Game Area)

In 2024 we observed an impressive array of nectar sources along the Ramney Road powerline right-of-way and savanna within the State Game Area (F003DS). This exhibits a successful partnership between DNR land managers and the powerline company, as DNR staff enhanced this site by seeding it with native wildflower seeds. The next priority for this site is the continued use of prescribed fire in combination with mechanical removal of woody plants to help expand the suitable habitat northwards from the right-of-way. As the last remaining known population at the State Game Area, this will help ensure that this isolated population continues to survive. We also recommend that the land managers at Flat River continue to work with the powerline company to manage for Karner blues. We suggest that the powerline to the east and west be both managed and surveyed for Karner blue.

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APPENDICES

Appendix A. Karner Blue survey protocol with descriptions of DAFOR rankings.

MICHIGAN NATURAL FEATURES INVENTORY
KARNER BLUE (*LYCAEIDES MELISSA SAMUELIS*) SURVEY PROTOCOL

Acceptable Survey Conditions
Surveys should not be conducted when the temperature is below 15° C (60° F), during rain, or when winds exceed 25 km/h (15 mph). When temperatures are 15 - 21° C (60 - 70° F), cloud cover should be ≤50% of the sky. There is no cloud cover restriction if the temperature is above 21° C (70° F). If weather conditions deteriorate during a survey, observers should terminate the survey and resurvey the entire site on a suitable day. Be sure to note that the survey was ended on the data form and record the final weather conditions.

Survey Area
We identified preliminary survey areas using ArcMap and data layers of known Karner blue element occurrences, mapped lupine patches, and non-forested openings digitized using aerial imagery. Surveys were focused on portions of Karner blue element occurrences having (1) mapped lupine and digitized openings; (2) mapped lupine; and (3) digitized openings. All locations having these conditions were merged to create our preliminary survey polygons. We then expanded our survey areas to include digitized openings and mapped lupine patches that were within 200 m of known Karner blue occurrences. These final survey polygons will be used to target on-the-ground Karner blue surveys. Although we are targeting surveys at these polygons, we are using a flexible survey approach to allow final survey routes to be modified as needed in the field. When in the field, areas within the polygons having one or more of the following conditions can be excluded from the survey: (1) > 60% tree canopy cover; (2) > 75% bare soil and no lupine; (3) planted crops or ground cover (e.g., grassland, lawn) lacking lupine and nectar sources; and/or (4) located on private land. Conversely, areas of potential habitat (i.e., ≤60% canopy cover with lupine/nectar sources) located on public land immediately outside of the polygon should be added to the survey. If a survey site needs to be modified in the field, map the new boundary using Field Maps or a GPS application.

Timing
Surveys can be conducted between 9 AM and 6 PM (EDT). Two surveys of each site should be conducted during the second Karner blue flight (approximately early July to early August).

Survey Methodology
Visual survey: The survey will typically consist of a series of transects paralleling the outer boundary of the identified habitat patch. The first transect will begin 5 m inward from the outer edge of the survey area (e.g., patch of savanna, opening). One surveyor will slowly walk along the first transect until the entire periphery of the site has been surveyed. The second transect will be located 10 m inward from the first transect and will be surveyed in the same manner. Additional transects are added until the entire patch has been surveyed. When possible,

additional surveyors can be used to cover large sites or smaller sites more quickly, as long as all transects are separated by 10 m. Each surveyor will look for and count butterflies within an area 5 m to either side of the transect, 5 m forward along the transect, and 5 m above the transect (imagine a 10 m x 5 m x 5 m, box-shaped, survey area). Surveyors should walk at a steady, slow speed of approximately 35 m/min. When Karner blues fly ahead of the observer, they can be ignored if the surveyor is certain that the individual was already counted. If the observer is uncertain as to whether or not the individual was counted, it should be counted and considered a new individual. When more than one person is surveying a site, It will be important that team members communicate about butterflies moving between transects (e.g., individual counted by one team member that flies into the area being surveyed by the other team member).

Survey data will be gathered using the Karner blue Survey123 form, so be sure to download the form to your tablet/phone before starting field work. A separate Survey123 form should be completed for each survey polygon. If multiple people survey the same site, each person can fill out a separate form to gather data on Karner detections, but information about weather, lupine, nectar sources, and threats only needs to be collected by one person. Karner blue detections will be recorded by individual or groups of butterflies when located within 5 m of one another. For each detection, surveyors will record the number of Karners observed, sex of the individual(s), wing wear rankings, behavior/activity, distance away from the transect, and a GPS waypoint. The total number observed for each detection will be recorded in the "total number detected" field; leave this field blank if no Karners are observed at a site. Next, break down the number observed by sex and use the "unknown" category if you are unable to determine the sex. For example, if you detect 5 Karners, you might enter 2 males, 2 females, and 1 unknown. Similarly, surveyors will break down the total number detected into the five wing wear categories described by Watt et al. (1977): (1) freshly emerged, wings still damp; (2) wings and other cuticle dry and hard, no visible damage; (3) noticeable wear of scales from wings or body; (4) wings showing fraying or tearing in their cuticle; and (5) wings with extensive scale wear and cuticle damage. Using the same example of 5 Karners detected, you could have 1 individual in wing wear category 1, 3 in category 2, and 1 in category 3. Next, break down the number observed in a detection into the following behavior/activity categories: nectaring, flying, perched, copulating, and ovipositing. For example, a detection of 5 Karners might be recorded as 4 nectaring and 1 flying. Surveyors will then enter the distance away from the transect that each individual/group was first detected using the following 0.5-meter bins provided in the form: 0.0–0.5 m, 0.5–1.0 m, 1.0–1.5 m, 1.5–2.0 m, 2.0–2.5 m, 2.5–3.0 m, 3.0–3.5 m, 3.5–4.0 m, 4.0–4.5 m, 4.5–5.0 m, and >5.0 m). Lastly, a waypoint will be collected for the individual/group using the button in the Survey123 form. If you walk off of a transect to collect a waypoint, be sure to move back to the point where you left off before continuing on with the survey. As much as possible, avoid flushing butterflies when collecting waypoints.

Surveyors should record their survey tracks using their tablet or phone. This could be done using the Field Maps or a GPS application. Set the application to record your location along the track at 30-sec intervals. Once your track has been recorded during the first visit to a particular site, the tracking function can be turned off during the second visit and the same tracks can be

followed during the second survey. It will be critical that each surveyor download their survey tracks at the end of the season to describe survey effort and facilitate surveying the same routes in future years.

Overall butterfly diversity: All butterfly species seen during Karner blue surveys should be recorded in the Survey123 form used for each site (polygon). Because estimating relative abundance would be difficult for multiple species and likely to distract observers from surveying for Karners, observers should simply check off species of butterflies seen in the pull-down menu of the form and should not attempt to count species other than Karner blue.

Weather: At the start and end of the survey, record the temperature (°C), percent relative humidity, cloud cover (expressed as the % of sky occluded), and maximum wind speed (km/h). If a survey needs to be terminated because of poor weather conditions, collect that same weather information at the time the survey is ended.

Site characterization: Observers will collect general information about survey sites during each visit, such as potential threats, presence of lupine, and nectar sources. At least one representative photograph should be taken of each survey site during one of the two visits. Several potential threats to Karner blue and its habitats are listed on the data form. Place a check mark next to all those that apply to the survey site. Potential threats not listed can be entered by checking "Other" in the pull-down menu. For invasive plant species, rank the abundance of those species observed as dominant (D), abundant (A), frequent (F), occasional (O), or rare (R) in the form. Invasive species not listed can be added in the form under the "Other" field. Below is specific guidance on using the DAFOR scale.

Dominant (D): In practice, the dominant ranking is rarely, if ever used. To be scored as D, a species would have to be the most common plant by far, covering over 75% of the site. If you are not sure if a species should be scored as D, then assign it a score of A.

Abundant (A): Only use A if the species is common in many parts of the survey site. For most species, this would mean that there are thousands of individual plants present. At most sites, few species will be ranked as A. If you are unsure if a species should be scored as A or F, then give it a ranking of F.

Frequent (F): Use F if you find a species at several places within the survey site and more than just a few individuals are present at each location. You could also use F if a plant species only occurs at one part of the site but is common at that location, with many individuals observed and a substantial area covered (e.g., between one eighth and one quarter of the site). If you are not sure if a species should be scored as F or O, then assign it a score of O.

Occasional (O): Use O for species that occurs in several places in the site, but whose populations are small at those locations. You could also use O for species that are common

at one location but occupy a small area (e.g., less than one eighth of the site). If you are not sure if a species should be ranked as O or R, then give it a score of R.

Rare (R): Use R for species that occur as a small number of individuals within the site. These individuals may be located in one place or scattered over several locations. If you are unsure if a species should be scored O or R, then assign it a score of R.

A list of possible nectar plant species for Karner blue is provided in the form. Rank the abundance of each available (i.e., flowering) nectar species observed at the site using the same DAFOR scale described above for invasive plant species. Nectar sources not on the list can be added in the "Other" field.

Because lupine is the larval host plant and a potential nectar source for Karner blue, we will rank is relative abundance in two ways on the data form using the DAFOR scale. First, the relative abundance of flowering lupine can be ranked under the nectar source section of the data form. Second, you should rank the overall abundance of lupine (both flowering and non-flowering plants) within the "Site info (end)" section of the form. In dry years, lupine can begin senescing early, which can be noted in the "Additional notes" field of the form.

Appendix B. Maximum abundance and raw densities of sites surveyed every year.

Site	Maximum Abundance							Density						
	2015	2016	2017	2018	2021	2023	2024	2015	2016	2017	2018	2021	2023	2024
A001	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A003	0	0	1	0	0	0	0	0.00	0.00	0.08	0.00	0.00	0.00	0.00
A007	4	5	0	0	2	1	0	0.07	0.09	0.00	0.00	0.04	0.09	0.00
A019	0	13	32	26	13	0	4	0.00	10.23	25.19	20.47	10.23	0.00	3.15
A021	9	23	40	28	33	3	3	2.93	7.48	13.01	9.10	10.73	0.97	0.97
A033	0	12	6	1	0	0	0	0.00	306.98	153.49	25.28	0.00	0.00	0.00
A034	13	2	0	0	2	0	1	13.18	2.03	0.00	0.00	2.03	0.00	0.90
A037	29	66	36	40	44	58	23	121.33	276.13	150.62	167.35	184.09	242.55	96.18
A038	2	0	6	16	0	0	0	3.97	0.00	11.90	31.74	0.00	0.00	0.00
A046	6	50	28	42	24	14	37	3.39	28.27	15.83	23.75	13.57	6.97	18.43
A049	0	1	2	0	0	1	1	0.00	0.73	1.47	0.00	0.00	0.60	0.60
A051	6	9	20	4	2	3	5	21.19	31.78	70.62	14.12	7.06	3.74	6.23
A055	8	5	17	9	0	6	3	7.35	4.59	15.62	8.27	0.00	2.10	1.05
A059	20	291	408	309	81	188	364	1.39	20.21	28.33	21.46	5.63	13.05	25.27
A060	2	12	19	25	20	4	3	3.50	21.03	33.30	43.81	35.05	7.01	5.26
A062	0	5	6	9	0	0	0	0.00	2.81	3.37	5.06	0.00	0.00	0.00
A068	11	3	3	0	4	10	2	0.50	0.14	0.14	0.00	0.18	0.30	0.06
A070	1	1	0	2	1	0	0	1.56	1.56	0.00	3.13	1.56	0.00	0.00
A073	403	868	830	396	331	252	285	21.49	46.29	44.27	21.12	17.65	11.88	13.44
A075	0	0	4	1	2	0	1	0.00	0.00	4.38	1.10	2.19	0.00	1.09
A082	0	0	5	12	0	1	0	0.00	0.00	1.12	2.70	0.00	0.09	0.00
A086	26	46	10	12	11	18	25	2.22	3.93	0.85	1.02	0.94	1.54	2.14
A088	1	4	1	2	17	2	0	1.44	5.77	1.44	2.89	24.54	0.92	0.00
A090	0	0	1	1	0	1	0	0.00	0.00	2.49	2.49	0.00	0.83	0.00
A094	0	81	34	16	49	34	12	0.00	27.26	11.44	5.39	16.49	6.76	2.39
A100	2	9	5	7	2	0	0	0.59	2.66	1.48	2.07	0.59	0.00	0.00
A105	0	3	0	2	2	0	0	0.00	0.68	0.00	0.46	0.46	0.00	0.00
A106	0	4	1	0	0	0	0	0.00	2.20	0.55	0.00	0.00	0.00	0.00
A108	1	5	13	3	6	11	40	0.07	0.34	0.89	0.21	0.41	0.62	2.27
A111	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A115	2	8	19	9	0	2	7	0.08	0.31	0.73	0.35	0.00	0.07	0.24
A117	2	1	3	3	0	0	0	1.78	0.89	2.67	2.67	0.00	0.00	0.00
A121	99	68	18	51	11	0	0	11.05	7.59	2.01	5.69	1.23	0.00	0.00
A123	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A126	0	11	4	2	0	0	0	0.00	2.43	0.88	0.44	0.00	0.00	0.00
A129	0	0	0	0	0	0	1	0.00	0.00	0.00	0.00	0.00	0.00	0.11
A130	1	0	0	0	0	0	0	0.49	0.00	0.00	0.00	0.00	0.00	0.00
F006	2	0	1	0	0	0	0	0.19	0.00	0.09	0.00	0.00	0.00	0.00
Naïve Occ	**0.58**	**0.71**	**0.76**	**0.684**	**0.53**	**0.47**	**0.474**							
Max Abu	**650**	**1606**	**1573**	**1028**	**657**	**609**	**817**							
Raw Den								**5.78**	**21.43**	**15.74**	**11.11**	**8.81**	**7.90**	**4.73**

Appendix C. The change in maximum abundance and raw density from 2023 to 2024 for the 53 sites surveyed both years.

Site	23 Max Abundance	24 Max Abundance	Change	23 Density	24 Density	Change
A001	0	0	0	0.00	0.00	0.00
A001DS	84	246	162	4.63	13.56	8.93
A002	0	0	0	0.00	0.00	0.00
A002DS	72	92	20	2.62	3.35	0.73
A003	0	0	0	0.00	0.00	0.00
A007	1	0	-1	0.09	0.00	-0.09
A019	0	4	4	0.00	3.15	3.15
A021	3	3	0	0.97	0.97	0.00
A033	0	0	0	0.00	0.00	0.00
A034	0	1	1	0.00	0.90	0.90
A037	58	23	-35	242.55	96.18	-146.37
A038	0	0	0	0.00	0.00	0.00
A046	14	37	23	6.97	18.43	11.46
A049	1	1	0	0.60	0.60	0.00
A051	3	5	2	3.74	6.23	2.49
A055	6	3	-3	2.10	1.05	-1.05
A059	188	364	176	13.05	25.27	12.22
A060	4	3	-1	7.01	5.26	-1.75
A062	0	0	0	0.00	0.00	0.00
A068	10	2	-8	0.30	0.06	-0.24
A070	0	0	0	0.00	0.00	0.00
A073	252	285	33	11.88	13.44	1.56
A075	0	1	1	0.00	1.09	1.09
A082	1	0	-1	0.09	0.00	-0.09
A086	18	25	7	1.54	2.14	0.60
A088	2	0	-2	0.92	0.00	-0.92
A090	1	0	-1	0.83	0.00	-0.83
A094	34	12	-22	6.76	2.39	-4.37
A100	0	0	0	0.00	0.00	0.00
A105	0	0	0	0.00	0.00	0.00
A106	0	0	0	0.00	0.00	0.00
A108	11	40	29	0.62	2.27	1.64
A111	0	0	0	0.00	0.00	0.00
A115	2	7	5	0.07	0.24	0.17
A117	0	0	0	0.00	0.00	0.00
A121	0	0	0	0.00	0.00	0.00
A123	0	0	0	0.00	0.00	0.00
A125	0	0	0	0.00	0.00	0.00
A126	0	0	0	0.00	0.00	0.00
A129	0	1	1	0.00	0.11	0.11
A130	0	0	0	0.00	0.00	0.00

Appendix C. Continued.

A201	0	0	0	0.00	0.00	0.00

A202	0	0	0	0.00	0.00	0.00
A203	2	1	-1	3.51	0.38	-3.12
A204	0	0	0	0.00	0.00	0.00
A205	0	0	0	0.00	0.00	0.00
A207	0	0	0	0.00	0.00	0.00
A208	21	168	147	3.28	26.23	22.95
F001DS	0	0	0	0.00	0.00	0.00
F002DS	0	0	0	0.00	0.00	0.00
F003DS	18	55	37	5.22	15.94	10.73
F006	0	0	0	0.00	0.00	0.00
P009	56	553	497	2.32	22.89	20.57

Appendix D. Habitat attributes collected at each survey site in Allegan, Flat River, and Muskegon state game areas in 2024. Pennsylvania (Penn) sedge and lupine abundance are on the DAFOR scale (dominant, abundant, frequent, occasional, rare). DAFOR rankings for each invasive plant and nectar plant species were converted to numeric values (1-5), and the scores represents the sum of those values at each site. In 2024, we collected ant mound data for the first time by estimating the total number of active mounds per site.

Area	Site name	General Threats	Penn Sedge Abundance	Invasive Plant Score	Nectar Score	Lupine Abundance	Est. No. of Active Ant Mounds
Allegan	A001	Shrub encroachment	frequent	0	1	rare	0
	A001DS	Shrub encroachment, ORV damage	abundant	2	15	frequent	220
	A002	Shrub encroachment	rare	0	0	none	0
	A002DS	Shrub encroachment, ORV damage, Equestrian	abundant	3	21	frequent	150
	A003	Shrub encroachment	frequent	0	1	rare	25
	A007		abundant	0	10	rare	0
	A019	Shrub encroachment	abundant	0	12	abundant	25
	A021	Shrub encroachment	abundant	1	11	abundant	30
	A033	Shrub encroachment	abundant	0	0	rare	5
	A034			0	8	occasional	0
	A037	Shrub encroachment, ORV damage, Bracken fern	frequent	1	7	abundant	22
	A038	Shrub encroachment	frequent	0	10	occasional	9
	A046	Shrub encroachment, ORV damage	rare	2	14	abundant	12
	A049	Shrub encroachment	frequent	0	3	rare	12
	A051	Shrub encroachment	frequent	0	8	occasional	21
	A055	Shrub encroachment	frequent	0	2	frequent	40
	A059	Shrub encroachment, ORV damage	abundant	1	16	abundant	200
	A060	Shrub encroachment	abundant	0	0	frequent	2
	A062	Shrub encroachment	abundant	1	8	none	0
	A068	Shrub encroachment, ORV damage	dominant	2	19	abundant	1
	A070	Shrub encroachment	frequent	0	0	rare	0
	A073	Shrub encroachment, ORV damage	frequent	1	24	occasional	250
	A075	Shrub encroachment	frequent	0	0	occasional	12
	A082	Shrub encroachment, ORV damage	abundant	3	14	frequent	28
	A086	ORV damage, Equestrian	abundant	3	19	frequent	75
	A088	Equestrian	abundant	0	15	rare	12
	A090	Shrub encroachment	abundant	1	16	rare	0
	A094	ORV damage, Equestrian	abundant	1	21	occasional	8
	A100	Shrub encroachment, ORV damage	occasional	0	9	occasional	4

Appendix D. Continued.

	A105	Shrub encroachment, ORV damage, Herbicide	abundant	1	18	frequent	55
	A106	Shrub encroachment, ORV damage	dominant	0	13	rare	5
	A108	Shrub encroachment, ORV damage	abundant	2	21	abundant	250
	A111	Shrub encroachment	occasional	0	6	occasional	12
	A115	Shrub encroachment, ORV damage	abundant	2	25	frequent	210
	A117	ORV damage	dominant	0	7	rare	22
	A121		abundant	0	22	abundant	1
	A123	Shrub encroachment	abundant	0	19	occasional	6
	A125	Shrub encroachment, ORV damage	occasional	2	14	abundant	0
	A126	Shrub encroachment, ORV damage	dominant	0	16	frequent	35
	A129	Shrub encroachment	frequent	1	26	abundant	0
	A130	Shrub encroachment	frequent	0	2	rare	0
	A201	ORV damage	abundant	0	1	frequent	17
	A202	Shrub encroachment	occasional	0	19	frequent	0
	A203	Shrub encroachment, ORV damage	rare	0	9	frequent	0
	A204			0	8	occasional	0
	A205	Shrub encroachment, ORV damage, Dumping	abundant	0	8	frequent	0
	A207	Shrub encroachment, ORV damage	dominant	2	17	abundant	30
	A208	Shrub encroachment, ORV damage	abundant	2	12	frequent	70
	A301	Shrub encroachment	abundant	1	9	rare	0
	A302	ORV damage	abundant	1	11	none	0
	A303	Shrub encroachment, ORV damage	abundant	0	9	abundant	0
	A304	Shrub encroachment, ORV damage	frequent	0	16	abundant	1
	A305	Spotted knapweed	abundant	1	13	occasional	0
	A306	Shrub encroachment	frequent	1	12	none	0
	A307	Shrub encroachment, ORV damage	dominant	0	10	rare	0
	A308	Shrub encroachment	dominant	0	14	occasional	0
	F001DS	Shrub encroachment	none	0	12	rare	15
	F002DS	Shrub encroachment, ORV damage	none	0	30	rare	10
Flat River	F003DS	Shrub encroachment, ORV damage	rare	2	20	frequent	26
	F006	Shrub encroachment	none	1	9	rare	3
	M100	Shrub encroachment, ORV damage		0	21	frequent	0
Muskegon	M101	Shrub encroachment, ORV damage		1	15	abundant	0
	M102	Shrub encroachment, Tractor/car	none	1	20	abundant	0

Appendix D. Continued.

M103	Shrub encroachment, Tractor/car	none	0	10	rare	0