Investigating the Use of Digital Surface Models to Assess Vegetation Succession to Inform Conservation and Recovery of Eastern Massasaugas

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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: Eastern Massasauga (*Sistrurus catenatus*) Habitat with Shrub Encroachment, Waterloo State Recreation Area. Photo by Yu Man Lee. Eastern Massasauga. Photo by Joseph Sage.

EXECUTIVE SUMMARY

Conservation of eastern massasauga rattlesnakes (*Sistrurus catenatus*, Federal and State Threatened) in Michigan is critical to the recovery of the species rangewide. Recovery of the eastern massasauga will require sustaining multiple, robust populations with stable or increasing demographic rates and sufficient quantities of high-quality habitat distributed across Michigan over the long term. Eastern massasaugas utilize early successional wetland and upland habitats with open or sparse canopy areas intermixed with shaded areas for thermoregulation, foraging, gestation/parturition, and retreat from predators (Sage 2005, Lipps 2008, Szymanski et al. 2016). Vegetative succession, typically through encroachment of woody vegetation and the introduction of nonnative or invasive species, has contributed significantly to habitat loss and degradation in many massasauga populations (Reinert and Buskar 1992, Johnson and Breisch 1993). Assessing the risk or degree of vegetative succession or canopy closure (i.e., through increase in shrubs, trees, and/or nonnative or invasive species) within and across massasauga populations can help target, prioritize, and evaluate habitat management to sustain these populations and help recover the species. However, the number and extent of massasauga populations in Michigan and limited resources to date have made it challenging to assess and determine the current status, potential viability, and threats, including vegetative succession, facing individual populations in the state. Additionally, current methods for assessing vegetative succession, which include aerial imagery interpretation, comparison of temporal land cover data, and field assessments, can be time- and resource-intensive, particularly if assessing large areas or multiple sites, and results may not be at a fine enough resolution to target management. As a result, habitat management or restoration may not occur where needed or may not be as strategic or as effective as they could be given limited information to help target, prioritize, and evaluate management.

This pilot project investigated the use of digital surface models (DSMs) in combination with other remote sensing imagery, land cover data, and geoprocessing to model and assess canopy cover (i.e., shrub and tree cover) within eastern massasauga populations to identify areas that may be undergoing vegetative succession and could benefit from management to enhance habitat for massasaugas. This project focused on nine priority or focal massasauga populations in two primary study regions, the Shiawassee River Headwaters region in southeast Michigan and Barry County in southwest Michigan. To conduct this project, Michigan Natural Features Inventory (MNFI) enlisted the expertise and assistance of Michigan Tech Research Institute (MTRI). Michigan Tech Research Institute compiled and used a time series of available high-resolution optical and DSM imagery, an existing wetland type map, and eastern massasauga element occurrences (EOs), field locations, and habitat condition data from MNFI to model and evaluate changes in shrub and tree cover, vegetation height, and canopy closure across critical habitat within the focal populations. A total of 31 available multispectral Worldview (DigitalGlobe/MAXAR) scenes and 16 total available stereopair-derived digital surface models (DSMs) were compiled for the two study regions combined. Additional layers were derived from the multispectral and DSM data to supplement the data stacks, including the normalized difference vegetation index (NDVI) and topographic position index (TPI). Data stacks and training data were read into the machine learning algorithm Random Forest (Breiman 2001) to

generate output pixel-based classifications which were reclassified to include only woody canopy classes of forest and shrub. For two priority massasauga sites and all massasauga EOs within the focal populations in the two study regions, we calculated the estimated area (total acres per class) and percentage (area target class/total area within the population or unit within a population) of shrub, forest, and combined shrub and forest canopy cover. We also conducted a neighborhood assessment in one study region in which the percent canopy cover within a 10 m x10 m (5 x 5 pixel area) neighborhood window around each pixel was calculated. To better understand where changes in shrub, forest and total canopy were occurring, final canopy maps from different dates with overlapping footprints were intersected to create canopy cover change maps for focal populations within the two study regions. We compared canopy acreages and percentages over time, where available, in order to understand general succession and shrubification patterns throughout the focal populations. We also compared available DSM data within intersecting footprints between different time periods to assess canopy height changes. To validate the model results, we collected data on shrub and forest cover in the field within two priority sites. We also evaluated the model results using high resolution NAIP aerial imagery and information from the land managers of the two sites.

Canopy cover and canopy change maps indicating areas with and changes in shrub and/or forest cover were generated for available time periods for focal populations within the two study regions. Areas that were estimated as having 50% or greater canopy cover were flagged for potential management. Percent cover estimates of shrub and/or forest cover ranged from <1% to 56% within two priority massasauga sites that have been actively managed to maintain open habitat conditions. Canopy cover was less than 50% across all the units and available time periods within these two priority sites except for two instances. Percent cover estimates of shrub and/or forest cover within massasauga EOs in the focal populations ranged from 0% to 98% but were generally below 50% except in a small number of locations. The neighborhood assessment identified specific local areas within sites with greater than 50% shrub and/or forest cover even though estimated canopy cover was less than 50% across an entire unit or site. After integrating the field data collected from canopy change areas with the NAIP validation data on unchanged areas across two sites, the overall accuracy was 85% when canopy classes were combined and 68% when forest and shrub were assessed separately. Comparing available DSM data within intersecting footprints between different time periods to assess canopy height changes had mixed results. Upon further investigation, this analysis was not possible since the DSMs were not normalized between scenes. Accuracy of the canopy change assessments was variable based on information from the land managers of the two sites.

Results from this pilot approach demonstrate that using high resolution Worldview 8 band imagery and corresponding DSMs can provide a useful resource for monitoring presence and change in extent of forest and shrub canopy for eastern massasauga habitat. Additional work is needed though to further evaluate and increase the accuracy and effectiveness of this approach. This includes securing additional and current DSMs and Worldview imagery, normalizing DSMs, and conducting field validation in additional areas. This approach could be used to target and prioritize habitat management efforts to sustain eastern massasauga populations in Michigan and better determine and secure resources needed to accomplish this.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Michigan Department of Natural Resources (MDNR), Wildlife Division. The following MNFI seasonal field technicians assisted with the field validation sampling: Justin Florkowski and Morgan Boyer. Administrative support was provided by Ashley Adkins, Brian Klatt, Sarah Carter, and Deb Richardson. We would like to thank Jennifer Kleitch with the MDNR Wildlife Division for her assistance and communications throughout this project. We also would like to thank the following MNFI staff and partners for providing information and consultation for this project: Dr. Jennifer Moore, Grand Valley State University; Helen Enander, MNFI GIS Analyst; Mike Losey, Springfield Township; and Andrew Bacon, Michigan Nature Association.

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INTRODUCTION

Conservation of eastern massasauga rattlesnakes (*Sistrurus catenatus,* Federal and State Threatened) in Michigan is critical to the recovery of the species rangewide. The U.S. Fish and Wildlife Service listed the eastern massasauga rattlesnake (EMR) as threatened under the federal Endangered Species Act in 2016 (U.S. Fish and Wildlife Service [USFWS] 2016). As of 2016, the number of presumed extant populations of eastern massasaugas rangewide (n=347) had declined by 38% from the number that was known historically, and the species' extent of occurrence had declined by 41%, particularly in the southern and western parts of its range (Szymanski et al. 2016, U.S. Fish and Wildlife Service [USFWS] USFWS 2016). Of the 347 presumed extant populations of eastern massasaugas rangewide in 2016, 139 (40%) were presumed to be quasi-extirpated (i.e., have 25 or fewer adult females), and only 105 (30%) were presumed to be demographically, genetically, and physiologically robust with only 19 (0.5%) presumed to be self-sustaining (Szymanski et al. 2016, USFWS 2016). The recovery vision for eastern massasaugas is that healthy populations are conserved in sufficient number and distribution to ensure the species' long-term viability (USWFS 2021). The strategy for achieving this vision includes identifying, managing, and conserving 135 robust populations among three conservation units (87 in the Central Unit which includes Michigan, Indiana and Ohio) and adequate quantity and configuration of high-quality summer and winter habitats to support these populations (USFWS 2021). Although the eastern massasauga is currently listed as State Threatened and has been identified as a Species of Greatest Conservation Need (SGCN) in Michigan's Wildlife Action Plan (Derosier et al. 2015), Michigan is considered to be the last stronghold for the species with more extant or presumed extant populations than any other state or province (205 [59%] of the 347 presumed extant populations rangewide in 2016, Szymanski et al. 2016). Additionally, a climate change vulnerability assessment for the eastern massasauga utilizing spatially explicit demographic models and climate and land cover variables predicted more populations with high probability of persistence in the northeastern part of the species' range, particularly in northern Michigan and Ontario, than in other parts of its range (Pomara et al. 2014). Recovery of the eastern massasauga rangewide will require sustaining multiple, robust, and resilient populations distributed across Michigan over the long term.

To sustain eastern massasauga populations over the long term, they require appropriate demographic rates and a sufficient quantity of high quality or suitable habitat. During the active season, massasaugas utilize wetland and/or upland habitats with early successional and open or sparse canopy areas intermixed with shaded areas for thermoregulation, foraging, gestation/parturition, and/or retreat from predators (Sage 2005, Lipps 2008, Szymanski et al. 2016). Suitable massasauga habitats in Michigan and across the species' range include bogs, fens (Kingsbury et al. 2003, Marshall et al. 2006), wet meadows, wet prairies, moist grasslands, marshes, shrub swamps (Wright 1941, Seigel 1986, Sage 2005), floodplain forests (Moore and Gillingham 2006), coniferous forests (Harvey and Weatherhead 2006), scrub-shrub forests, forest edges (DeGregorio et al. 2011), old fields (Reinert and Kodrich 1982), barrens, and savannas. In addition to active season habitat, suitable overwintering habitat also must be available and hydrological and ecological processes that create and maintain suitable habitat must be intact to maintain populations over time (Szymanski et al. 2016).

The primary threats to long-term viability of eastern massasauga populations in Michigan and across the species' range include habitat loss, degradation, and fragmentation, especially through development and vegetative succession (Szymanski et al. 2016, USFWS 2016). Road mortality, hydrological alterations resulting in drought or flooding, persecution, collection, mortality due to habitat management, and disease also have contributed to the species decline (Szymanski et al. 2016, USFWS 2016). Vegetative succession, typically through encroachment of woody vegetation and the introduction of nonnative or invasive species (e.g., glossy buckthorn, *Frangula alnus*), has contributed significantly to habitat loss and degradation in many (i.e., 81%, Szymanski et al. 2016) extant massasauga populations (Reinert and Buskar 1992, Johnson and Breisch 1993). Reducing open canopy areas and altering habitat structure and quality can decrease and eventually eliminate thermoregulatory and retreat areas for massasaugas, reduce the prey base, and adversely impact massasauga populations (Kingsbury 2002, Szymanski et al. 2016, USFWS 2016). Recent results from occupancy modelling found canopy cover (i.e., of shrubs and trees) to be the most important factor for determining habitats that support massasaugas (Thacker 2020, Thacker et al. 2023). Models showed that the probability of massasauga occupancy effectively dropped to zero as canopy cover approached 50-60% coverage (Thacker 2020, Thacker et al. 2023). These results illustrate the importance of maintaining open canopy habitat for sustaining viable eastern massasauga populations.

Assessing the risk or degree of vegetative succession or canopy closure (i.e., through increase in shrubs, trees, and/or nonnative or invasive species) within and across massasauga populations can help target, prioritize, and evaluate habitat management to sustain these populations and help recover the species. However, the abundance of populations and habitat for this species in Michigan and limited resources to date have made it challenging to ascertain the status, potential viability, and type and level of threats, including vegetative succession or canopy closure, facing individual populations in the state. Additionally, current methods for assessing vegetative succession/canopy cover include aerial imagery interpretation, comparison of temporal land cover data, and field assessments which can be time- and resource-intensive, particularly if assessing large areas or multiple sites, and results may not be at a fine enough resolution to target management. As a result, habitat management or restoration may not occur where needed or may not be as strategic or as effective as they could be given limited information to help target, prioritize, and evaluate management.

This pilot project investigated the use of digital surface models (DSMs) in combination with other remote sensing imagery, land cover data, and geoprocessing to model and assess canopy cover (i.e., shrub and tree cover) at sites within massasauga populations to identify areas that could benefit from habitat management to enhance habitat for massasaugas. A digital surface model is an elevation model that represents the topography of the Earth's surface and captures and maps both the natural and built/artificial features on it, including buildings, trees, powerlines, and other objects (Figure 1). A digital surface model can be viewed as a canopy model as it only maps the tops of all above ground features where there is nothing else above it (Marwaha and Duffy 2021). Digital surface models are generated by applying fully automated, stereo auto-correlation techniques to overlapping pairs of high-resolution optical satellite images using the open-source Surface Extraction from TIN-based Searchspace Minimization

(SETSM) software, developed by M.J. Noh and Ian Howat at the Ohio State University. Digital surface models and other data from different time periods, if available, could be used to model, assess, and monitor change in vegetation conditions over time. This approach, if effective, could provide an accurate, high resolution, and more efficient process for assessing canopy cover/vegetative succession within massasauga populations across Michigan and potentially rangewide.

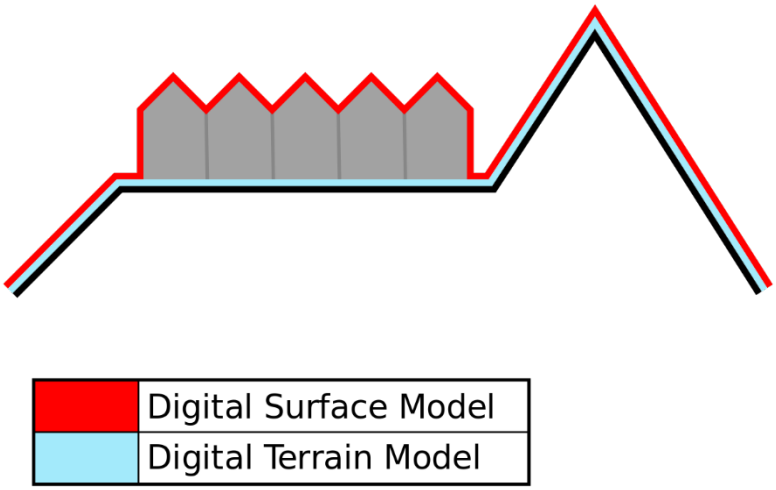


Figure 1. Diagrams illustrating concept of a digital surface model (DSM) compared to a digital terrain model (DTM) or digital elevation model (DEM).
(Top diagram by Yodin based on file: DTM DSM.png by User: MartinOver., CC BY-SA 4.0, Wikipedia, https://commons.wikimedia.org/w/index.php?curid=44279694. Bottom diagram by Anindya Naskar 2021, 3D Digital Surface Model with Python and Pylidar, https://thinkinfi.com/3d-digital-surface-model-with-python-and-pylidar/)

METHODS

Project Objective

This project addressed the following objective:

1) Investigate the use of digital surface models (DSMs) and other available remote sensing data and geoprocessing tools to develop a model and GIS (Geographic Information System) layer showing amount of canopy cover/vegetation succession in occupied and adjacent habitats within two focal eastern massasauga populations in Michigan.

Study Area

This project focused on nine priority or focal eastern massasauga populations in two primary study regions in southern Michigan which included six focal populations in the Shiawassee River Headwaters region in northwest Oakland County and three focal populations in Barry County (Figure 2). These populations were identified and delineated in 2015 based on a population model using known massasauga element occurrences (EOs) in Michigan's Natural Heritage Database (NHD) and a cost-weighted distance analysis (Lee and Enander 2015). An element occurrence is an area of land or water where an element of biodiversity (in this case, an eastern massasauga) currently or historically occurred. Each EO may be comprised of multiple observations of a species (or natural community) through space or time. The delineated massasauga populations often included multiple EOs and sites. Delineated massasauga populations ranked as having excellent, good, or fair estimated viability were then evaluated based on a number of criteria and expert knowledge or opinion in 2016-2017 to identify priority or focal populations for management to sustain the species in perpetuity in the state (Lee 2017). Multi-year, intensive population monitoring has been occurring at specific sites within three of the focal populations included in this study, two in the Shiawassee study region [redacted] and one in the Barry study region [redacted] (Figure 2). Eastern massasauga presence surveys have been conducted at additional sites within these populations [redacted] (Figure 2).

Figure 2. Map of the eastern massasauga element occurrences (EOs) in the Michigan Natural Heritage Database (blue) (MNFI 2023), focal populations (pink), and specific sites (i.e., [redacted] within three focal populations in the Shiawassee River Headwaters and Barry County regions that were included in the modelling and/or field validation components of this project.

Data Compilation

To conduct this project, Michigan Natural Features Inventory (MNFI) enlisted the expertise and assistance of Michigan Tech Research Institute (MTRI). MTRI has extensive experience using remote sensing to model habitat conditions to inform and guide natural resource management including the use of DSMs (see this StoryMap for more information). Michigan Tech Research Institute has access to DSMs for areas within Michigan, which are currently only available to federal agencies. In order to assess habitat conditions for eastern massasauga rattlesnakes (EMRs) geospatially, MTRI compiled and used a time series of high-resolution optical and DSM imagery, their existing wetland type map for the state of Michigan, and eastern massasauga element occurrences (EOs), field locations, and habitat condition data from MNFI to evaluate changes in shrub and tree cover, vegetation height, and canopy closure across critical habitat within the focal populations. Quantifying shrub cover provided insights into habitat conditions as increased shrubification and canopy closure are known indicators of massasauga habitat degradation. Shrub cover was assessed through traditional landcover classification extents and percent cover estimates. Prior to data compilation and modelling shrub and tree canopy cover, MNFI and MTRI staff met with Dr. Jennifer Moore from Grand Valley State University, a project partner, to discuss and provide information on eastern massasauga ecology and habitat needs, including the impact of canopy cover on massasaugas, to help inform modelling efforts.

Michigan Tech Research Institute compiled a total of 31 available multispectral Worldview (DigitalGlobe/MAXAR) scenes and 16 total available stereopair-derived digital surface models (DSMs) (Klassen et al. 2021) for the two study regions combined. These included 22 total available multispectral Worldview scenes that covered the Shiawassee River Headwaters study region ranging from April 2006 to August 2023, and 9 stereopair-derived digital surface models (DSMs) (Klassen et al. 2021) ranging from March 2010 to August 2017. The Barry County study region had nine available multispectral Worldview scenes ranging from August 2009 to May 2020 and seven DSMs from August 2008 and 2017. We aggregated overlapping extents of multispectral and DSM data for mapping by date, resulting in six data stacks for classification (Table 1). In the Shiawassee study region, we included multispectral images from June 19, 2022 and June 1, 2023 for mapping despite the lack of available DSM data for this time period so that canopy cover maps could be compared to current conditions and management in the field for model validation (Table 1). Without the DSM, we expected higher confusion between forest and shrub canopy for the maps generated from the 2022 and 2023 multispectral images.

Table 1. Data stacks were prepared by overlapping geographic region and image collection date.

Study Region	Multispectral Worldview Date	Digital Surface Model (DSM) Date	Notes
Shiawassee	June 1, 2023	NA	Partial coverage from multispectral. No DSM available.
Shiawassee	June 19, 2022	NA	Partial coverage from multispectral. No DSM available.
Shiawassee	June 2, 2016	June 12, 2017 (west) August 27, 2014 (east)	Multiple DSM dates were used as individual DSM layers did not cover full extent.
Shiawassee	June 27, 2012	May 19, 2012	Partial coverage from available DSM. Rest of area classified with only multispectral.
Shiawassee	May 22, 2011	March 16, 2010	Partial extent for both multispectral and DSM.
Barry	September 24, 2017	September 24, 2017	
Barry	June 27, 2012	May 19, 2012	Partial coverage from available DSM. Rest of area classified with only multispectral.
Barry	October 5, 2011	August 26, 2008	Partial scenes on far east and far west. No data available in the central region.

Additional layers were derived from the multispectral and DSM data to supplement the stacks (Figure 3). For each multispectral image, we calculated the normalized difference vegetation index (NDVI). This index quantifies vegetation health and density by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). NDVI values range from -1.0 to 1.0, with negative values indicating clouds and water, positive values near zero indicating no vegetation or bare soil, and higher positive values indicating sparse or unhealthy to dense, healthy vegetation as values approach 1. For each DSM, we also generated the topographic position index (TPI) (Weiss 2001), which relates each pixel's elevation to the neighboring cells of a set window size, at the 100 m and 500 m scale. These TPI layers differentiate shrub and tree height differences from surrounding ecotypes while minimizing the variation of DSM absolute heights across the scene.

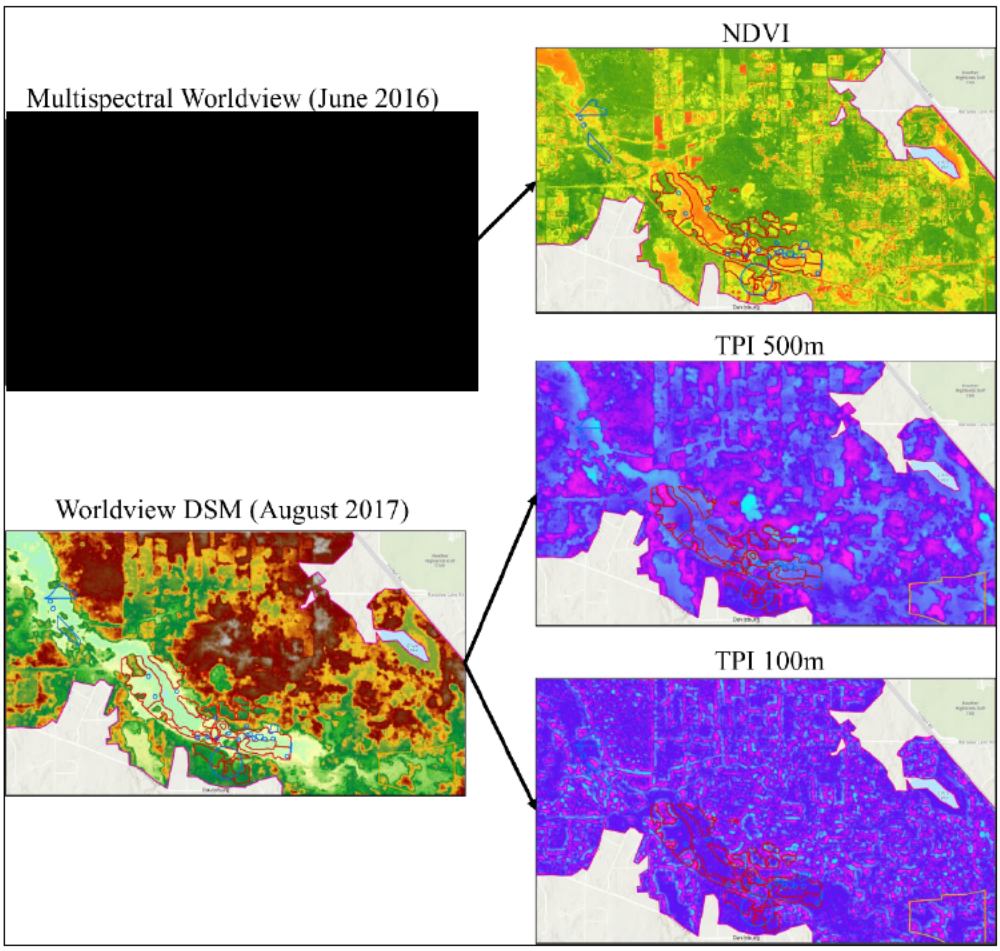


Figure 3. Data stack for each map classification included eight bands of multispectral worldview, the normalized difference vegetation index (NDVI), and two topographic position index (TPI) layers derived from the digital surface model (DSM).

Canopy Cover Modeling and Assessment

Canopy Mapping

Training data polygons were generated for each of the final data stacks from image interpretation of the high-resolution data. Non-shrub and non-forest landcover classes, such as developed, agriculture, water, and emergent wetland, were included as necessary to assist the decision-making process of the classifier. Data stacks and training data were read into the machine learning algorithm Random Forest (Breiman 2001) to generate output pixel-based classifications and classification confidence layers. The confidence data represents the percentage of votes the classifier put toward each class, with the highest ranked class assigned to the pixel (note this may have been less than 50% for a given pixel). Output classifications were reclassified to include only woody canopy classes of forest and shrub (Figure 4).

We compared forest and shrub class extents to image stacks and assigned threshold masks where appropriate from the confidence layer (e.g., for the Barry 2011 classification, only pixels with $\geq$ 60% confidence were kept in the final classification). In the Shiawassee study region, we made additional manual edits within specified regions of prioritized eastern massasauga habitat (i.e., within [redacted], and EO regions) (Figure 2).

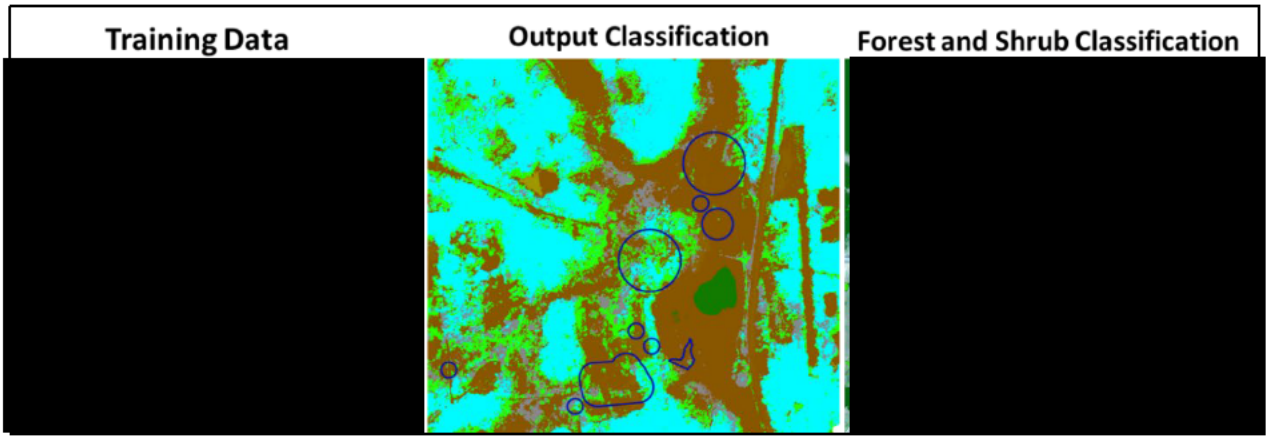


Figure 4. Sample data were drawn for representative classes within the image stack. Output classifications were created with Random Forest and the non-woody (shrub or forest) classes were removed. Training data are represented by red and yellow polygons. Blue circles represent MNFI locations of eastern massasauga element occurrences. Output classifications (center) were assigned random colors until canopy symbology (shrub = light green, forest = dark green) was assigned.

Land Cover Analysis

We used a highly accurate wetland type map previously generated by MTRI for Michigan using multi-temporal, multi-sensor data (https://geodjango.mtri.org/coastal-wetlands/) to identify fens and other emergent wetlands within the study populations. This circa 2010 map was generated using multispectral Landsat and synthetic aperture radar (SAR) PALSAR data at a 12.5 m pixel resolution and 0.2 ha minimum mapping unit and had a total accuracy of 81%. Twenty-four distinct landcover classes are included in this classification, of which 11 classes are wetland types. Eastern massasaugas are typically found within fen and emergent wetland types, particularly in southern Michigan. Therefore, these class extents from the landcover map were compared with the canopy maps generated from the 2-m resolution Worldview data to focus the canopy cover assessment within these wetland classes.

In heterogeneous wetland areas, particularly where the separate type patches were smaller than 12.5 m x 12.5 m, only assessing fen and emergent wetland classes excluded large areas of desirable massasauga habitat. This was particularly evident within the [redacted] Since the boundaries of these focal populations already did a good job of delineating potential massasauga habitat from non-habitat, we used the boundaries of these populations to assess and estimate area and percentage of canopy cover (i.e., shrub and tree cover) instead of using the land cover maps.

The eastern massasauga element occurrences (EOs) within the focal populations outside of [redacted] however, included both potential habitat and non-habitat land cover classes such as agriculture, development, water, and upland forests. The landscape or land cover maps for these EOs were very helpful in removing non-target areas from the canopy cover analysis. We reclassified non-target land cover classes (e.g., urban, suburban, urban grass, urban road, agriculture, upland forest, pine plantation, barren light, and forested wetland) within these EOs into a non-habitat land cover mask (Figure 5). We excluded these masked out areas from the analysis and all canopy area and percentage estimates within the EO boundaries.

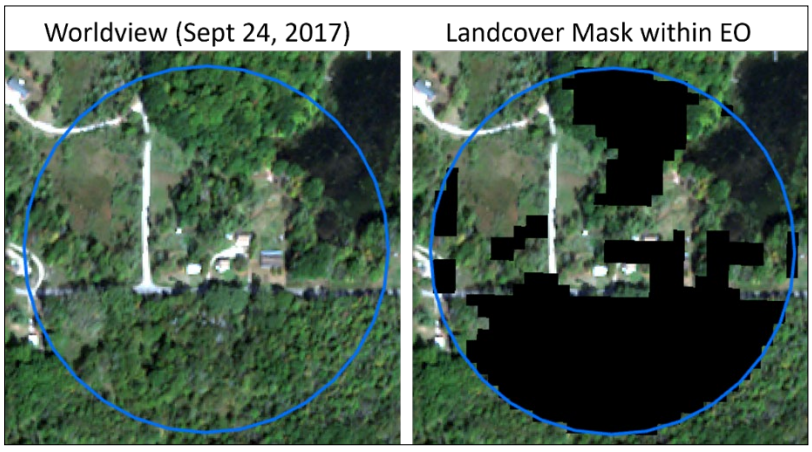


Figure 5. Example of the generated land cover mask excluding non-massasauga habitat from the canopy assessments within eastern massasauga element occurrences (EOs) in the focal study populations.

Canopy Cover

We assessed the final canopy (i.e., of forest and shrub classes) maps for each focal population and available time period for total canopy cover. In general, eastern massasauga rattlesnakes prefer wetland areas with less than 50-60% total canopy cover (Thacker 2020). For each focal population or units within a population, we calculated the estimated area (total acres per class) and percentage (area target class/total area within the population or unit within a population) of shrub, forest, and combined shrub and forest canopy cover. Areas that were estimated as having 50% or greater canopy cover were flagged for potential management. Land cover masks, as described above, were utilized to remove areas of non-massasauga habitat within the massasauga EO data extents from canopy cover estimations. These masks were not applied for the [redacted] target populations as those boundaries primarily only captured possible massasauga habitat.

In addition to the total percentage canopy for each population extent, we conducted a neighborhood assessment for a portion of the Shiawassee River Headwaters study region. For each pixel, the percent canopy within a 10 m x10 m (5x5 pixel area) neighborhood window around it was calculated. This analysis allows managers to assess canopy density at a more local scale from any given point within a population. These neighborhood values were calculated for shrubs, forest, and combined total canopy (Figure 6).

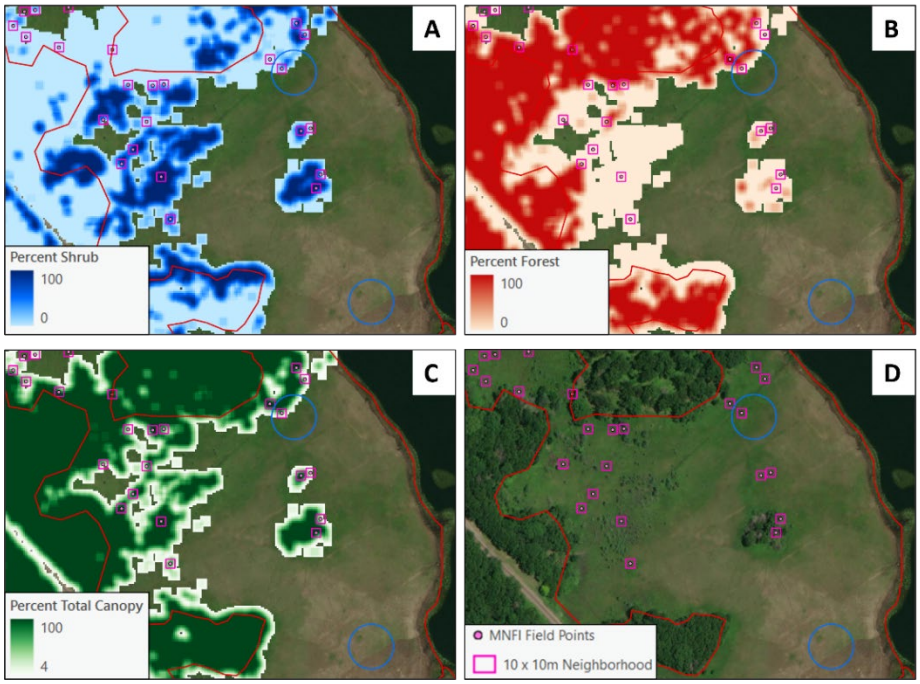


Figure 6. Example of the neighborhood assessment of canopy cover within a 10 m x10 m plot around each given pixel for class types: A) shrub, B) forest, and C) total canopy compared to D) base imagery. Areas with darker shades of the color indicate higher percent cover of the respective class type.

Canopy Change

To better understand where the changes in shrub, forest and total canopy were occurring, final canopy maps from different dates with overlapping footprints were intersected to create canopy cover change maps for focal populations within each of the two study regions (Figure 7). We compared canopy areas and percentages over time where available in order to understand general succession and shrubification patterns throughout the focal populations, particularly in the [redacted] populations. These maps allow managers to identify more dynamic and stable canopy areas within the focal study populations. Areas with increasing canopy/shrub trends were noted for potential management.

Final outputs were reclassified as follows:
Forest = Classified as forest in both time periods.
Shrub = Classified as shrub in both time periods.
Forest Gain = Classified as forest in the newer map but not in the older map.
Shrub Gain = Classified as shrub in the newer map but not in the older map.
Forest Loss = Classified as forest in the older map but not in the newer map.
Shrub Loss = Classified as shrub in the older map but not in the newer map.
Forest/Shrub Mix = Classified as forest in the older map and as shrub in newer or vice versa.

Canopy Height Change

In addition to being used in the canopy classifications, we compared available DSM data within intersecting footprints between different time periods to assess canopy height changes. We focused this analysis on two priority sites within the [redacted] populations. We calculated average, minimum, and maximum change trends for each of the seven canopy change classes within the [redacted]. We expected that, in general, woody vegetation classes would grow taller both throughout one season and across multiple years.

Figure 7. Example of canopy change between 2023 and 2022 within a priority site within the [redacted] The polygons outlined in orange indicate areas with open wetland or upland habitats that represent suitable massasauga habitat. Field validation sampling points are represented in pink. Note that for 2022 and 2023, digital surface model data were not available to include in the canopy classifications.

Field Validation

Canopy Cover

To validate the model output/results, we collected data in the field on shrub and tree cover at randomly selected points within two sites [redacted] associated with the [redacted] in the Shiawassee River Headwaters study region (Figure 2). We focused the field validation sampling on this population because we had canopy cover model results from 2022 and 2023 for this population that could be compared with current canopy conditions in the field. The canopy model results for focal populations in the Barry County study region were based on imagery from 2014 or 2017 (latest years for available DSM and Worldview imagery for the area around these focal populations). We decided that field data collected in 2023 might not correlate well with model results based on DSM and imagery from 2017, and as a result, we did not conduct field testing of the model results for focal populations within the Barry County study region. Additionally, we have been conducting massasauga surveys within the [redacted] and had access to sample sites within this population. The [redacted] site within the [redacted] is one of the target study populations where we reviewed the canopy maps and made additional manual edits to the maps, and thus map accuracy was expected to be higher. While the [redacted] site is within the [redacted] focal population, we did not make additional post-processing edits to the canopy map for this site and so this site was more representative of the rest of the non-target mapped areas within the SBP and other focal populations. Since most of the map dates for the SBP were more than 6 – 15 years ago, only the 2022 and 2023 canopy maps were viable for field validation. It is again of note that these maps did not have available DSM data to supplement the models, thus increasing uncertainty between shrub and forest classes.

We developed a sampling protocol for estimating canopy (shrub and tree) cover in the field that would help evaluate the model outputs. We also strived to develop a method that would be accurate and practical for other researchers and land managers to potentially implement in the field at their respective sites. To validate the 2022-2023 canopy cover maps, we randomly selected 80 total field sampling points within each of the two field validation sites within the SBP. We randomly selected 20 field validation points in each of four classes from the 2023-2022 canopy change map (i.e., shrub gain, shrub loss, forest gain, forest loss) (Figure 7). Eleven of the randomly selected sampling points in the [redacted] site were inaccessible to the field team. These points were replaced with eleven new points selected by the field team at locations with potential inconsistencies between the 2023 canopy model and the actual vegetation cover in the field. We sampled 80 points at one site ([redacted]) and 61 points at the second site ([redacted]), for a total of 141 field validation points. We overlaid a 2 m x 2 m plot and a 10 m x 10 m plot around each field validation point. Within the 2 m x 2 m plot around each field validation point, we visually estimated percent canopy cover of shrubs and trees separately and estimated the canopy cover of shrubs and trees combined at 30 cm and 120 cm above the ground using a spherical densiometer. The spherical densiometer consisted of either a concave or a convex mirror with twenty-four 0.6 cm x 0.6 cm (1/4 in x 1/4 in) squares engraved on the surface. We counted the total number of squares on the densiometer with canopy openings (i.e., no canopy). The total number of

squares was then divided by 24 to obtain the percent of overhead area not occupied by canopy. The difference between this percentage and 100% is the estimated overstory density or canopy cover in percent. We recorded spherical densiometer readings at 30 cm and 120 cm above the ground facing each cardinal direction from the center of each 2 m x 2 m plot and averaged the canopy cover estimates from each direction to generate an overall canopy cover estimate for 30 cm and 120 cm above the ground within each 2m x 2m plot. Within each 2 m x 2 m plot, we also categorized the overall presence of shrub and/or tree canopy cover (i.e., shrub, forest/tree, forest/shrub mixed, and none) overhead within the center of the plot based on visual inspection. Within the 10 m x 10 plot around each field validation point, we visually estimated the percent cover of shrubs. We only included shrub cover that could be seen or detected from overhead (i.e., from a bird's eye view). We photographed the vegetation, particularly the shrub and tree cover, within the 2m x 2m and 10 m x 10 m field sampling plots. We recorded data and photographs in the field using a Survey123 data form. Shrub and forest/tree cover estimates from the field sampling were compared with the model results to evaluate the accuracy of the canopy cover models.

Using higher resolution aerial imagery for training or validation is an acceptable alternative to field data collection, particularly for areas of no change that are easily distinguished in the aerial imagery. Since field sampling targeted areas of canopy change, areas mapped as no change for forest or shrub (i.e., classification stayed the same between 2022 and 2023) were validated through image interpretation of 0.5 m resolution NAIP imagery. Field cover estimates and NAIP canopy designations at the sample points were compared to the canopy map. Field points where the accuracy of GPS was in question were excluded from the validation.

Canopy Change

To assess or validate the canopy change model results, we met with the land managers of the [redacted] site within the [redacted] in the Shiawassee study region to review the model results. We compared the canopy change model results, particularly areas of forest and/or shrub loss or gain, to their firsthand knowledge of site conditions and timing and areas where land management had occurred at the site. These comparisons or assessments were qualitative since quantitative estimates of canopy cover have not been collected in the field and are not available for these sites.

RESULTS

Canopy Cover Modeling and Assessment

Canopy Cover

We generated canopy cover maps indicating areas with shrub and forest/tree cover from Worldview multispectral imagery and/or DSM data for available time periods for each focal population within the Shiawassee River Headwaters and Barry County study regions. Canopy cover maps for 2011, 2012, 2017, 2022, and 2023 were generated for all or portions of the focal populations in the Shiawassee region based on available imagery (Figure 8; Appendices A, B, and C). Canopy cover maps for 2011, 2014, and 2017 were generated for all or portions of the focal populations in the Barry County study region based on available imagery (Figure 9, Appendices D and E).

From the canopy cover models and maps, we calculated the estimated area (total acres per class) and percentage (area target class/total area within the population or unit within a population) of shrub, forest/tree, and combined shrub and forest canopy cover in priority areas and EOs within focal populations in the Shiawassee and Barry study regions. We estimated areas/acreages and percentages of shrub and forest cover within two priority sites ([redacted]) within the [redacted] focal populations (Tables 2 and 3). Shrub and forest cover were estimated within and across specific units that have been delineated and monitored for massasaugas within the two priority sites (Tables 2 and 3). Complete results for shrub and forest cover within the [redacted] site are provided in Appendices F and G. We also estimated the areas/acreages and percentages of shrub and forest cover within all the masasasauga EOs (based on remaining habitat were not removed from the land cover masks within these EOs) located within the focal populations in the Shiawassee and Barry study regions (Table 4). Complete canopy cover results for the massasauga EOs located within the two study regions for all available time periods are provided in Appendices H, I, J, K, L, M, N, and O). Areas that were estimated as having 50% or greater canopy cover within the two priority sites and massasauga EOs within the Shiawassee and Barry study regions were flagged for potential management (Tables 2, 3, and 4; Appendices F-O). In general, the estimated percentages of canopy cover of forest and/or shrubs were less than 50% in all the units within both priority sites in all modeled years except for one unit in 2017 and one unit in 2023 within the [redacted] priority site and several areas or source features within four EOs across both study regions (Tables 2, 3, and 4; Appendices F-O).

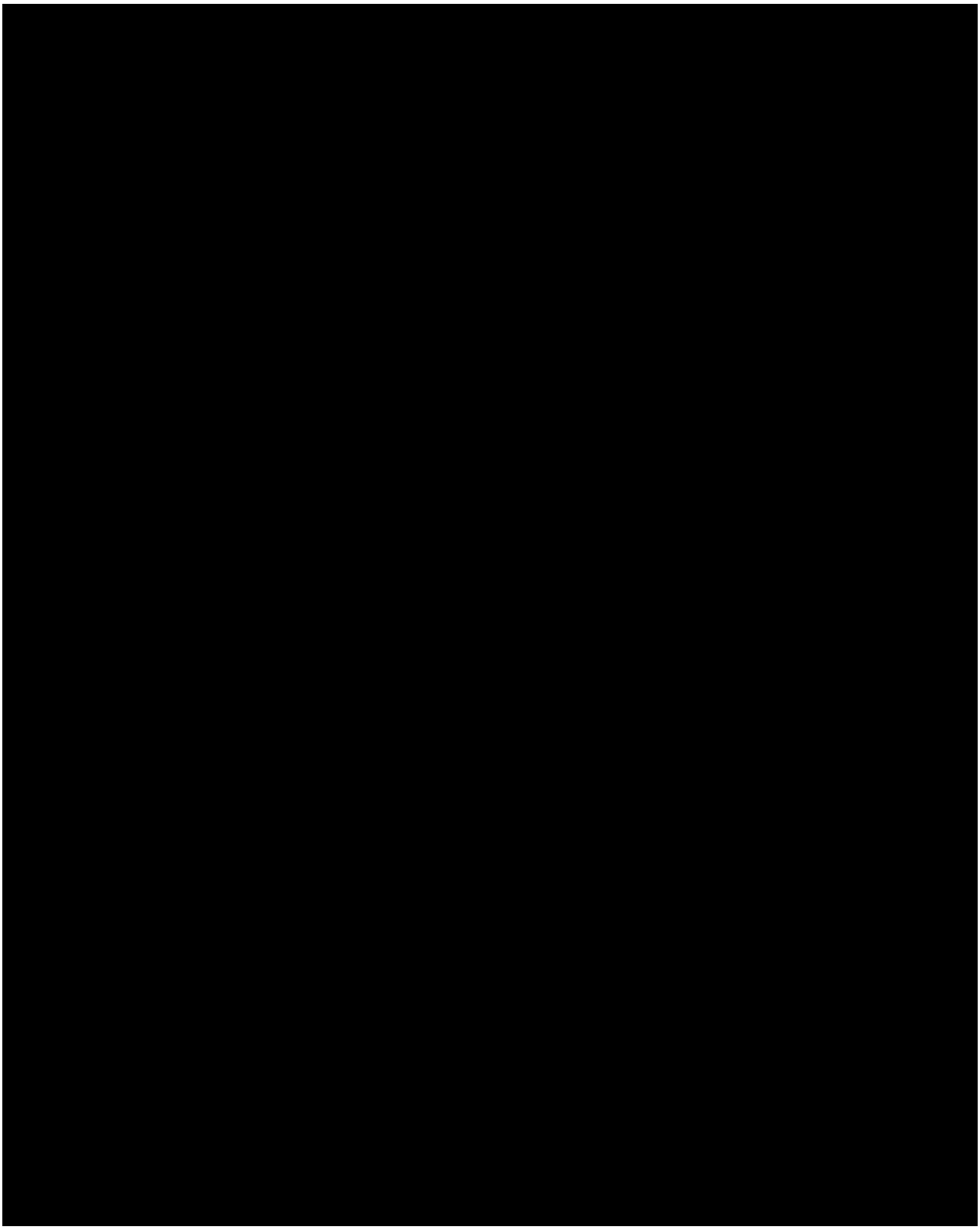


Figure 8. Canopy cover map for focal populations within the Shiawassee River Headwaters study region.

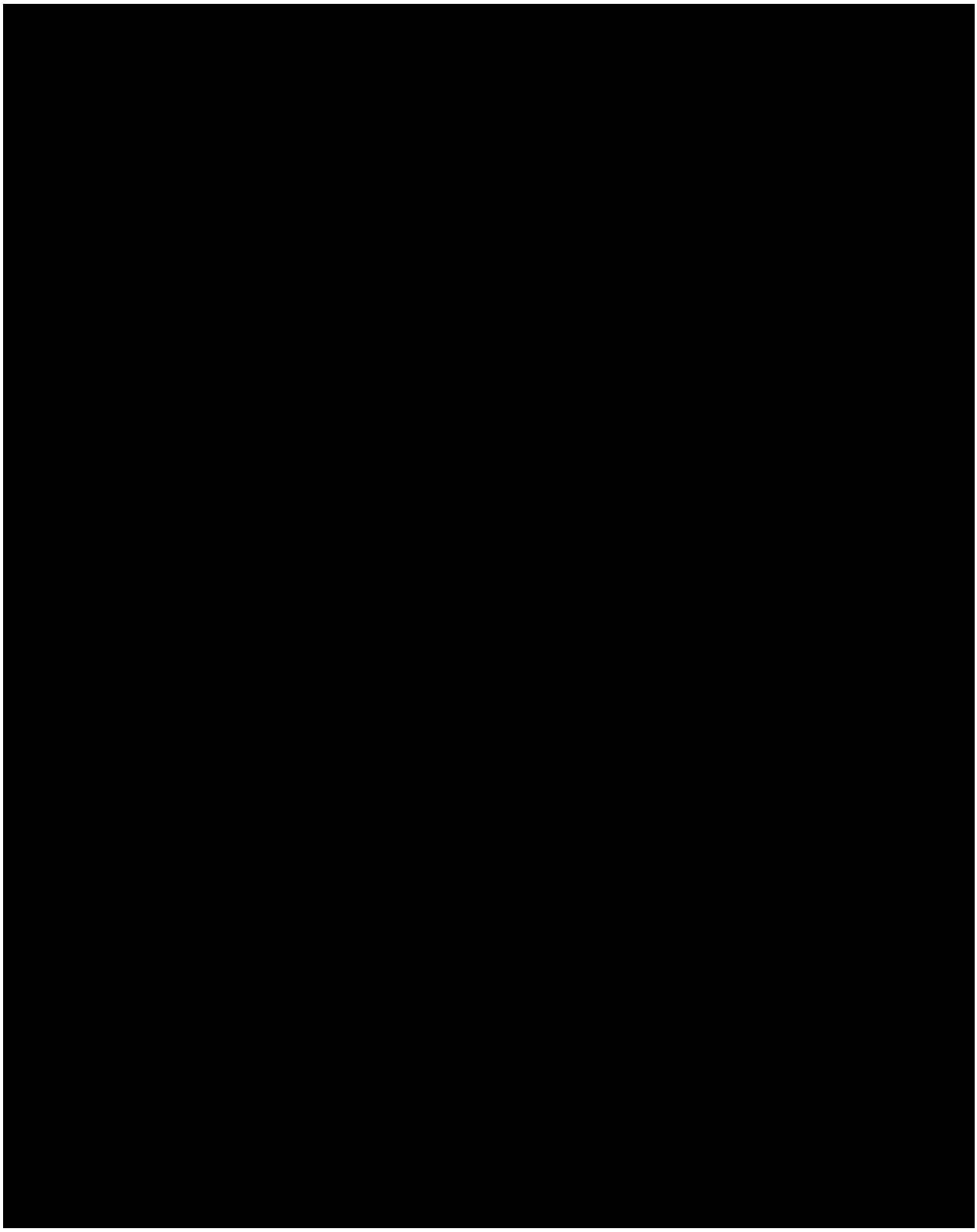


Figure 9. Canopy cover map for focal populations within the Barry County study region.

Table 2. Subset of shrub and forest canopy cover assessment results by percentage for each unit for 2017, 2022, and 2023 within the [redacted] site within the [redacted] in the Shiawassee study region. Full results for this site are provided in Appendices F and G. Units with >50% shrub and/or forest canopy cover are highlighted in red.

[redacted]	Forest and Shrub Cover - Percent Cover								
	2023			2022			2017		
Unit Name	Forest	Shrub	Canopy Total	Forest	Shrub	Canopy Total	Forest	Shrub	Canopy Total
[redacted] River South	15.8	29.4	45.1	26.4	18.4	44.8	45.8	6.6	52.5
[redacted] South	0.3	14.4	14.7	4.4	4.8	9.2	0.4	6.3	6.7
[redacted] North	5.0	6.7	11.7	4.7	11.8	16.5	2.8	7.1	9.9
[redacted] River North	17.4	20.6	38.0	10.5	18.4	28.8	7.8	9.2	17.0
[redacted] North	8.5	8.7	17.2	5.2	13.5	18.7	26.4	22.7	49.0
[redacted] Additional	2.1	6.9	9.1	3.1	5.7	8.8	1.2	29.7	30.9
Old Field Upland	14.3	8.5	22.8	15.7	16.2	31.9	32.4	7.8	40.2
[redacted] NW Burn Unit	11.0	12.7	23.7	8.4	12.8	21.2	8.3	5.7	14.0
[redacted] SW Mgmt Unit	17.0	15.3	32.3	21.6	8.6	30.2	21.9	3.7	25.6
[redacted] Pvt	2.8	29.0	31.8	5.0	17.4	22.4	3.0	10.1	13.1
[redacted] Center Main	2.6	7.0	9.6	3.5	4.4	7.9	8.5	0.5	9.0
[redacted] Center SW	1.7	6.4	8.0	0.5	1.8	2.3	14.9	15.2	30.1
[redacted] Center SE	1.3	3.6	4.9	3.4	6.4	9.9	2.4	2.1	4.5
[redacted] Center N	11.8	14.1	25.9	17.0	7.1	24.2	14.2	8.6	22.7
[redacted] Center W	21.2	7.0	28.2	21.4	14.2	35.6	28.2	1.1	29.3
Cut Field North	10.0	13.9	23.9	13.6	5.3	18.9	13.5	5.9	19.4
North Field 3	27.9	12.7	40.7	32.1	15.1	47.2	36.1	12.2	48.3
North Field 2	17.0	8.1	25.1	20.4	11.9	32.3	25.7	7.3	33.0
North Field 1	16.4	6.9	23.3	15.0	12.7	27.7	10.8	4.3	15.1
North Hill 1	23.4	15.4	38.8	28.3	2.9	31.2	22.5	2.1	24.6
NW Clearing 4	23.0	32.8	55.8	35.8	2.7	38.5	9.5	9.3	18.8
NW Clearing 2	17.4	17.3	34.7	19.4	10.9	30.3	34.9	2.3	37.2
TOTAL	**9.6**	**12.6**	**22.3**	**10.6**	**10.8**	**21.5**	**13.4**	**8.8**	**22.2**

Table 3. Shrub and forest cover assessment results by area/acreage and percentage within each unit for 2012, 2017, and 2022 within the [redacted] in the Shiawassee study region. Units with >50% shrub and/or forest canopy cover are highlighted in red.

[redacted] Forest and Shrub Cover - Area (acres)									
	2022			2017			2012		
Unit Name	Forest	Shrub	Total Canopy	Forest	Shrub	Total Canopy	Forest	Shrub	Total Canopy
Red	1.456	0.692	2.148	0.606	0.503	1.109	0.614	1.574	2.187
Green	0.030	0.292	0.322	0.268	0.408	0.676	0.287	1.427	1.714
Yellow	1.153	1.558	2.711	1.478	2.321	3.799	2.234	2.641	4.875
Blue	0.613	0.489	1.102	0.254	1.029	1.283	0.495	1.509	2.005
Orange	0.102	0.311	0.413	0.018	0.213	0.230	0.103	0.303	0.406
Pink	1.780	0.641	2.421	2.484	0.221	2.705	1.927	0.688	2.615
TOTAL	**5.13**	**3.98**	**9.12**	**5.11**	**4.70**	**9.80**	**5.66**	**8.14**	**13.80**
[redacted] Forest and Shrub Cover – Percent Cover									
	2022			2017			2012		
Unit Name	Forest	Shrub	Total Canopy	Forest	Shrub	Total Canopy	Forest	Shrub	Total Canopy
Red	12.5	5.9	18.4	5.2	4.3	9.5	5.3	13.5	18.7
Green	0.3	3.4	3.7	3.1	4.7	7.9	3.3	16.6	19.9
Yellow	10.4	14.0	24.4	13.3	20.8	34.1	20.1	23.7	43.8
Blue	9.1	7.3	16.4	3.8	15.3	19.1	7.4	22.4	29.8
Orange	1.5	4.5	6.0	0.3	3.1	3.4	1.5	4.4	5.9
Pink	22.5	8.1	30.6	31.4	2.8	34.2	24.4	8.7	33.1
TOTAL	**9.7**	**7.5**	**17.2**	**9.7**	**8.9**	**18.5**	**10.7**	**15.4**	**26.1**

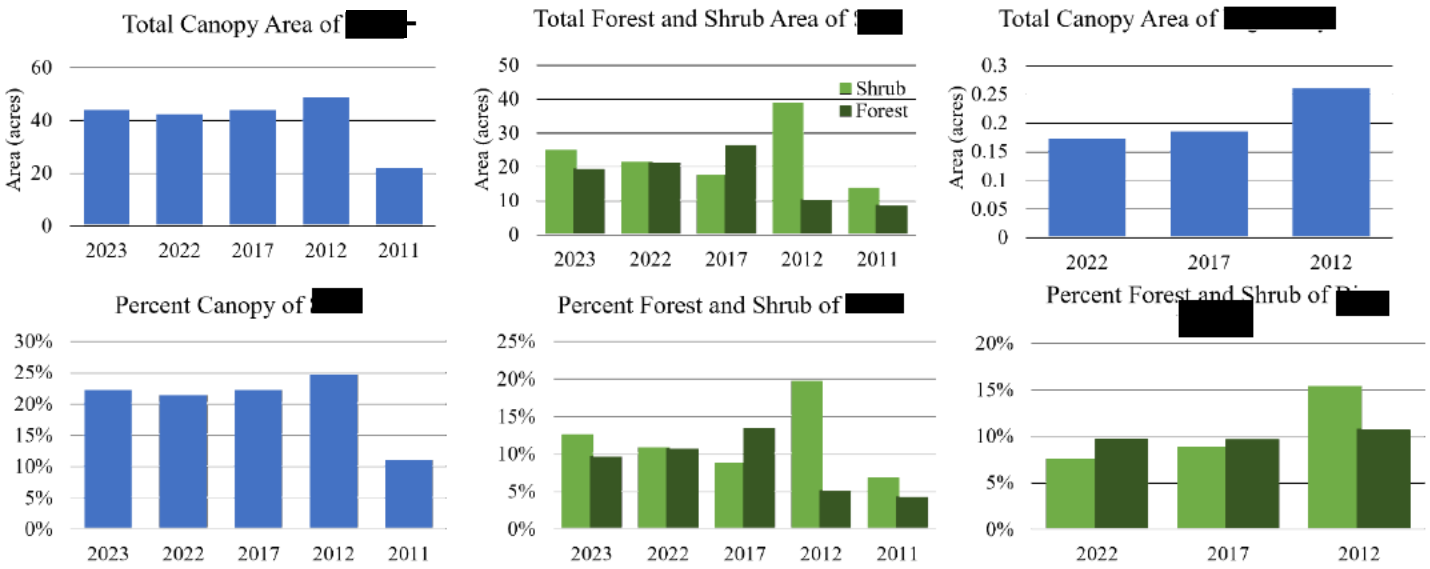


Figure 10. General shrubification trends were estimated for the [redacted] priority areas through the quantification of total canopy and forest and shrub area (acres) as well as canopy percentage based on the extent of the priority areas.

Table 4. Subset of forest and shrub cover assessment results for 2023 for eastern massasauga (EMR) element occurrences (EOs) located within focal populations in the Shiawassee River Headwaters study region. Portions of individual source features or sub-regions within EOs were masked to exclude areas of non-EMR habitat (e.g., developed, agriculture, water, etc). Forest and shrub cover assessments focused on areas within the source features or sub-regions within EOs that were not masked and were presumed to be EMR habitat. EO source features/sub-regions with >50% canopy cover are highlighted in red. Full forest and shrub cover assessment results for EOs within the two study regions are provided in Appendices H, I, J, K, L, M, N, and O.

Shiawassee River Headwaters Study Region Element Occurrences – Canopy Cover 2023							
EO_ID split	Forest (m^2)	Shrub (m^2)	Total Canopy	Total EO Area	Percent Cover Forest	Percent Cover Shrub	Percent Cover All Canopy
3130_10	1304	80	1384	1953	66.77%	4.10%	70.87%
3130_9	356	1024	1380	1953	18.23%	52.43%	70.66%
3130_11	8	1164	1172	1953	0.41%	59.60%	60.01%
6223_19	116	1020	1136	1953	5.94%	52.23%	58.17%
6223_13	12	20	32	63	19.05%	31.75%	50.79%
3130_2	220	1536	1756	3659	6.01%	41.98%	47.99%
6223_18	556	376	932	1953	28.47%	19.25%	47.72%
3130_17	0	864	864	1953	0.00%	44.24%	44.24%
3130_15	888	8	896	2186	40.62%	0.37%	40.99%

In addition to modeling and estimating forest and shrub cover for each population extent, we conducted a neighborhood assessment for a portion of the Shiawassee River Headwaters study region. For this analysis, the percent canopy cover within a 10 m x10 m (5 x 5 pixel area) neighborhood window around each pixel were calculated. These neighborhood values were calculated for shrubs, forest, and combined total canopy. Maps illustrating the results of the neighborhood assessment for the [redacted] site are provided in Figures 11 and 12. These results indicate that although the estimated percentages of forest and tree cover were less than 50% in almost all the units within one of the priority sites (i.e., [redacted]) that was included in this analysis, shrub and/or forest cover was higher than 50% in some of the 10 m x 10 m plots or at specific locations within the units (Figures 11 and 12).

Figure 11. Base imagery (A) and results of neighborhood assessment of canopy within a 10 m x 10 m plot around each pixel for total canopy/shrub and forest cover combined (B) and shrub (C) and forest (D) canopy cover separately within the eastern half of an eastern massasauga priority site within the [redacted] in the Shiawassee River Headwaters study region. Darker shades of the color in B, C, and D indicate higher percent canopy cover.

Figure 12. Base imagery (A) and results of neighborhood assessment of canopy within a 10 m x 10 m plot around each pixel for total canopy/shrub and forest cover combined (B) and shrub (C) and forest (D) canopy cover separately within the western half of an eastern massasauga priority site within the [redacted] in the Shiawassee River Headwaters study region. Darker shades of the color in B, C, and D indicate higher percent canopy cover.

Canopy Change

To better understand where changes in shrub, forest and total canopy were occurring, final canopy maps from different dates with overlapping footprints were intersected to create canopy cover change maps for focal populations within each of the two study regions (Figures 13 and 14). We compared estimated areas (acreages) and percentages of forest and shrub cover over time where available to identify areas where forest and/or shrub cover have increased or decreased to better understand general succession and shrubification patterns throughout the focal populations, particularly within two priority sites ([redacted] populations (Figures 15, 16, and 17). These maps allow managers to identify more dynamic and stable canopy areas within the focal study populations. Areas with increasing canopy/shrub trends were noted and could be evaluated for potential management.

Canopy change results varied by site, across units within a site, and across massasauga EOs and focal populations within the two study regions. Within the priority site in the [redacted] area, shrub cover, in general, has been gradually increasing from 2011 to 2023, with the exception of 2012 which had a large increase in mapped shrub cover (Table 2, Figure 10, Appendices F and G). However, shrub cover did decrease in most units between 2012 and 2017 and in some units during other time periods (e.g., in [redacted] Old Field Upland, [redacted] Center W, North Field 1, North Field 2, and North Field 3 from 2022-2023) (Table 2). Within the priority site in the [redacted], shrub cover has been gradually decreasing from 2012 to 2022 in general although shrub cover did increase in several units from 2017 to 2022 (Table 3, Figure 10).

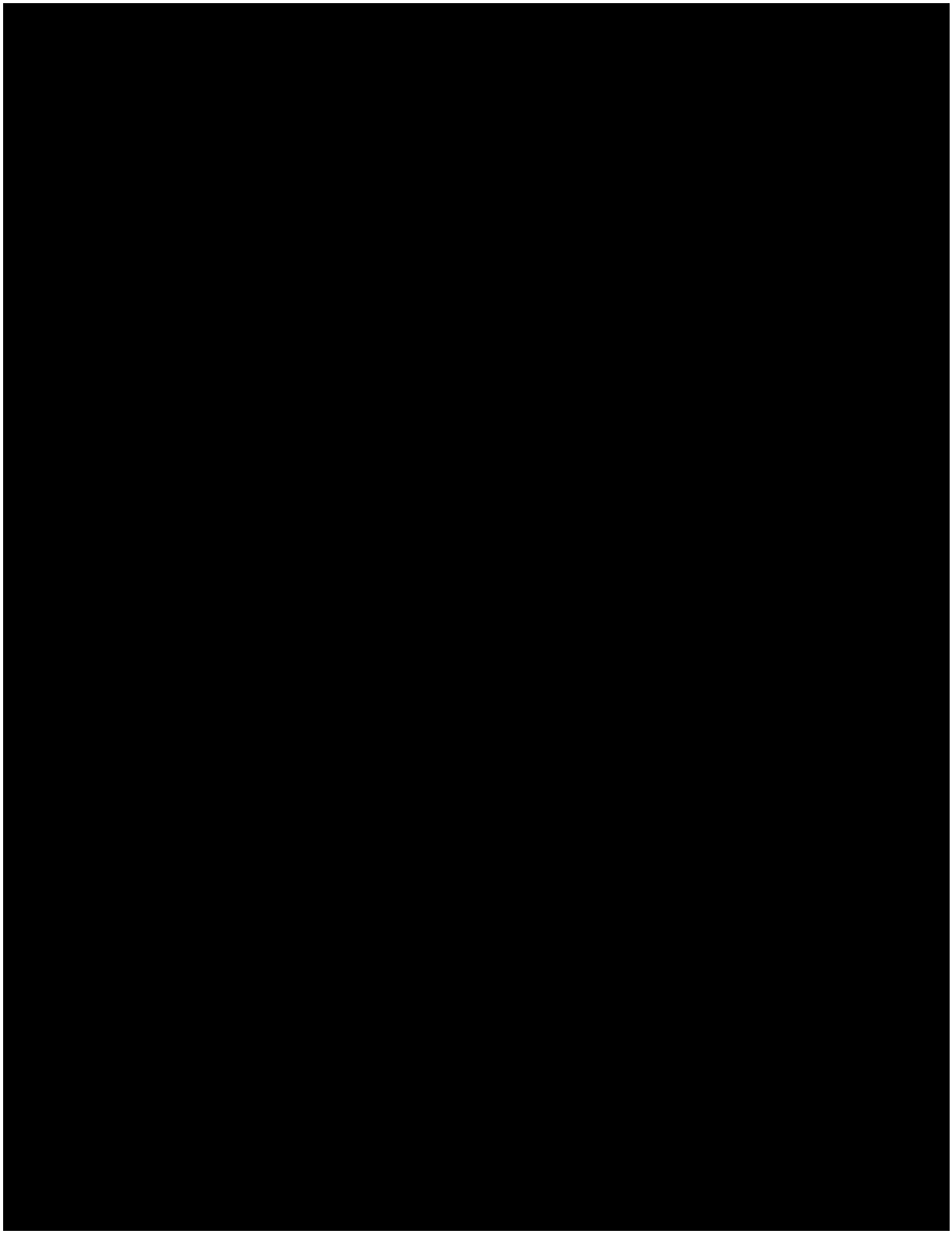


Figure 13. Composite canopy change map for eastern massasauga focal populations and element occurrences (EOs) within the Shiawassee River Headwaters study region between 2012 and 2017 or 2022 and 2023.

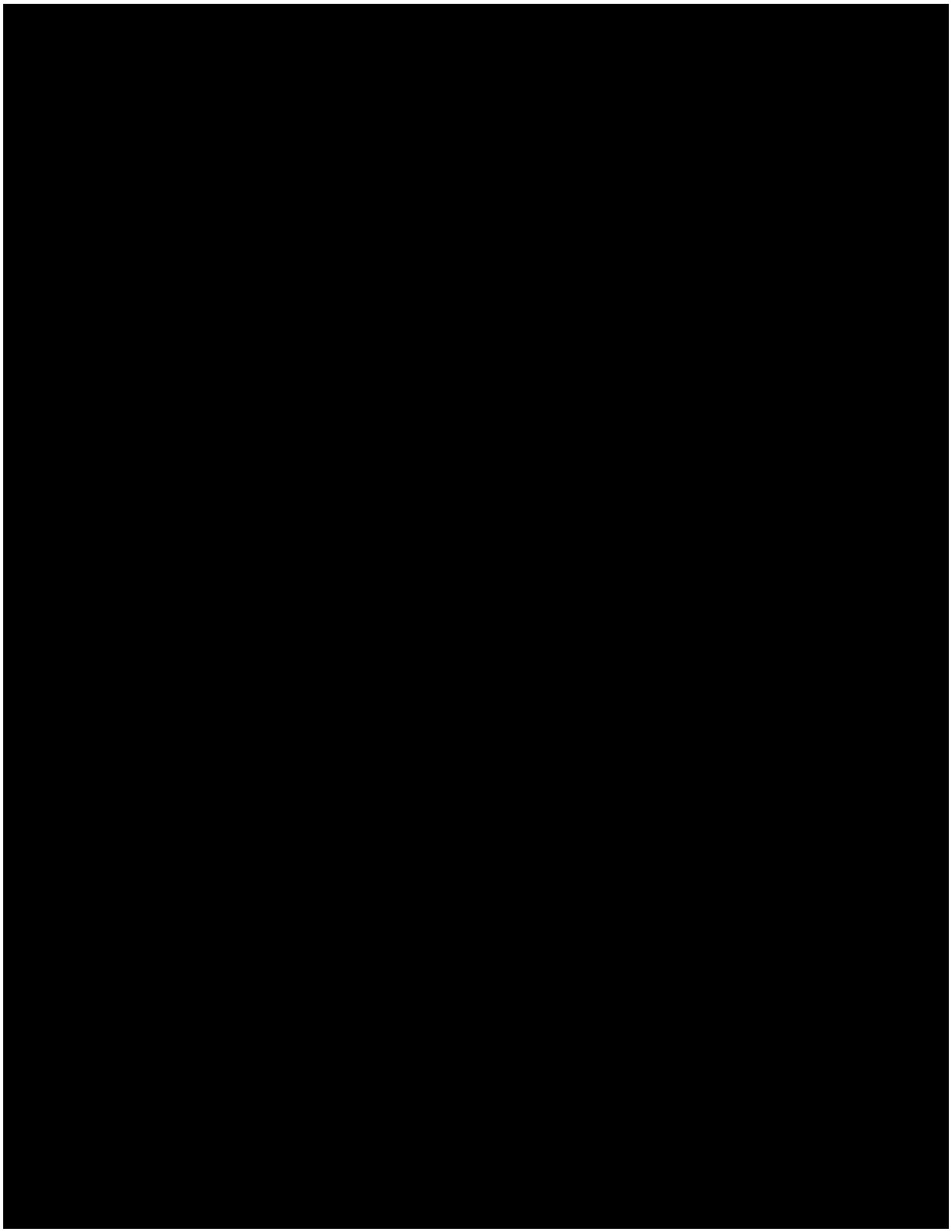


Figure 14. Composite canopy change map for eastern massasauga focal populations and element occurrences (EOs) within the Barry County study region between 2011, 2014, and/or 2017.

Figure 15. Canopy change maps for four time periods between 2011 and 2023 for the eastern half of an eastern massasauga priority site, [redacted], located within the [redacted] in the Shiawassee River Headwaters study region.

Figure 16. Canopy change maps for four time periods between 2011 and 2023 for the western half of an eastern massasauga priority site, [redacted], located within the [redacted] in the Shiawassee River Headwaters study region.

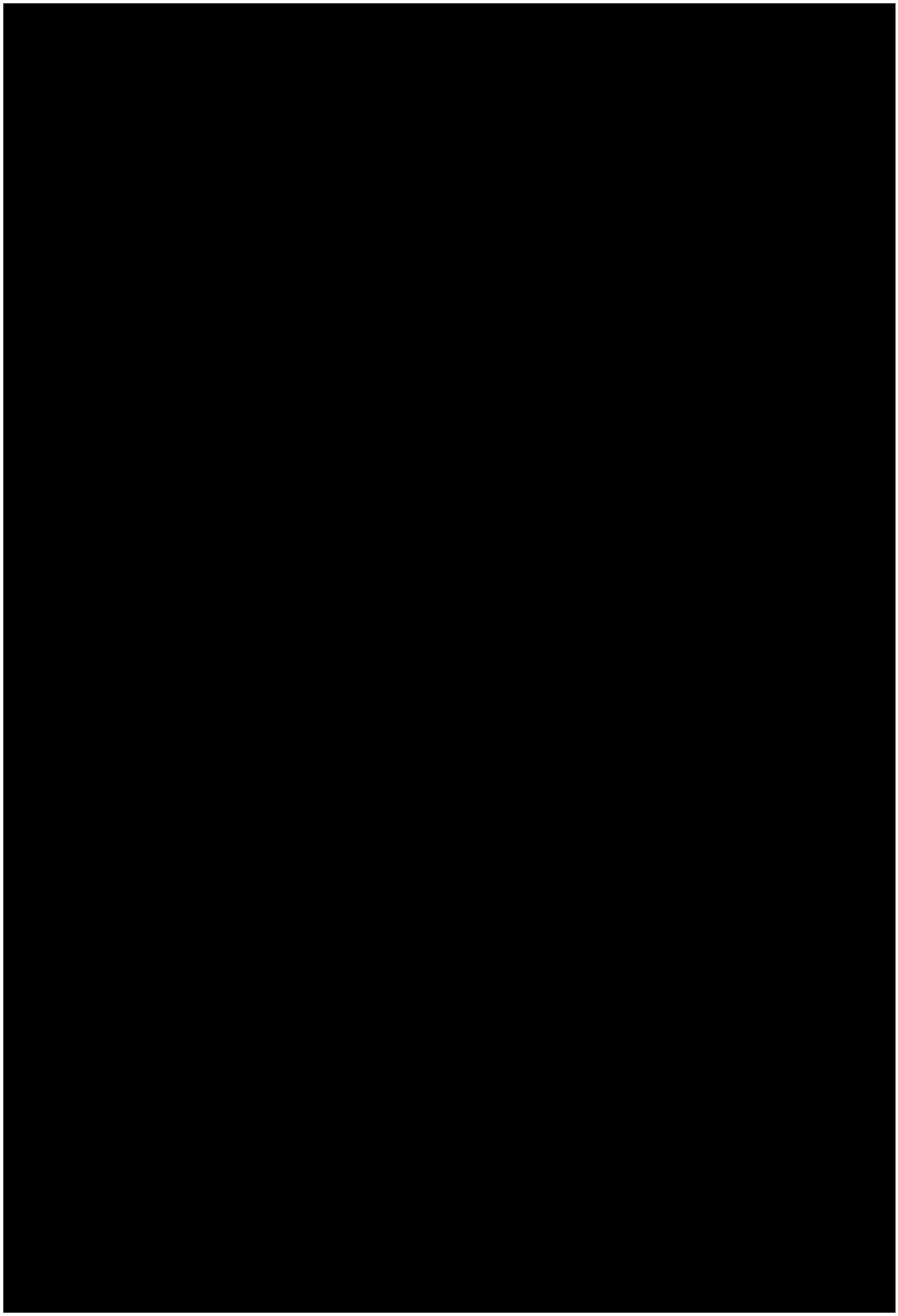


Figure 17. Canopy change maps for two time periods between 2012 and 2022 for an eastern massasauga priority site, [redacted] in the Shiawassee River Headwaters study region.

Canopy Height Change

Comparing available DSM data within intersecting footprints between different time periods to assess canopy height changes had mixed results. We focused this analysis on two priority sites within the [redacted] populations. We calculated average, minimum, and maximum change trends for each of the seven canopy change classes within the [redacted] While some local area spot checks seemed to be working (Figure 18), analysis of trends across larger areas within the priority sites raised some concern. We expected that, in general, woody vegetation classes would grow taller both throughout one season and across multiple years. However, the data showed average losses across almost all categories ranging from a 20 cm decrease to losses of 2 meters from October 2013 to August 2017-. There were similar losses observed when comparing the DSM data from May 2012 to August 2017, except for the forest/shrub mix cover class which increased 1 m [redacted] to 2.5 m [redacted] on average. Comparisons of DSM data from August 2017 and May 2012, respectively, to March 2010 showed increases in all classes ranging from 6 m – 19 m. Interannual comparisons between June 2017 - August 2017 had forest and shrub regions growing three to four meters. These results seemed highly variable and inaccurate. Upon further investigation, discrepancies across the layer rendered this analysis impossible with the current data as the DSMs are not normalized between scenes. The discrepancies are not uniform across the scene; therefore, correction and direct comparison were not feasible.

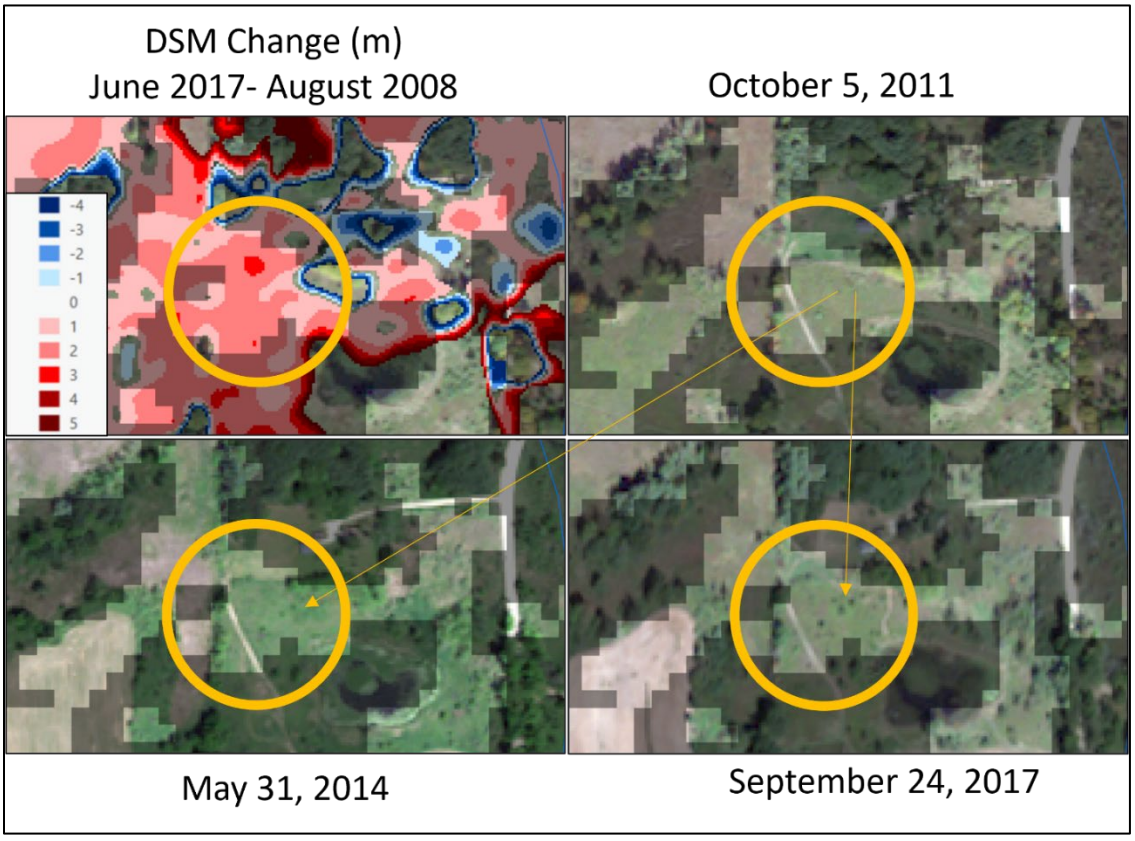


Figure 18. Example of shrubification throughout time being captured by the difference in DSMs.

Field Validation

Canopy Cover

Using higher resolution aerial imagery for training or validation is an acceptable alternative to field data collection, particularly for areas of no change that are easily distinguished in the aerial imagery. Since the field validation focused on areas of canopy change, areas mapped as no change for forest or shrub from 2022 to 2023 (i.e., they were consistent in 2022 or 2023), were validated through image interpretation of 0.5 m NAIP imagery from 2023. The results of this comparison are presented in the accuracy tables of Table 5. As expected, the canopy cover map based on the Worldview 2023 imagery for the [redacted] priority site within the [redacted], which was a targeted area, had the highest accuracy (93% overall), while the [redacted] site within the [redacted] had lower accuracy (76%) with more confusion between shrub and forest (Table 5). The combined accuracy of these two areas was 85% overall accuracy (Table 5). Had the DSM for the [redacted] area been available for 2023, it would have improved the distinction between shrub and forest and overall accuracy.

After integrating the field data collected from canopy change areas with the NAIP validation data on unchanged areas, the [redacted] priority site had a total mapped accuracy of 74% when forest and shrub cover were assessed separately (Table 6), with most of the uncertainty coming from the confusion of the forest and shrub class. Much of the confusion is likely due to the lack of canopy height data available from the DSM for this time period. When the shrub and forest classes were combined, the overall accuracy improved to 83%. The overall accuracy in the [redacted] site was 62% when shrub and forest cover were separate and 76% when combined into one canopy class (Table 6). Across both locations, the total accuracy was 85% when canopy classes were combined and 68% when forest and shrub were assessed separately (Table 6).

These validation results were based on comparisons of the forest and shrub cover data collected from the 2 m x 2 m sampling plots with the canopy models/maps. Since the percent shrub cover (from a bird's eye-view) data from the 10 m x 10 m sampling plots did not include percent forest canopy cover, we were unable to compare these data to the remote sensing products at this time.

Table 5. Error matrices for the non-edge forest and shrub regions within the [redacted] sites in the [redacted] using NAIP imagery to assess accuracy of the canopy cover model results.

Combined (NAIP validation)					
	Forest	Shrub	None	Sum	User's Accuracy
Forest	37	8	0	45	0.82
Shrub	3	31	0	34	0.91
None	0	1	0	1	1
Sum	40	40	0	Overall Accuracy	
Producer's Accuracy	0.93	0.76	0	0.85	
[redacted] (NAIP validation)					
	Forest	Shrub	None	Sum	User's Accuracy
Forest	17	0	0	17	1.00
Shrub	3	20	0	23	0.87
None	0	0	0	0	1
Sum	20	20	0	Overall Accuracy	
Producer's Accuracy	0.85	1	0	0.93	
[redacted] (NAIP validation)					
	Forest	Shrub	None	Sum	User's Accuracy
Forest	20	8	0	28	0.71
Shrub	0	11	0	11	1
None	0	1	0	1	1
Sum	20	20	0	Overall Accuracy	
Producer's Accuracy	1	0.55	1	0.76	

Table 6. Accuracy for the 2023 [redacted] canopy model results.

		Overall Accuracy	Average Producer's Accuracy	Average User's Accuracy
Total Canopy	Combined 2023	84.9%	74.0%	71.2%
	[redacted]	83.0%	79.8%	83.1%
	[redacted]	76.2%	70.1%	68.2%
Forest and Shrub Separate	Combined 2023	68.4%	68.2%	68.9%
	[redacted]	74.0%	74.3%	75.8%
	[redacted]	62.2%	62.1%	60.4%

Canopy Change

Accuracy of the canopy change assessments for the [redacted] site within the [redacted] was variable based on information from the land manager of this site. At the [redacted], intensive shrub removal efforts in eastern massasauga habitats started in 2016. For example, in the center of the Blue Unit, the canopy change model/map for 2012-2017 (Figure 15) indicated shrub loss which likely corresponds to shrub removal that occurred in this area in 2016. However, the canopy change model/map for 2022-2023 indicated shrub loss in the same area but no management treatment occurred in this area during this time period (Figure 15). In the Yellow Unit, dense buckthorn was removed in the western end of the unit in 2019 and the area was burned in 2021. The canopy change map for 2017-2022 (Figure 15) indicated some shrub loss in the western end of the Yellow Unit but map appeared to underrepresent the amount of shrub removal or loss that had occurred in that area based on feedback from the land manager. The Shrub removal occurred in the Gold Unit and the northwest end of the Silver Unit from 2018-2021. The canopy change map for 2017-2021 accurately indicated extensive shrub loss in the Gold Unit (Figure 16). The canopy change map for 2017-2022 indicated forest loss in the northwest end of the Silver Unit instead of shrub loss but it did capture loss of canopy in this area during this time period. Similarly, the removal of shrubs (i.e., dogwood, autumn olive, and honeysuckle) that occurred in the Purple Unit between 2018-2021 was largely represented in the canopy change map from 2017-2022 as forest loss instead of shrub loss (Figure 15).

Accuracy of the canopy change assessments for the [redacted] site within the [redacted] also was variable based on information from the land manager of this site. Shrub removal occurred in two small areas in the southwestern and southeastern portions of the site in 2022. The canopy change map for this site for 2017-2022 (Figure 17) indicated some shrub loss in the treated areas but not as extensive as it should have been based on information from the site manager. Several areas within this site also were burned in 2014, 2015, 2016, 2017, 2021, or 2022. However, the canopy change maps from 2012-2017 and 2017-2022 indicated some shrub loss in only two of the burned areas during the right time period (e.g., west side of the Green Unit from 2017-2021 and south side of the Orange Unit from 2012-2017) (Figure 17). This may have been due to low density of shrubs initially present in the burned areas prior to treatment and/or the prescribed fire did not cause significant mortality or loss of shrubs and/or trees.

Some of the canopy change maps for both sites also indicated shrub or forest loss or gain in areas where management had not occurred or site managers could not verify. Some of the shrub loss areas (or portions of these areas) could have been due to natural causes such as flooding from beavers (e.g., southeastern end of the [redacted] site in the 2012-2017 canopy change map). Other areas mapped as shrub or forest loss did not appear to be accurate based on current or available aerial imagery (e.g., southern end of the [redacted] site in the 2017-2022 canopy change map).

Online Web Application

Michigan Tech Research Institute shared data and canopy model results with MNFI in two ways: 1) zipped copies of the GIS data and Excel analysis; and 2) through an ArcGIS online shared group. A web application was also generated for easy data viewing (Figure 19). Along the top right green menu bar (see Figure 19), the user has the option to view the legend for currently displayed layers (legend icon), toggle on/off individual boundaries (polygon icon), toggle on/off point layers (3 points icon), change displayed product layers including canopy classifications, canopy change files and landcover mask layers (layer stack icon), as well as view the individual RGB composites for each of the mapped dates. On the upper left side, the user is provided tools to zoom in or out, search an address, return to the home view (house icon), find their location on the map (target icon), change the base layer (4 squares icon), measure distances or areas (measuring tape icon), view the legend, select features, and use a swipe between layers. Along the bottom of the window an up arrow allows the user to view the associated metadata through an attribute.

Figure 19. Example of the web application built to view data layers for the canopy cover and canopy change model results for the Shiawassee River Headwaters and Barry County study regions.

DISCUSSION

Results from this pilot approach demonstrate that using high resolution Worldview 8 band imagery and corresponding DSMs (produced from stereo pairs of Worldview imagery) can provide a useful resource for monitoring presence and change in extent of forest and shrub canopy for eastern massasauga habitat. Several maps for the study regions were produced from the early 2000s to 2017, and change maps between years showed gain or loss in shrub and/or forest cover. These products were made available via a WebApp as well as direct sharing of layers (see Results). Initial efforts to validate the 2023 canopy cover model at two sites using NAIP imagery and field sampling resulted in accuracy rates of around 80% or higher, particularly when forest and shrub cover were combined. However, the accuracy of the canopy change models seemed to vary depending on the area and time period.

This analysis was constrained by available data extents and time periods. The available multispectral imagery did not cover the entirety of the desired study regions for each mapped year and did not always have corresponding DSM footprints or dates to match. The DSM data was only available up until 2017 and so the most recent multispectral images from June 2022 and 2023 did not have any relative canopy height data to train between the shrub and forest classes, which is particularly important because these can be otherwise spectrally similar. Additionally, while the worldview DSMs offered high-resolution single date data that was beneficial for canopy classifications, these data were not normalized between scenes and so canopy height changes throughout time could not be directly compared.

While this analysis found the Worldview DSM to be useful for distinguishing relative height including differences in shrub and tree heights, a method of normalization between dates of DSM products and improved future DSM product availability would make the resource even more useful, as we would have been able to assess changes in vegetation height and produced more accurate maps for 2022-2023 (when DSMs were unavailable). Correspondence with the Polar Geospatial Center provided information on future 2022 and 2023 DSM products (under the EarthDEM project) that would be available to Federal U.S. government agencies and grant recipients from those agencies soon. This would improve the 2022-2023 map products.

The approach of integrating the DSM and multi-band imagery may also be applied to other data sources that provide multi-band data and stereo images to produce a DSM, such as unmanned aerial vehicles (UAVs) (e.g., drones) with their overlapping flight lines. While drone imagery would not allow for assessing change back in time, it provides a tool to obtain timely multi-spectral and DSM data over an area of interest at fairly low cost. This approach may provide higher resolution, more accurate, and more timely data for assessing and monitoring canopy cover and succession. Other supplemental data that may be useful in massasauga habitat analysis would be LiDAR. While not routinely collected, LiDAR data would provide data on tree heights and a digital elevation model (DEM) which could provide a baseline for change analysis (note that LiDAR data are typically collected in spring at leaf off). If the LiDAR could be matched in time to a DSM, it could be normalized. Other sources of DSMs with high resolution imagery or NAIP digital products would allow for the improvement and expansion of this analysis.

Reviewing similar studies (e.g., Waser and Ginzler 2008) may provide additional insights that could enhance this analysis.

For future field validation efforts, a focus on both areas of change and non-change in forest and shrub cover would fully assess the accuracy of canopy cover and change maps. The field data collection in summer 2023 was focused on areas of change, which were primarily on edges and were difficult to capture in the field for comparison to the remote sensing product because of geolocation errors and also timing of the Worldview imagery (early June 2023 when leaf out and tree and shrub growth w*ere* minimal) in comparison to late summer/fall field data collection when leaves were fully flushed. For field validation of both individual date maps and of canopy cover change from remote sensing, a birds-eye view for trees and shrubs is needed to assess in the field what the sensor is viewing. In this study, this was done for shrub cover only in the 10 m x 10 m plots and a comparison to the remote sensing could not be evaluated.

While the use of high-resolution Worldview imagery and corresponding DSMs appears promising for mapping the extent and change in canopy/forest and shrub cover in open or early successional habitat for eastern massasaugas, additional work is needed to further evaluate and increase the accuracy and effectiveness of this approach. This includes securing additional and current DSMs and Worldview imagery and conducting field validation in additional areas within priority massasauga populations. With more complete DSMs and Worldview imagery spatially and temporally and further evaluation and refinement, this approach could provide a more efficient approach for assessing canopy cover within eastern massasauga populations in Michigan, particularly priority or focal populations. This approach could be used to identify potential sites that could benefit from habitat management to maintain open canopy conditions and landscape connectivity for massasaugas within focal populations. This information would help the MDNR and its partners target and prioritize management efforts to sustain the eastern massasauga in Michigan and better determine and secure resources needed to accomplish this. This approach also could be used to monitor and inform adaptive management efforts, particularly if used in conjunction with massasauga population monitoring. Additionally, this approach could potentially be applied to eastern massasauga populations in other states/province as well as other focal species that rely on open canopy or early successional habitat conditions in Michigan.

LITERATURE CITED

Breiman, L. 2001. Random Forests. Machine Learning 45(1):5-32. doi: 10.1023/A:1010933404324

DeGregorio, B.A., J.V. Manning, N. Bieser, and B.A. Kingsbury. 2011. The spatial ecology of the eastern massasauga (*Sistrurus c. catenatus*) in Northern Michigan. Herpetologica 67: 71-79.

Derosier, A.L., S.K. Hanshue, K.E. Wehrly, J.K. Farkas, and M.J. Nichols. 2015. Michigan's Wildlife Action Plan. Michigan Department of Natural Resources, Lansing, MI. http://www.michigan.gov/dnrwildlifeaction

Harvey, D.S. and P.J. Weatherhead. 2006. A test of the hierarchical model of habitat selection using eastern massasauga rattlesnakes (*Sistrurus c. catenatus*). Biological Conservation 130: 206-216.

Johnson, G. and A.R. Breisch. 1993. The eastern massasauga rattlesnake in New York: occurrence and habitat management. Pages 48-54 *in* International symposium and workshop on the conservation of the eastern massasauga rattlesnake, *Sistrurus catenatus catenatus*. B. Johnson and V. Menzies, editors. Toronto Zoo, Toronto, Ontario, Canada.

Kingsbury, B.A. 2002. R9 conservation approach for the eastern massasauga (*Sistrurus c. catenatus*) on the Huron-Manistee National Forests. Unpublished report to the United States Forest Service, Indiana-Purdue University, Ft. Wayne, IN, USA.

Kingsbury, B.A., J.C. Marshall, and J. Manning. 2003. Activity patterns and spatial resource selection of the eastern massasauga rattlesnake in northeastern Indiana. Unpublished report, Indiana-Purdue University, Ft. Wayne, IN.

Klassen, J., C. Porter, P. Morin, I. Howat, M. Noh, B. Bates, K. Peterman, S. Keesey, M. Schlenk, J. Gardiner, K. Tomko, M. Willis, C. Kelleher, M. Cloutier, E. Husby, S. Foga, H. Nakamura, M. Platson, M. Wethington, Jr., C. Williamson, G. Bauer, J. Enos, G. Arnold, W. Kramer, P. Becker, A. Doshi, C. D'Souza, P. Cummens, F. Laurier, and M. Bojesen. 2021. GLARS-DSM. https://glars.org, V1, [04/10/2023].

Lee, Y. 2017. Developing management plans for core eastern massasauga populations in Michigan – Phase I. Michigan Natural Features Inventory, Report Number 2017-08, Lansing, MI.

Lee, Y. and H. D. Enander. 2015. Developing an eastern massasauga conservation plan for Michigan – Phase I. Michigan Natural Features Inventory, Report Number 2015-10, Lansing, MI.

Lipps, G.J. 2008. Survey of the eastern massasauga in northeastern Ohio. Unpublished report to the Ohio Division of Wildlife, Columbus, OH.

Marshall, J.C., J. Manning, and B. Kingsbury. 2006. Movement and macrohabitat selection of the eastern massasauga in fen habitat. Herpetologica 62: 141-150.

Marwaha, N. and E. Duffy. 2021. Everything you need to know about digital elevation models (DEMs), digital surface models (DSMs), and digital terrain models (DTMs). <https://up42.com/blog/everything-you-need-to-know-about-digital-elevation-models-dem-digital#:~:text=A%20Digital%20Surface%20Model%20(DSM,is%20nothing%20else%20above%20it)>. Accessed 5 October 2023.

Michigan Natural Features Inventory (MNFI). 2023. Michigan Natural Heritage Database, Lansing, MI.

Moore, J.A. and J.C. Gillingham. 2006. Spatial ecology and multi-scale habitat selection by a threatened rattlesnake: the eastern massasauga (*Sistrurus catenatus catenatus*). Copeia 2006: 742–751.

Naskar, A. 2021. 3D Digital surface model with python and pylidar. < https://thinkinfi.com/3d-digital-surface-model-with-python-and-pylidar/>. Accessed 22 October 2023.

Pomara, L.Y., O.E. Ledee, K.J. Martin, and B. Zuckerberg. 2014. Demographic consequences of climate change and land cover help explain a history of extirpations and range contractions in a declining snake species. Global Change Biology 20: 2087-2099.

Reinert, H.K. 1978. The ecology and morphological variation of the massasauga rattlesnake, *Sistrurus catenatus*. MS Thesis, Clarion State College, Clarion, PA.

Reinert, H.K. and L.M. Buskar. 1992. The massasauga rattlesnake in Pennsylvania: continuing habitat loss and population isolation. Pages 55-59 *in* International symposium and workshop on the conservation of the eastern massasauga rattlesnake, *Sistrurus catenatus catenatus*. B. Johnson and V. Menzies, editors. Toronto Zoo, Toronto, Ontario, Canada.

Sage, J.R. 2005. Spatial ecology, habitat utilization, and hibernation ecology of the eastern massasauga (*Sistrurus catenatus catenatus*) in a disturbed landscape. MS Thesis, Purdue University, Ft. Wayne, IN, USA.

Seigel, R. A. 1986. Ecology and conservation of an endangered rattlesnake, *Sistrurus catenatus*, in Missouri, USA. Biological Conservation 35:333–346.

Szymanski, J., C. Pollack, L. Ragan, M. Redmer, L. Clemency, K. Voorhies, and J. JaKa. Species status assessment for the eastern massasauga rattlesnake (*Sistrurus catenatus*). SSA Report Version 2. July 2016.

Thacker, A.J. 2020. Great Lakes snake: estimating the occupancy and detection probabilities of the eastern massasauga rattlesnake (*Sistrurus catenatus*). MS Thesis, Grand Valley State University, Allendale, MI, USA. https://scholarworks.gvsu.edu/theses/984

Thacker, A.J., E.T. Hileman, P. Keenlance, E.M. McCluskey, A. Swinehart, J. Kovach, and J.A. Moore. 2023. Modeling occupancy and detection probabilities to update the status of threatened eastern massasauga rattlesnake populations. Global Ecology and Conservation 43. e02422. 10.1016/j.gecco.2023.e02422.

U.S. Fish and Wildlife Service (USFWS). 2016. Endangered and threatened wildlife and plants: threatened species status for the eastern massasauga rattlesnake. U.S. Fish and Wildlife Service Final Rule. 50 CFR Part 17, Docket No. FWS-R3-ES-2015-0145; 4500030113, RIN 1018-BA98. Federal Register 81(190):67193-67214.

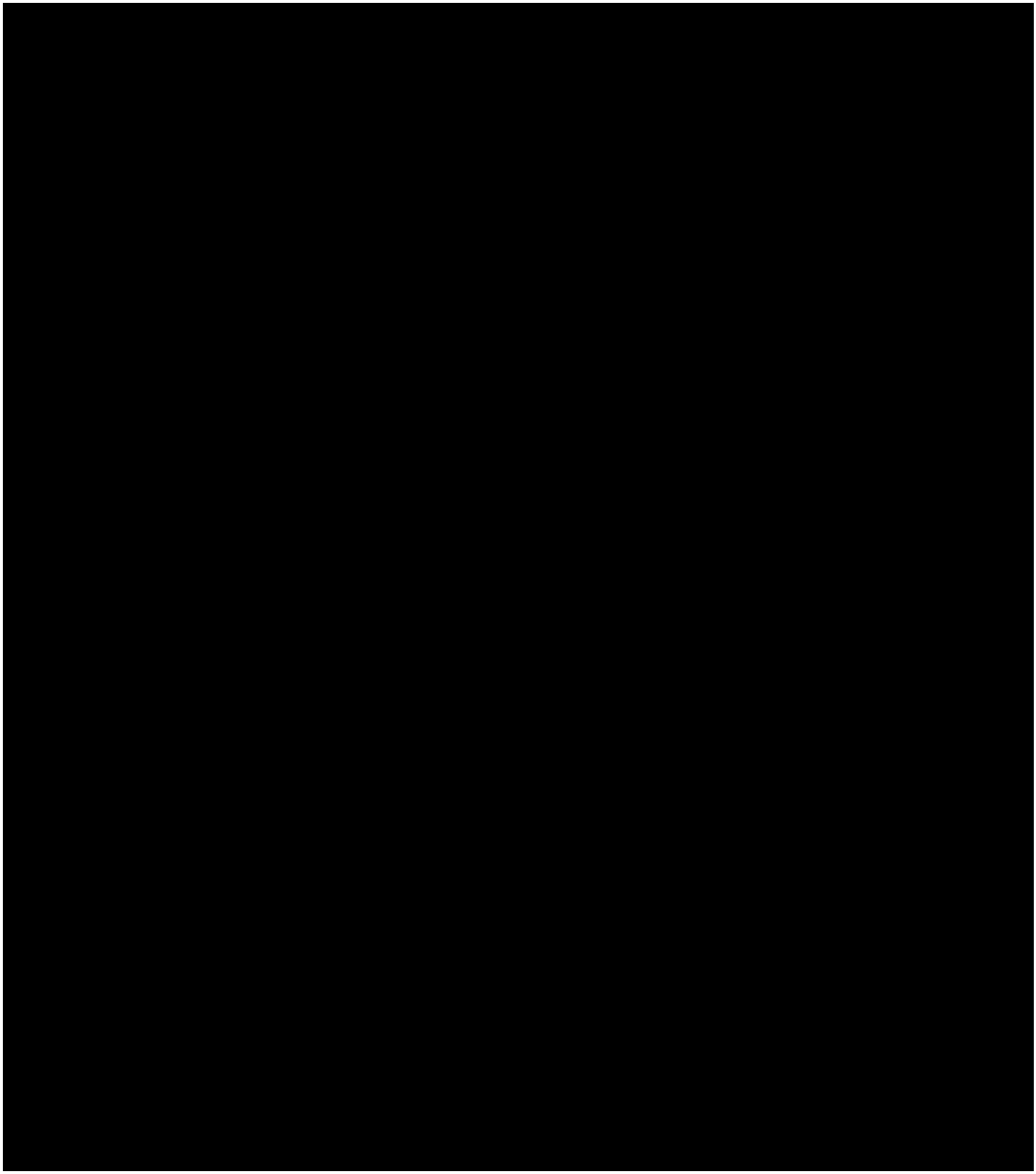
U.S. Fish and Wildlife Service (USWFS). 2021. Recovery plan for the eastern massasauga rattlesnake (*Sistrurus catenatus*). USFWS Great Lakes Region (Region 3), Bloomington, MN.

Waser, L. T., E. Baltsavias, K. Ecker, H. Eisenbeiss, C. Ginzler, M. Küchler, P. Thee, and L. Zhang. 2008. High-resolution digital surface models (DSMs) for modelling fractional shrub/tree cover in a mire environment. International Journal of Remote Sensing 29(5):1261 – 1276.

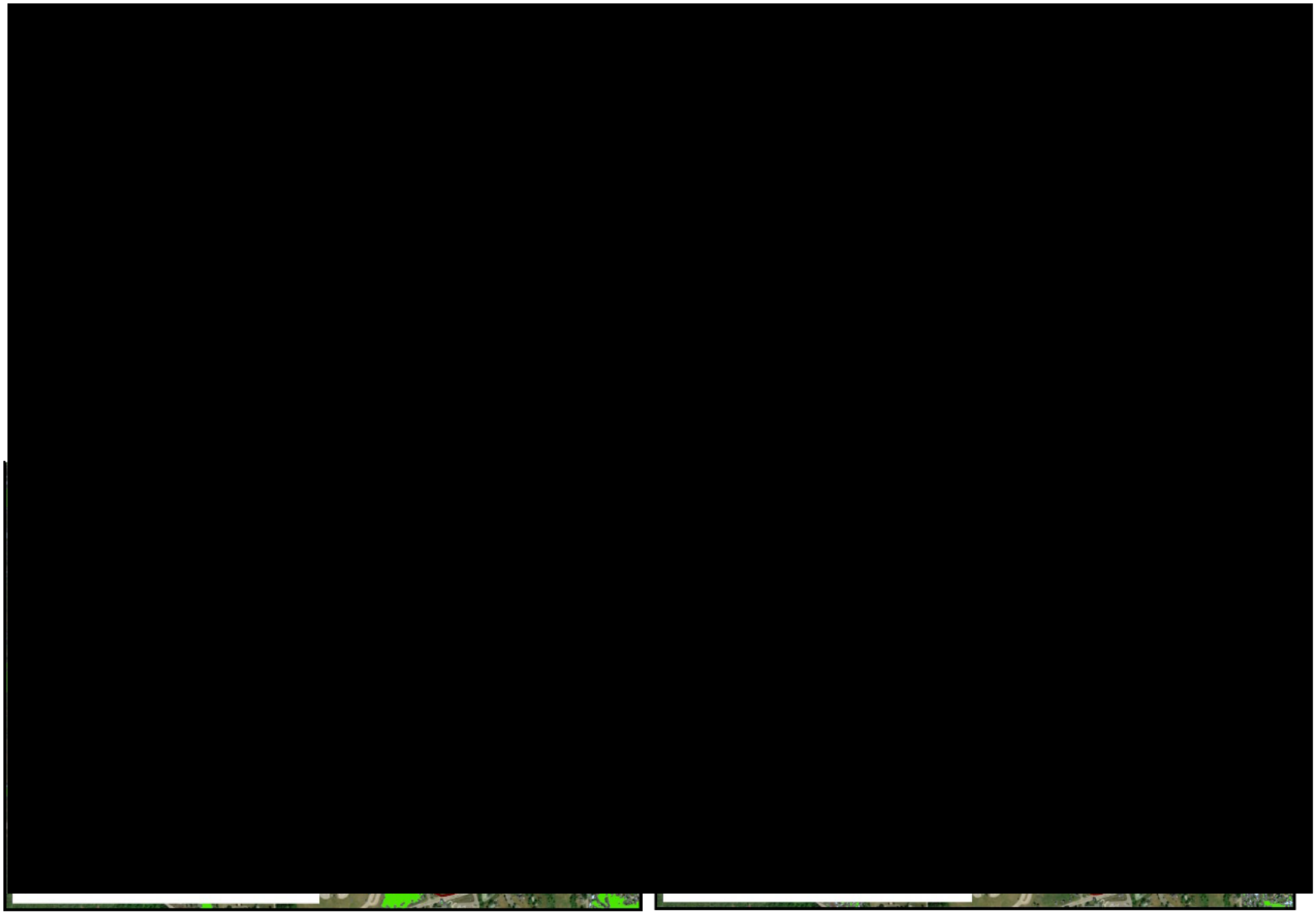
Weiss, A. 2001. Topographic position and landforms analysis. Poster presentation, ESRI user conference, San Diego, CA (Vol. 200).

Wright, B.A. 1941. Habit and habitat studies of the massasauga rattlesnake (*Sistrurus catenatus catenatus* Raf.) in Northeastern Illinois. American Midland Naturalist 25: 659-672.

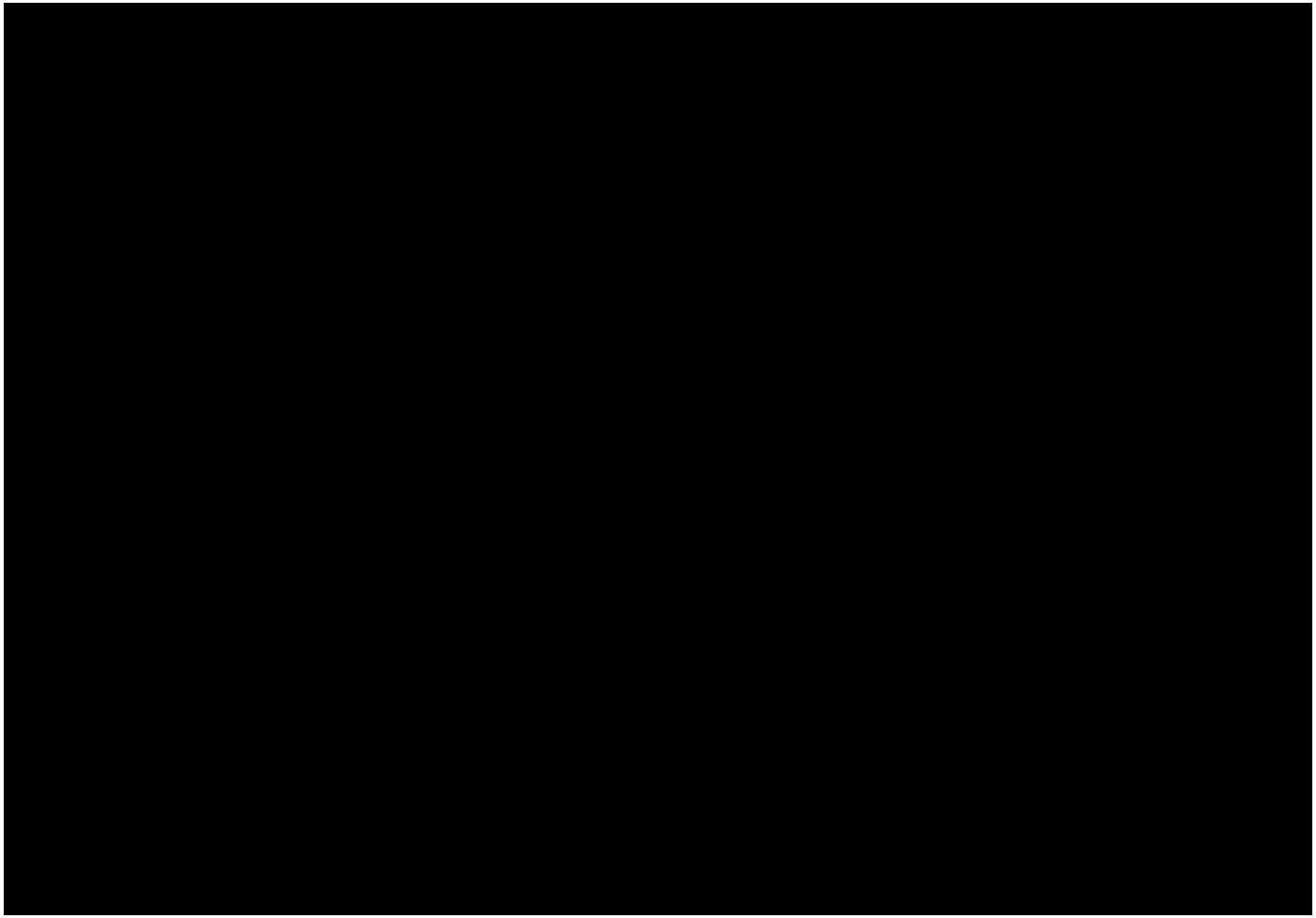
APPENDIX A: CANOPY COVER MAPS FOR THE SHIAWASSEE RIVER HEADWATERS STUDY REGION FROM 2012, 2017, 2022, AND 2023.



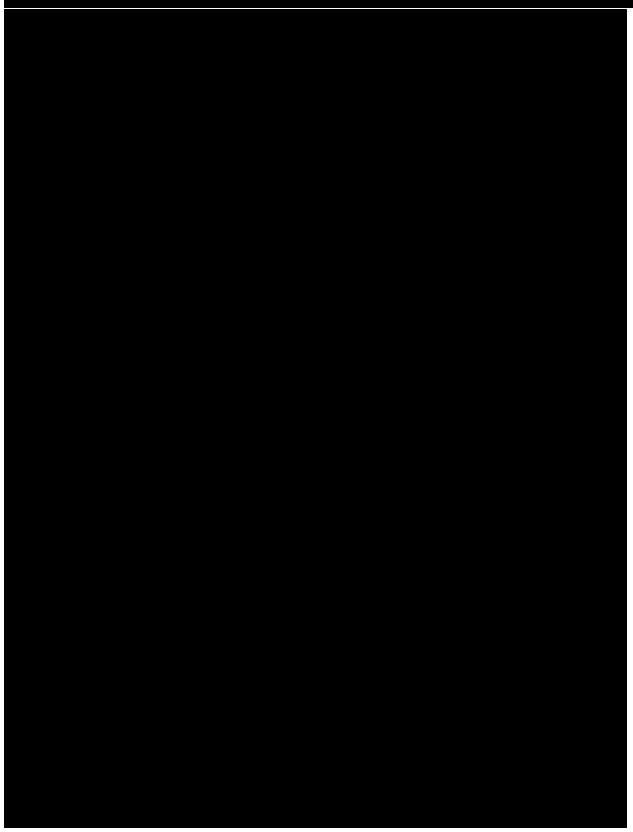
APPENDIX B: CANOPY COVER MAPS FOR THE [redacted] SITE WITHIN THE SHIAWASSEE RIVER HEADWATERS STUDY REGION FROM 2011, 2012, 2017, 2022, AND 2023.



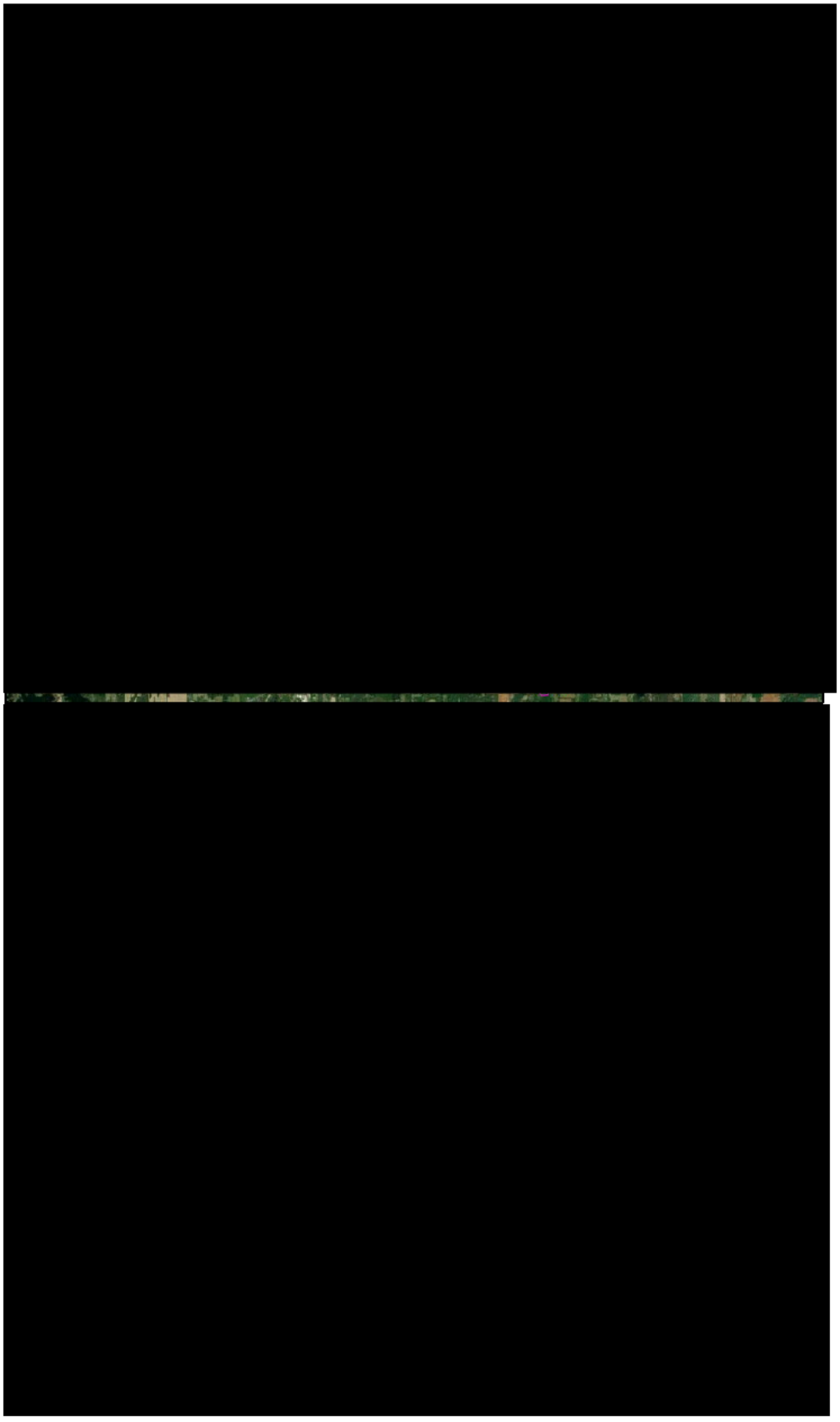
APPENDIX B (Continued): CANOPY COVER MAPS FOR THE [redacted] SITE WITHIN THE SHIAWASSEE RIVER HEADWATERS STUDY REGION from 2011, 2012, 2017, 2022, and 2023.



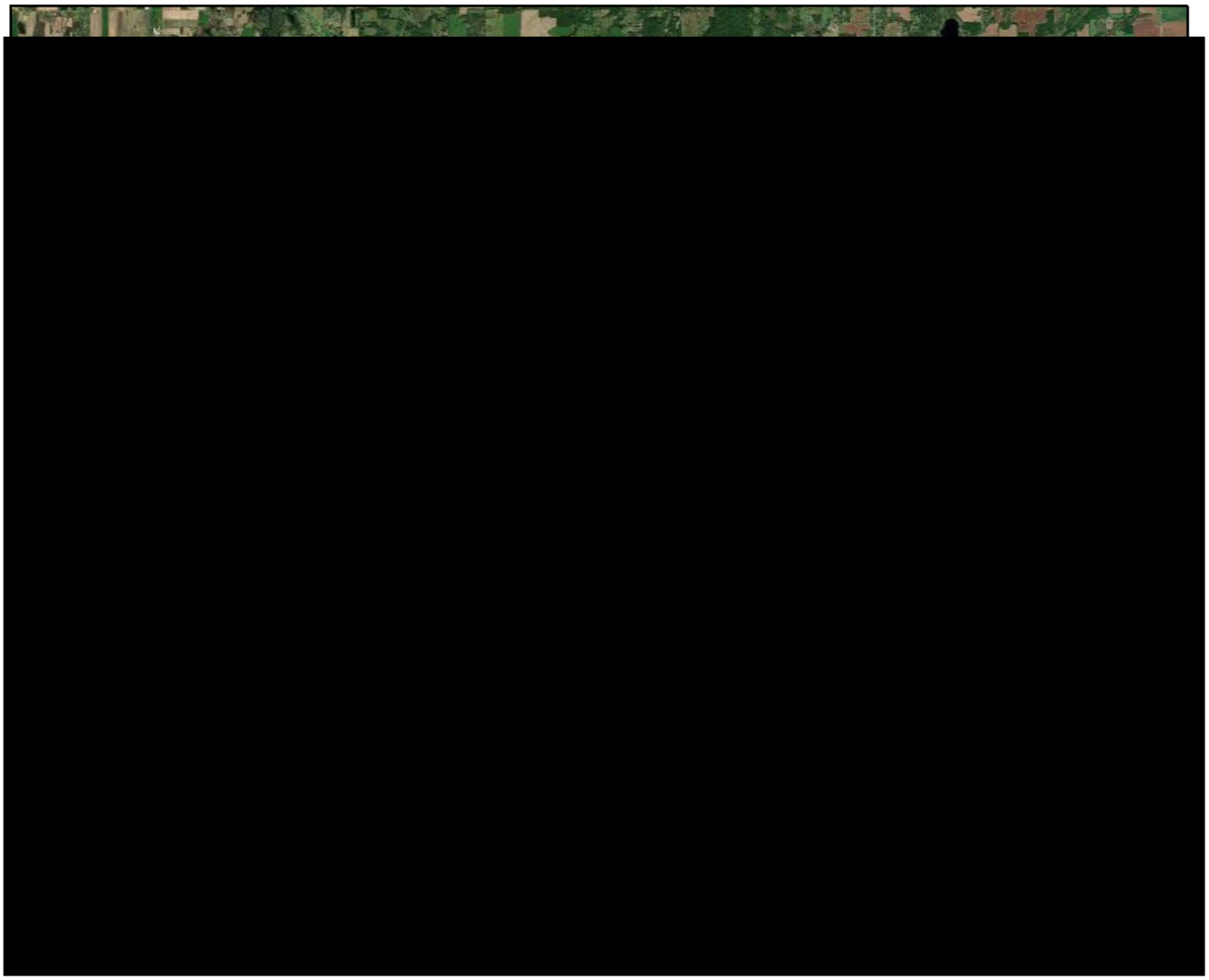
APPENDIX C: CANOPY COVER MAPS FOR THE [redacted] SITE WITHIN THE SHIAWASSEE RIVER HEADWATERS STUDY REGION FROM 2012, 2017, AND 2022.



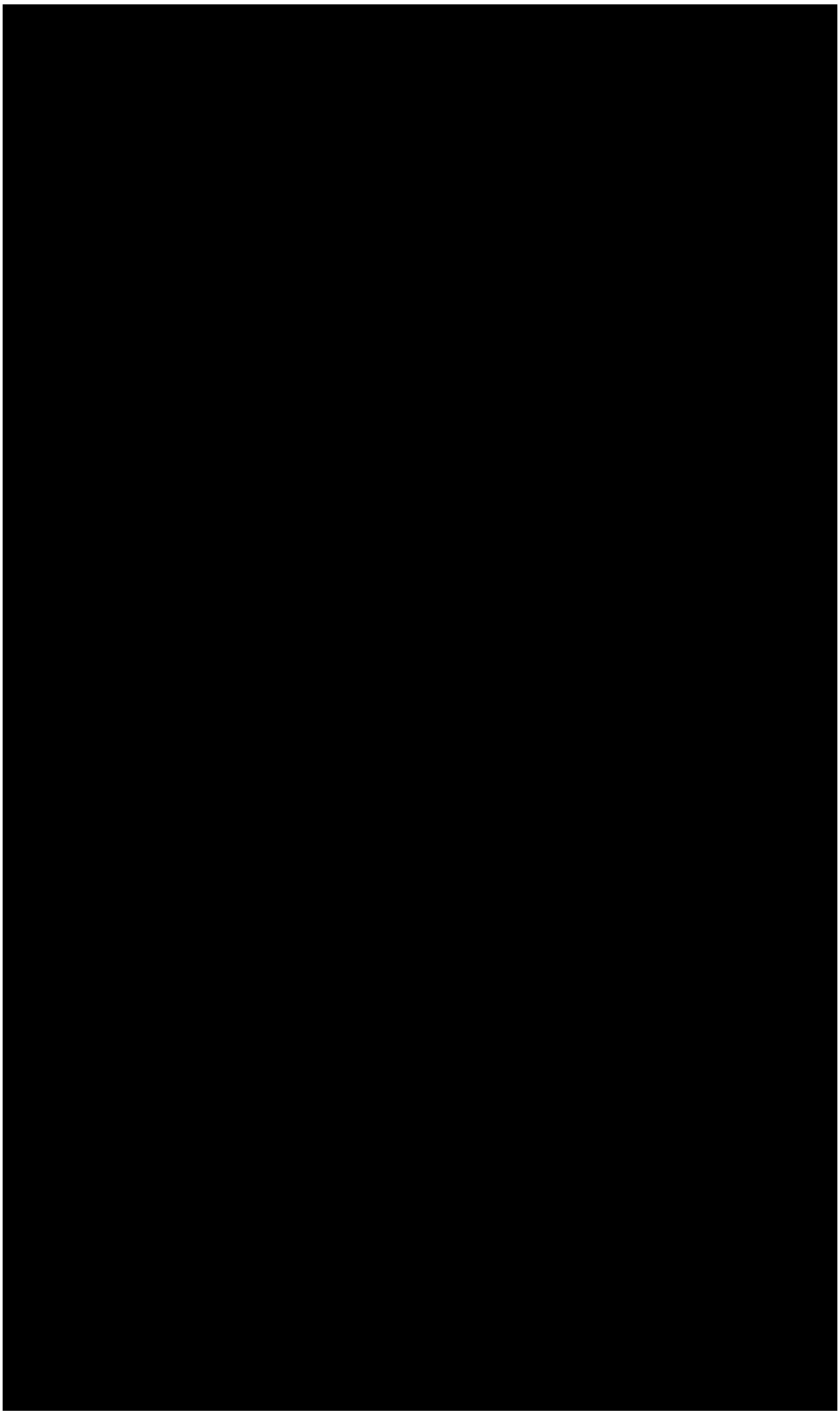
APPENDIX D: CANOPY COVER MAPS FOR THE BARRY COUNTY STUDY REGION FROM 2011, 2014, AND 2017.



APPENDIX D (Continued): CANOPY COVER MAPS FOR THE BARRY COUNTY STUDY REGION FROM 2011, 2014, AND 2017.



APPENDIX E: CANOPY COVER MAPS FOR THE [redacted] SITE WITHIN THE BARRY COUNTY STUDY REGION FROM 2014.



APPENDIX F: CANOPY COVER ESTIMATES IN AREA/ACRES FOR UNITS WITHIN THE [redacted] SITE IN THE SHIAWASSEE RIVER HEADWATERS STUDY REGION FROM 2011-2023.

[redacted] Canopy Cover - Area (acres)															
	2023			2022			2017			2012			2011		
Unit Name	Forest	Shrub	Canopy Total	Forest	Shrub	Canopy Total	Forest	Shrub	Canopy Total	Forest	Shrub	Canopy Total	Forest	Shrub	Canopy Total
[redacted] River South	1.98	3.69	5.67	3.32	2.32	5.63	5.76	0.83	6.59	2.67	3.42	6.09	3.13	1.05	4.18
[redacted] South	0.05	2.28	2.33	0.70	0.76	1.46	0.06	0.99	1.05	0.02	3.93	3.95	0.02	1.17	1.19
[redacted] North	0.98	1.31	2.30	0.92	2.31	3.23	0.54	1.39	1.93	0.12	4.94	5.05	0.03	1.45	1.48
[redacted] North	1.59	1.88	3.47	0.95	1.68	2.63	0.71	0.84	1.55	0.14	2.47	2.61	0.26	1.39	1.65
[redacted] North	0.74	0.76	1.49	0.45	1.17	1.62	2.29	1.97	4.27	0.18	2.75	2.93	0.22	0.82	1.04
[redacted] Additional	0.34	1.09	1.43	0.48	0.90	1.38	0.19	4.67	4.86	0.04	5.57	5.61	0.19	2.09	2.27
Old Field Upland	1.14	0.68	1.81	1.24	1.29	2.53	2.57	0.62	3.20	0.68	1.78	2.45	0.62	0.05	0.67
[redacted] NW Burn Unit	4.45	5.12	9.57	3.41	5.19	8.59	3.35	2.31	5.66	1.95	4.67	6.62	0.86	1.66	2.53
[redacted] SW Mgmt Unit	1.84	1.65	3.49	2.33	0.93	3.26	2.37	0.40	2.77	1.70	1.31	3.02	1.80	0.13	1.94
[redacted] Pvt	0.17	1.79	1.96	0.31	1.07	1.38	0.18	0.63	0.81	0.04	1.62	1.66	0.03	0.77	0.80
[redacted] Center Main	0.36	0.98	1.35	0.49	0.61	1.10	1.18	0.08	1.26	0.14	0.41	0.55	0.15	0.65	0.80
[redacted] Center SW	0.08	0.30	0.38	0.02	0.08	0.11	0.71	0.73	1.44	0.00	0.05	0.05	0.01	0.09	0.10
[redacted] Center SE	0.08	0.23	0.32	0.22	0.41	0.63	0.15	0.13	0.29	0.00	0.05	0.05	0.00	0.09	0.09
[redacted] Center N	0.31	0.37	0.68	0.45	0.19	0.63	0.37	0.22	0.60	0.02	0.41	0.43	0.10	0.02	0.12
[redacted] Center W	0.21	0.07	0.28	0.21	0.14	0.35	0.28	0.01	0.29	0.00	0.21	0.21	0.04	0.01	0.05
Cut Field North	0.24	0.33	0.58	0.33	0.13	0.45	0.32	0.14	0.47	0.07	0.73	0.80	0.06	0.23	0.29
North Field 3	2.15	0.98	3.13	2.47	1.16	3.63	2.77	0.94	3.71	1.33	2.11	3.44	0.37	1.28	1.65

North Field 2	0.71	0.34	1.05	0.86	0.50	1.36	1.08	0.31	1.39	0.38	1.03	1.41	0.17	0.18	0.35
North Field 1	0.53	0.22	0.76	0.49	0.41	0.90	0.35	0.14	0.49	0.07	0.40	0.47	0.05	0.10	0.15
North Hill 1	0.95	0.62	1.57	1.15	0.12	1.26	0.91	0.09	1.00	0.25	0.79	1.04	0.13	0.31	0.44
NW Clearing 4	0.08	0.12	0.20	0.13	0.01	0.14	0.03	0.03	0.07	0.01	0.14	0.15	0.01	0.00	0.01
NW Clearing 2	0.11	0.11	0.21	0.12	0.07	0.19	0.21	0.01	0.23	0.09	0.07	0.15	0.07	0.00	0.07
All Zones	**19.08**	**24.93**	**44.00**	**21.04**	**21.43**	**42.47**	**26.41**	**17.48**	**43.89**	**9.90**	**38.86**	**48.77**	**8.32**	**13.54**	**21.87**

APPENDIX G: CANOPY COVER ESTIMATES IN PERCENT COVER FOR UNITS WITHIN THE [redacted] SITE IN THE SHIAWASSEE RIVER HEADWATERS STUDY REGION FROM 2011-2023. (NOTE: CELLS HIGHLIGHTED IN RED INDICATE UNITS WITH CANOPY ESTIMATES GREATER THAN 50% AND POTENTIAL AREAS FOR HABITAT MANAGEMENT FOR EASTERN MASSASAUGAS.)

[redacted] Canopy Cover – Percent Cover															
	2023			2022			2017			2012			2011		
Unit Name	Forest	Shrub	Canopy Total	Forest	Shrub	Canopy Total	Forest	Shrub	Canopy Total	Forest	Shrub	Canopy Total	Forest	Shrub	Canopy Total
[redacted]outh	15.8	29.4	45.1	26.4	18.4	44.8	45.8	6.6	52.5	21.2	27.2	48.5	24.9	8.4	33.3
[redacted] South	0.3	14.4	14.7	4.4	4.8	9.2	0.4	6.3	6.7	0.1	24.9	25.0	0.1	7.4	7.5
[redacted] North	5.0	6.7	11.7	4.7	11.8	16.5	2.8	7.1	9.9	0.6	25.2	25.8	0.1	7.4	7.6
[redacted] North	17.4	20.6	38.0	10.5	18.4	28.8	7.8	9.2	17.0	1.6	27.1	28.6	2.9	15.2	18.1
[redacted] North	8.5	8.7	17.2	5.2	13.5	18.7	26.4	22.7	49.0	2.1	31.6	33.7	2.5	9.4	12.0
[redacted] Additional	2.1	6.9	9.1	3.1	5.7	8.8	1.2	29.7	30.9	0.2	35.5	35.7	1.2	13.3	14.5
Old Field Upland	14.3	8.5	22.8	15.7	16.2	31.9	32.4	7.8	40.2	8.5	22.4	30.9	7.8	0.7	8.5
[redacted] NW Burn Unit	11.0	12.7	23.7	8.4	12.8	21.2	8.3	5.7	14.0	4.8	11.5	16.4	2.1	4.1	6.2
[redacted] SW Mgmt Unit	17.0	15.3	32.3	21.6	8.6	30.2	21.9	3.7	25.6	15.8	12.2	27.9	16.7	1.2	17.9
[redacted] Pvt	2.8	29.0	31.8	5.0	17.4	22.4	3.0	10.1	13.1	0.7	26.3	27.0	0.4	12.5	12.9
[redacted] Center Main	2.6	7.0	9.6	3.5	4.4	7.9	8.5	0.5	9.0	1.0	2.9	3.9	1.1	4.7	5.8
[redacted] Center SW	1.7	6.4	8.0	0.5	1.8	2.3	14.9	15.2	30.1	0.0	1.0	1.0	0.2	1.9	2.1
[redacted] Center SE	1.3	3.6	4.9	3.4	6.4	9.9	2.4	2.1	4.5	0.0	0.8	0.8	0.0	1.3	1.3
[redacted] Center N	11.8	14.1	25.9	17.0	7.1	24.2	14.2	8.6	22.7	0.7	15.7	16.4	3.8	0.8	4.6
[redacted] Center W	21.2	7.0	28.2	21.4	14.2	35.6	28.2	1.1	29.3	0.0	21.7	21.7	4.4	1.1	5.5

Cut Field North	10.0	13.9	23.9	13.6	5.3	18.9	13.5	5.9	19.4	3.0	30.4	33.4	2.4	9.6	12.0
North Field 3	27.9	12.7	40.7	32.1	15.1	47.2	36.1	12.2	48.3	17.4	27.5	44.8	4.8	16.6	21.4
North Field 2	17.0	8.1	25.1	20.4	11.9	32.3	25.7	7.3	33.0	9.1	24.6	33.7	4.1	4.2	8.3
North Field 1	16.4	6.9	23.3	15.0	12.7	27.7	10.8	4.3	15.1	2.3	12.3	14.6	1.5	3.1	4.6
North Hill 1	23.4	15.4	38.8	28.3	2.9	31.2	22.5	2.1	24.6	6.1	19.5	25.6	3.1	7.6	10.8
NW Clearing 4	23.0	32.8	55.8	35.8	2.7	38.5	9.5	9.3	18.8	4.2	38.4	42.6	3.6	0.0	3.6
NW Clearing 2	17.4	17.3	34.7	19.4	10.9	30.3	34.9	2.3	37.2	13.9	10.8	24.7	11.6	0.0	11.6
All Zones	**9.6**	**12.6**	**22.3**	**10.6**	**10.8**	**21.5**	**13.4**	**8.8**	**22.2**	**5.0**	**19.7**	**24.7**	**4.2**	**6.8**	**11.1**

APPENDIX H: CANOPY COVER ESTIMATES (AREA AND PERCENT COVER) FOR EASTERN MASSASAUGA (EMR) ELEMENT OCCURRENCES (EOS) IN THE SHIAWASSEE STUDY REGION FOR 2011. (NOTE: EO_ID SPLIT INDICATES INDIVIDUAL SOURCE FEATURES/LOCATIONS THAT COMPRISE EACH EO. CELLS HIGHLIGHTED IN RED INDICATE AREAS WITH CANOPY ESTIMATES GREATER THAN 50% AND POTENTIAL AREAS FOR HABITAT MANAGEMENT FOR EMRS.)

2011							
EO_ID split	Forest (m^2)	Shrub (m^2)	Total Canopy	Total EO Area	Percent Cover Forest	Percent Cover Shrub	Percent Cover All Canopy
19055_2	0	1132	1132	1953	0.00%	57.96%	57.96%
3130_2	0	1708	1708	3659	0.00%	46.68%	46.68%
3130_11	84	724	808	1953	4.30%	37.07%	41.37%
10511_1	2124	912	3036	7811	27.19%	11.68%	38.87%
6223_19	24	704	728	1953	1.23%	36.05%	37.28%
6223_8	0	612	612	1953	0.00%	31.34%	31.34%
3130_9	0	556	556	1953	0.00%	28.47%	28.47%
3130_5	0	520	520	1953	0.00%	26.63%	26.63%
3130_15	64	504	568	2186	2.93%	23.06%	25.98%
3130_10	364	104	468	1953	18.64%	5.33%	23.96%
3130_4	292	164	456	1953	14.95%	8.40%	23.35%
20057_2	428	4	432	1953	21.92%	0.20%	22.12%
3130_19	344	80	424	1953	17.61%	4.10%	21.71%
3130_17	0	420	420	1953	0.00%	21.51%	21.51%
6223_5	16	344	360	1953	0.82%	17.61%	18.43%
20057_1	52724	13332	66056	365048	14.44%	3.65%	18.10%
6223_10	204	140	344	1953	10.45%	7.17%	17.61%
3130_12	252	376	628	3868	6.51%	9.72%	16.24%
3130_18	40	228	268	1953	2.05%	11.67%	13.72%
6223_12	0	724	724	5302	0.00%	13.66%	13.66%
6223_14	4	516	520	3903	0.10%	13.22%	13.32%
6223_3	5484	8740	14224	125279	4.38%	6.98%	11.35%
6223_11	52	160	212	1953	2.66%	8.19%	10.86%
11371_2	0	20	20	214	0.00%	9.35%	9.35%
19055_4	2172	744	2916	33134	6.56%	2.25%	8.80%
5567_22	17744	7332	25076	456382	3.89%	1.61%	5.49%
3130_7	0	100	100	1953	0.00%	5.12%	5.12%
3130_6	272	1240	1512	32487	0.84%	3.82%	4.65%
3130_8	0	80	80	1953	0.00%	4.10%	4.10%
6223_18	44	36	80	1953	2.25%	1.84%	4.10%

19055_3	3112	60	3172	85912	3.62%	0.07%	3.69%
3130_3	0	152	152	4665	0.00%	3.26%	3.26%
6223_16	16	44	60	1953	0.82%	2.25%	3.07%
5567_21	52	4	56	1953	2.66%	0.20%	2.87%
3130_1	0	16	16	589	0.00%	2.72%	2.72%
6223_9	0	52	52	1953	0.00%	2.66%	2.66%
3130_20	16	80	96	3620	0.44%	2.21%	2.65%
6223_21	660	260	920	35326	1.87%	0.74%	2.60%
6223_4	0	12	12	1146	0.00%	1.05%	1.05%
6223_6	0	20	20	1953	0.00%	1.02%	1.02%
6223_17	0	84	84	9421	0.00%	0.89%	0.89%
1422	0	0	0	8351493	0.00%	0.00%	0.00%
1419	0	0	0	1436848	0.00%	0.00%	0.00%
3130_13	0	0	0	1953	0.00%	0.00%	0.00%
3130_14	0	0	0	873	0.00%	0.00%	0.00%
3130_16	0	0	0	5172	0.00%	0.00%	0.00%
6223_1	0	0	0	1953	0.00%	0.00%	0.00%
6223_2	0	0	0	1953	0.00%	0.00%	0.00%
6223_7	0	0	0	1953	0.00%	0.00%	0.00%
6223_13	0	0	0	63	0.00%	0.00%	0.00%
6223_15	0	0	0	1953	0.00%	0.00%	0.00%
6223_20	0	0	0	1953	0.00%	0.00%	0.00%
6223_22	0	0	0	2630	0.00%	0.00%	0.00%
6223_23	0	0	0	1953	0.00%	0.00%	0.00%
6223_24	0	0	0	40613	0.00%	0.00%	0.00%
7670_1	0	0	0	1953	0.00%	0.00%	0.00%
7670_2	0	0	0	31248	0.00%	0.00%	0.00%
11364_1	0	0	0	1953	0.00%	0.00%	0.00%
11364_2	0	0	0	1953	0.00%	0.00%	0.00%
11364_3	0	0	0	178	0.00%	0.00%	0.00%
11364_4	0	0	0	7513	0.00%	0.00%	0.00%
11364_5	0	0	0	7811	0.00%	0.00%	0.00%
11364_6	0	0	0	1953	0.00%	0.00%	0.00%
11364_7	0	0	0	93732	0.00%	0.00%	0.00%
11364_8	0	0	0	111572	0.00%	0.00%	0.00%
19055_1	0	0	0	1953	0.00%	0.00%	0.00%
19055_5	0	0	0	1953	0.00%	0.00%	0.00%
10511_2	0	0	0	1953	0.00%	0.00%	0.00%
10511_3	0	0	0	30692	0.00%	0.00%	0.00%
10511_4	0	0	0	1953	0.00%	0.00%	0.00%
10511_5	0	0	0	2879	0.00%	0.00%	0.00%

10511_6	0	0	0	1953	0.00%	0.00%	0.00%
10511_7	0	0	0	1953	0.00%	0.00%	0.00%
10511_8	0	0	0	31245	0.00%	0.00%	0.00%
10511_9	0	0	0	7811	0.00%	0.00%	0.00%
10511_10	0	0	0	1953	0.00%	0.00%	0.00%
10511_11	0	0	0	31247	0.00%	0.00%	0.00%
10511_12	0	0	0	1953	0.00%	0.00%	0.00%
10511_13	0	0	0	1953	0.00%	0.00%	0.00%
11371_1	0	0	0	399	0.00%	0.00%	0.00%
11371_3	0	0	0	1160194	0.00%	0.00%	0.00%

APPENDIX I: CANOPY COVER ESTIMATES (AREA AND PERCENT COVER) FOR EASTERN MASSASAUGA (EMR) ELEMENT OCCURRENCES (EOS) IN THE SHIAWASSEE STUDY REGION FOR 2012. (NOTE: EO_ID SPLIT INDICATES INDIVIDUAL SOURCE FEATURES/LOCATIONS THAT COMPRISE EACH EO. CELLS HIGHLIGHTED IN RED INDICATE AREAS WITH CANOPY ESTIMATES GREATER THAN 50% AND POTENTIAL AREAS FOR HABITAT MANAGEMENT FOR EMRS.)

2012							
EO_ID split	Forest (m^2)	Shrub (m^2)	Total Canopy	Total EO Area	Percent Cover Forest	Percent Cover Shrub	Percent Cover All Canopy
11364_6	1892	20	1912	1953	96.88%	1.02%	97.90%
6223_19	0	1696	1696	1953	0.00%	86.84%	86.84%
3130_17	200	1440	1640	1953	10.24%	73.73%	83.97%
10511_2	1164	364	1528	1953	59.60%	18.64%	78.24%
10511_12	660	720	1380	1953	33.79%	36.87%	70.66%
6223_10	0	1200	1200	1953	0.00%	61.44%	61.44%
19055_2	0	1184	1184	1953	0.00%	60.62%	60.62%
10511_6	944	184	1128	1953	48.34%	9.42%	57.76%
3130_11	104	992	1096	1953	5.33%	50.79%	56.12%
6223_14	0	1912	1912	3903	0.00%	48.99%	48.99%
10511_1	1948	1876	3824	7811	24.94%	24.02%	48.96%
3130_10	796	120	916	1953	40.76%	6.14%	46.90%
11364_7	22664	17632	40296	93732	24.18%	18.81%	42.99%
6223_18	552	280	832	1953	28.26%	14.34%	42.60%
3130_19	652	140	792	1953	33.38%	7.17%	40.55%
6223_5	116	664	780	1953	5.94%	34.00%	39.94%
3130_9	488	284	772	1953	24.99%	14.54%	39.53%
3130_12	1316	204	1520	3868	34.02%	5.27%	39.30%
6223_7	0	724	724	1953	0.00%	37.07%	37.07%
20057_2	548	164	712	1953	28.06%	8.40%	36.46%
3130_2	1148	172	1320	3659	31.37%	4.70%	36.08%
3130_4	320	348	668	1953	16.39%	17.82%	34.20%
7670_1	600	68	668	1953	30.72%	3.48%	34.20%
11364_3	40	20	60	178	22.47%	11.24%	33.71%
10511_8	7040	3404	10444	31245	22.53%	10.89%	33.43%
7670_2	6224	4100	10324	31248	19.92%	13.12%	33.04%
6223_6	0	636	636	1953	0.00%	32.57%	32.57%
20057_1	51708	66408	118116	365048	14.16%	18.19%	32.36%
10511_4	8	608	616	1953	0.41%	31.13%	31.54%

6223_8	0	592	592	1953	0.00%	30.31%	30.31%
11371_2	0	64	64	214	0.00%	29.91%	29.91%
11364_2	572	8	580	1953	29.29%	0.41%	29.70%
10511_3	4984	3940	8924	30692	16.24%	12.84%	29.08%
11364_8	28776	3512	32288	111572	25.79%	3.15%	28.94%
10511_11	1860	6540	8400	31247	5.95%	20.93%	26.88%
3130_18	204	320	524	1953	10.45%	16.39%	26.83%
11371_3	173296	128128	301424	1160194	14.94%	11.04%	25.98%
6223_12	0	1284	1284	5302	0.00%	24.22%	24.22%
6223_22	164	464	628	2630	6.24%	17.64%	23.88%
6223_11	0	464	464	1953	0.00%	23.76%	23.76%
3130_5	312	148	460	1953	15.98%	7.58%	23.55%
10511_5	576	88	664	2879	20.01%	3.06%	23.06%
1422	1363256	325260	1688516	8351493	16.32%	3.89%	20.22%
3130_15	132	304	436	2186	6.04%	13.91%	19.95%
11364_1	132	256	388	1953	6.76%	13.11%	19.87%
19055_4	2104	4164	6268	33134	6.35%	12.57%	18.92%
6223_4	0	216	216	1146	0.00%	18.85%	18.85%
6223_21	1120	5480	6600	35326	3.17%	15.51%	18.68%
6223_17	32	1652	1684	9421	0.34%	17.54%	17.87%
6223_24	692	6464	7156	40613	1.70%	15.92%	17.62%
6223_16	332	12	344	1953	17.00%	0.61%	17.61%
6223_3	4028	16380	20408	125279	3.22%	13.07%	16.29%
11364_5	1220	28	1248	7811	15.62%	0.36%	15.98%
11364_4	608	344	952	7513	8.09%	4.58%	12.67%
1419	92740	81408	174148	1436848	6.45%	5.67%	12.12%
10511_13	32	184	216	1953	1.64%	9.42%	11.06%
3130_3	20	480	500	4665	0.43%	10.29%	10.72%
19055_1	0	208	208	1953	0.00%	10.65%	10.65%
19055_3	2848	4332	7180	85912	3.32%	5.04%	8.36%
5567_22	9824	26136	35960	456382	2.15%	5.73%	7.88%
3130_6	1088	1032	2120	32487	3.35%	3.18%	6.53%
3130_20	0	184	184	3620	0.00%	5.08%	5.08%
3130_1	4	24	28	589	0.68%	4.07%	4.75%
3130_7	80	0	80	1953	4.10%	0.00%	4.10%
10511_7	8	64	72	1953	0.41%	3.28%	3.69%
11371_1	0	12	12	399	0.00%	3.01%	3.01%
5567_21	56	0	56	1953	2.87%	0.00%	2.87%
6223_9	0	32	32	1953	0.00%	1.64%	1.64%
6223_23	0	32	32	1953	0.00%	1.64%	1.64%
6223_15	0	20	20	1953	0.00%	1.02%	1.02%

3130_8	0	0	0	1953	0.00%	0.00%	0.00%
3130_13	0	0	0	1953	0.00%	0.00%	0.00%
3130_14	0	0	0	873	0.00%	0.00%	0.00%
3130_16	0	0	0	5172	0.00%	0.00%	0.00%
6223_1	0	0	0	1953	0.00%	0.00%	0.00%
6223_2	0	0	0	1953	0.00%	0.00%	0.00%
6223_13	0	0	0	63	0.00%	0.00%	0.00%
6223_20	0	0	0	1953	0.00%	0.00%	0.00%
19055_5	0	0	0	1953	0.00%	0.00%	0.00%
10511_9	0	0	0	7811	0.00%	0.00%	0.00%
10511_10	0	0	0	1953	0.00%	0.00%	0.00%

APPENDIX J: CANOPY COVER ESTIMATES (AREA AND PERCENT COVER) FOR EASTERN MASSASAUGA (EMR) ELEMENT OCCURRENCES (EOS) IN THE SHIAWASSEE STUDY REGION FOR 2017. (NOTE: EO_ID SPLIT INDICATES INDIVIDUAL SOURCE FEATURES/LOCATIONS THAT COMPRISE EACH EO. CELLS HIGHLIGHTED IN RED INDICATE AREAS WITH CANOPY ESTIMATES GREATER THAN 50% AND POTENTIAL AREAS FOR HABITAT MANAGEMENT FOR EMRS.)

2017							
EO_ID split	Forest (m^2)	Shrub (m^2)	Total Canopy	Total EO Area	Percent Cover Forest	Percent Cover Shrub	Percent Cover All Canopy
11364_6	1684	116	1800	1953	86.23%	5.94%	92.17%
6223_19	24	1716	1740	1953	1.23%	87.86%	89.09%
10511_6	1416	12	1428	1953	72.50%	0.61%	73.12%
3130_10	1352	28	1380	1953	69.23%	1.43%	70.66%
10511_2	1076	288	1364	1953	55.09%	14.75%	69.84%
3130_17	76	1188	1264	1953	3.89%	60.83%	64.72%
3130_11	560	520	1080	1953	28.67%	26.63%	55.30%
11364_2	972	60	1032	1953	49.77%	3.07%	52.84%
7670_1	600	336	936	1953	30.72%	17.20%	47.93%
6223_18	856	56	912	1953	43.83%	2.87%	46.70%
10511_1	2316	1076	3392	7811	29.65%	13.78%	43.43%
6223_10	264	520	784	1953	13.52%	26.63%	40.14%
10511_12	428	272	700	1953	21.92%	13.93%	35.84%
3130_12	1316	40	1356	3868	34.02%	1.03%	35.06%
10511_8	7796	2752	10548	31245	24.95%	8.81%	33.76%
11364_7	8820	22400	31220	93732	9.41%	23.90%	33.31%
20057_1	57960	57028	114988	365048	15.88%	15.62%	31.50%
6223_5	420	184	604	1953	21.51%	9.42%	30.93%
20057_2	492	112	604	1953	25.19%	5.73%	30.93%
3130_15	620	36	656	2186	28.36%	1.65%	30.01%
7670_2	2892	6080	8972	31248	9.25%	19.46%	28.71%
3130_18	320	180	500	1953	16.39%	9.22%	25.60%
3130_19	496	4	500	1953	25.40%	0.20%	25.60%
3130_9	348	144	492	1953	17.82%	7.37%	25.19%
11364_3	44	0	44	178	24.72%	0.00%	24.72%
11364_8	14416	13040	27456	111572	12.92%	11.69%	24.61%
3130_5	0	480	480	1953	0.00%	24.58%	24.58%
6223_3	23364	6800	30164	125279	18.65%	5.43%	24.08%
10511_3	5232	2156	7388	30692	17.05%	7.02%	24.07%

6223_22	132	500	632	2630	5.02%	19.01%	24.03%
3130_4	260	136	396	1953	13.31%	6.96%	20.28%
6223_16	356	0	356	1953	18.23%	0.00%	18.23%
11371_3	143624	48548	192172	1160194	12.38%	4.18%	16.56%
1422	1115120	153900	1269020	8351493	13.35%	1.84%	15.20%
11364_5	392	772	1164	7811	5.02%	9.88%	14.90%
19055_4	3056	1860	4916	33134	9.22%	5.61%	14.84%
6223_21	1320	3760	5080	35326	3.74%	10.64%	14.38%
3130_2	24	484	508	3659	0.66%	13.23%	13.88%
6223_24	2156	3460	5616	40613	5.31%	8.52%	13.83%
10511_11	1444	2264	3708	31247	4.62%	7.25%	11.87%
10511_4	0	208	208	1953	0.00%	10.65%	10.65%
11364_1	0	188	188	1953	0.00%	9.63%	9.63%
3130_1	36	16	52	589	6.11%	2.72%	8.83%
1419	74656	47720	122376	1436848	5.20%	3.32%	8.52%
3130_6	2644	76	2720	32487	8.14%	0.23%	8.37%
6223_17	600	184	784	9421	6.37%	1.95%	8.32%
5567_22	15992	21864	37856	456382	3.50%	4.79%	8.29%
6223_8	116	44	160	1953	5.94%	2.25%	8.19%
3130_7	108	0	108	1953	5.53%	0.00%	5.53%
10511_7	96	12	108	1953	4.92%	0.61%	5.53%
19055_3	3040	1568	4608	85912	3.54%	1.83%	5.36%
3130_20	100	84	184	3620	2.76%	2.32%	5.08%
6223_4	0	56	56	1146	0.00%	4.89%	4.89%
6223_14	0	160	160	3903	0.00%	4.10%	4.10%
6223_23	0	68	68	1953	0.00%	3.48%	3.48%
6223_12	0	184	184	5302	0.00%	3.47%	3.47%
5567_21	56	0	56	1953	2.87%	0.00%	2.87%
3130_3	0	108	108	4665	0.00%	2.32%	2.32%
10511_13	40	4	44	1953	2.05%	0.20%	2.25%
11364_4	0	152	152	7513	0.00%	2.02%	2.02%
6223_1	24	12	36	1953	1.23%	0.61%	1.84%
6223_7	0	36	36	1953	0.00%	1.84%	1.84%
6223_15	8	0	8	1953	0.41%	0.00%	0.41%
19055_2	4	4	8	1953	0.20%	0.20%	0.41%
19055_1	4	0	4	1953	0.20%	0.00%	0.20%
3130_8	0	0	0	1953	0.00%	0.00%	0.00%
3130_13	0	0	0	1953	0.00%	0.00%	0.00%
3130_14	0	0	0	873	0.00%	0.00%	0.00%
3130_16	0	0	0	5172	0.00%	0.00%	0.00%
6223_2	0	0	0	1953	0.00%	0.00%	0.00%

6223_6	0	0	0	1953	0.00%	0.00%	0.00%
6223_9	0	0	0	1953	0.00%	0.00%	0.00%
6223_11	0	0	0	1953	0.00%	0.00%	0.00%
6223_13	0	0	0	63	0.00%	0.00%	0.00%
6223_20	0	0	0	1953	0.00%	0.00%	0.00%
19055_5	0	0	0	1953	0.00%	0.00%	0.00%
10511_5	0	0	0	2879	0.00%	0.00%	0.00%
10511_9	0	0	0	7811	0.00%	0.00%	0.00%
10511_10	0	0	0	1953	0.00%	0.00%	0.00%
11371_1	0	0	0	399	0.00%	0.00%	0.00%
11371_2	0	0	0	214	0.00%	0.00%	0.00%

APPENDIX K: CANOPY COVER ESTIMATES (AREA AND PERCENT COVER) FOR EASTERN MASSASAUGA (EMR) ELEMENT OCCURRENCES (EOS) IN THE SHIAWASSEE STUDY REGION FOR 2022. (NOTE: EO_ID SPLIT INDICATES INDIVIDUAL SOURCE FEATURES/LOCATIONS THAT COMPRISE EACH EO. CELLS HIGHLIGHTED IN RED INDICATE AREAS WITH CANOPY ESTIMATES GREATER THAN 50% AND POTENTIAL AREAS FOR HABITAT MANAGEMENT FOR EMRS.)

2022							
EO_ID split	Forest (m^2)	Shrub (m^2)	Total Canopy	Total EO Area	Percent Cover Forest	Percent Cover Shrub	Percent Cover All Canopy
3130_11	917	795	1712	1953	46.97%	40.68%	87.66%
3130_9	676	895	1571	1953	34.60%	45.82%	80.42%
6223_19	2	1386	1388	1953	0.10%	70.99%	71.09%
3130_2	424	1870	2294	3659	11.58%	51.10%	62.68%
6223_18	948	258	1206	1953	48.55%	13.21%	61.76%
10511_2	760	322	1081	1953	38.90%	16.46%	55.36%
10511_1	694	3078	3772	7811	8.89%	39.40%	48.29%
10511_12	770	166	936	1953	39.42%	8.49%	47.92%
10511_6	788	119	907	1953	40.37%	6.08%	46.45%
3130_5	78	784	862	1953	3.98%	40.16%	44.14%
6223_10	180	575	756	1953	9.23%	29.46%	38.69%
20057_2	471	258	729	1953	24.12%	13.21%	37.33%
6223_22	641	319	960	2630	24.37%	12.15%	36.52%
20057_1	91173	41101	132274	365048	24.98%	11.26%	36.23%
6223_6	0	633	633	1953	0.00%	32.40%	32.40%
19055_4	1833	7454	9287	33134	5.53%	22.50%	28.03%
3130_4	401	139	541	1953	20.55%	7.13%	27.68%
10511_8	5580	2955	8535	31245	17.86%	9.46%	27.32%
11371_3	164443	134648	299090	1160194	14.17%	11.61%	25.78%
6223_5	285	172	457	1953	14.57%	8.81%	23.38%
10511_3	6475	694	7169	30692	21.10%	2.26%	23.36%
11371_2	49	0	49	214	22.97%	0.00%	22.97%
6223_3	18055	9078	27133	125279	14.41%	7.25%	21.66%
6223_21	2605	4544	7149	35326	7.37%	12.86%	20.24%
10511_11	4137	1884	6020	31247	13.24%	6.03%	19.27%
6223_16	295	0	295	1953	15.10%	0.00%	15.10%
6223_7	31	246	276	1953	1.57%	12.58%	14.16%
19055_2	0	272	272	1953	0.00%	13.95%	13.95%
10511_4	39	211	250	1953	1.99%	10.80%	12.79%
10511_13	43	170	213	1953	2.20%	8.70%	10.90%

6223_24	1644	2676	4321	40613	4.05%	6.59%	10.64%
5567_22	38527	9596	48123	456382	8.44%	2.10%	10.54%
6223_17	584	332	915	9421	6.19%	3.52%	9.72%
3130_3	2	408	410	4665	0.04%	8.74%	8.78%
6223_11	4	143	147	1953	0.21%	7.34%	7.55%
19055_3	4597	1876	6473	85912	5.35%	2.18%	7.53%
11371_1	27	0	27	399	6.67%	0.00%	6.67%
6223_8	51	78	129	1953	2.62%	3.98%	6.61%
10511_7	74	35	109	1953	3.77%	1.78%	5.56%
10511_5	96	18	115	2879	3.34%	0.64%	3.98%
5567_21	61	14	76	1953	3.15%	0.73%	3.88%
6223_9	70	4	74	1953	3.57%	0.21%	3.77%
19055_1	0	61	61	1953	0.00%	3.15%	3.15%
6223_4	23	0	23	1146	1.97%	0.00%	1.97%
6223_12	51	14	66	5302	0.97%	0.27%	1.24%
6223_14	31	12	43	3903	0.79%	0.31%	1.10%
6223_1	8	0	8	1953	0.42%	0.00%	0.42%
6223_15	0	8	8	1953	0.00%	0.42%	0.42%
6223_23	0	6	6	1953	0.00%	0.31%	0.31%
1422	0	0	0	8351493	0.00%	0.00%	0.00%
1419	0	0	0	1436848	0.00%	0.00%	0.00%
3130_1	0	0	0	589	0.00%	0.00%	0.00%
3130_6	0	0	0	32487	0.00%	0.00%	0.00%
3130_7	0	0	0	1953	0.00%	0.00%	0.00%
3130_8	0	0	0	1953	0.00%	0.00%	0.00%
3130_10	0	0	0	1953	0.00%	0.00%	0.00%
3130_12	0	0	0	3868	0.00%	0.00%	0.00%
3130_13	0	0	0	1953	0.00%	0.00%	0.00%
3130_14	0	0	0	873	0.00%	0.00%	0.00%
3130_15	0	0	0	2186	0.00%	0.00%	0.00%
3130_16	0	0	0	5172	0.00%	0.00%	0.00%
3130_17	0	0	0	1953	0.00%	0.00%	0.00%
3130_18	0	0	0	1953	0.00%	0.00%	0.00%
3130_19	0	0	0	1953	0.00%	0.00%	0.00%
3130_20	0	0	0	3620	0.00%	0.00%	0.00%
6223_2	0	0	0	1953	0.00%	0.00%	0.00%
6223_13	0	0	0	63	0.00%	0.00%	0.00%
6223_20	0	0	0	1953	0.00%	0.00%	0.00%
7670_1	0	0	0	1953	0.00%	0.00%	0.00%
7670_2	0	0	0	31248	0.00%	0.00%	0.00%
11364_1	0	0	0	1953	0.00%	0.00%	0.00%

11364_2	0	0	0	1953	0.00%	0.00%	0.00%
11364_3	0	0	0	178	0.00%	0.00%	0.00%
11364_4	0	0	0	7513	0.00%	0.00%	0.00%
11364_5	0	0	0	7811	0.00%	0.00%	0.00%
11364_6	0	0	0	1953	0.00%	0.00%	0.00%
11364_7	0	0	0	93732	0.00%	0.00%	0.00%
11364_8	0	0	0	111572	0.00%	0.00%	0.00%
19055_5	0	0	0	1953	0.00%	0.00%	0.00%
10511_9	0	0	0	7811	0.00%	0.00%	0.00%
10511_10	0	0	0	1953	0.00%	0.00%	0.00%

APPENDIX L: CANOPY COVER ESTIMATES (AREA AND PERCENT COVER) FOR EASTERN MASSASAUGA (EMR) ELEMENT OCCURRENCES (EOS) IN THE SHIAWASSEE STUDY REGION FOR 2023. (NOTE: EO_ID SPLIT INDICATES INDIVIDUAL SOURCE FEATURES/LOCATIONS THAT COMPRISE EACH EO. CELLS HIGHLIGHTED IN RED INDICATE AREAS WITH CANOPY ESTIMATES GREATER THAN 50% AND POTENTIAL AREAS FOR HABITAT MANAGEMENT FOR EMRS.)

2023							
EO_ID split	Forest (m^2)	Shrub (m^2)	Total Canopy	Total EO Area	Percent Cover Forest	Percent Cover Shrub	Percent Cover All Canopy
3130_10	1304	80	1384	1953	66.77%	4.10%	70.87%
3130_9	356	1024	1380	1953	18.23%	52.43%	70.66%
3130_11	8	1164	1172	1953	0.41%	59.60%	60.01%
6223_19	116	1020	1136	1953	5.94%	52.23%	58.17%
6223_13	12	20	32	63	19.05%	31.75%	50.79%
3130_2	220	1536	1756	3659	6.01%	41.98%	47.99%
6223_18	556	376	932	1953	28.47%	19.25%	47.72%
3130_17	0	864	864	1953	0.00%	44.24%	44.24%
3130_15	888	8	896	2186	40.62%	0.37%	40.99%
3130_19	284	500	784	1953	14.54%	25.60%	40.14%
3130_18	388	292	680	1953	19.87%	14.95%	34.82%
3130_4	176	440	616	1953	9.01%	22.53%	31.54%
6223_10	72	540	612	1953	3.69%	27.65%	31.34%
3130_12	324	788	1112	3868	8.38%	20.37%	28.75%
6223_5	140	352	492	1953	7.17%	18.02%	25.19%
6223_3	19348	10536	29884	125279	15.44%	8.41%	23.85%
3130_5	8	444	452	1953	0.41%	22.73%	23.14%
6223_17	1344	812	2156	9421	14.27%	8.62%	22.89%
6223_16	308	48	356	1953	15.77%	2.46%	18.23%
6223_20	224	104	328	1953	11.47%	5.33%	16.79%
6223_9	76	200	276	1953	3.89%	10.24%	14.13%
3130_3	12	576	588	4665	0.26%	12.35%	12.60%
3130_6	296	3732	4028	32487	0.91%	11.49%	12.40%
6223_8	68	160	228	1953	3.48%	8.19%	11.67%
3130_20	0	232	232	3620	0.00%	6.41%	6.41%
6223_4	0	64	64	1146	0.00%	5.58%	5.58%
6223_14	12	184	196	3903	0.31%	4.71%	5.02%
6223_11	12	76	88	1953	0.61%	3.89%	4.51%
3130_13	0	76	76	1953	0.00%	3.89%	3.89%
3130_7	16	36	52	1953	0.82%	1.84%	2.66%

6223_15	0	48	48	1953	0.00%	2.46%	2.46%
3130_8	0	24	24	1953	0.00%	1.23%	1.23%
6223_7	0	4	4	1953	0.00%	0.20%	0.20%
3130_16	0	8	8	5172	0.00%	0.15%	0.15%
1422	0	0	0	8351493	0.00%	0.00%	0.00%
1419	0	0	0	1436848	0.00%	0.00%	0.00%
3130_1	0	0	0	589	0.00%	0.00%	0.00%
3130_14	0	0	0	873	0.00%	0.00%	0.00%
5567_21	0	0	0	1953	0.00%	0.00%	0.00%
5567_22	0	0	0	456382	0.00%	0.00%	0.00%
6223_1	0	0	0	1953	0.00%	0.00%	0.00%
6223_2	0	0	0	1953	0.00%	0.00%	0.00%
6223_6	0	0	0	1953	0.00%	0.00%	0.00%
6223_12	0	0	0	5302	0.00%	0.00%	0.00%
6223_21	0	0	0	35326	0.00%	0.00%	0.00%
6223_22	0	0	0	2630	0.00%	0.00%	0.00%
6223_23	0	0	0	1953	0.00%	0.00%	0.00%
6223_24	0	0	0	40613	0.00%	0.00%	0.00%
7670_1	0	0	0	1953	0.00%	0.00%	0.00%
7670_2	0	0	0	31248	0.00%	0.00%	0.00%
11364_1	0	0	0	1953	0.00%	0.00%	0.00%
11364_2	0	0	0	1953	0.00%	0.00%	0.00%
11364_3	0	0	0	178	0.00%	0.00%	0.00%
11364_4	0	0	0	7513	0.00%	0.00%	0.00%
11364_5	0	0	0	7811	0.00%	0.00%	0.00%
11364_6	0	0	0	1953	0.00%	0.00%	0.00%
11364_7	0	0	0	93732	0.00%	0.00%	0.00%
11364_8	0	0	0	111572	0.00%	0.00%	0.00%
19055_1	0	0	0	1953	0.00%	0.00%	0.00%
19055_2	0	0	0	1953	0.00%	0.00%	0.00%
19055_3	0	0	0	85912	0.00%	0.00%	0.00%
19055_4	0	0	0	33134	0.00%	0.00%	0.00%
19055_5	0	0	0	1953	0.00%	0.00%	0.00%
10511_1	0	0	0	7811	0.00%	0.00%	0.00%
10511_2	0	0	0	1953	0.00%	0.00%	0.00%
10511_3	0	0	0	30692	0.00%	0.00%	0.00%
10511_4	0	0	0	1953	0.00%	0.00%	0.00%
10511_5	0	0	0	2879	0.00%	0.00%	0.00%
10511_6	0	0	0	1953	0.00%	0.00%	0.00%
10511_7	0	0	0	1953	0.00%	0.00%	0.00%
10511_8	0	0	0	31245	0.00%	0.00%	0.00%

10511_9	0	0	0	7811	0.00%	0.00%	0.00%
10511_10	0	0	0	1953	0.00%	0.00%	0.00%
10511_11	0	0	0	31247	0.00%	0.00%	0.00%
10511_12	0	0	0	1953	0.00%	0.00%	0.00%
10511_13	0	0	0	1953	0.00%	0.00%	0.00%
20057_1	0	0	0	365048	0.00%	0.00%	0.00%
20057_2	0	0	0	1953	0.00%	0.00%	0.00%
11371_1	0	0	0	399	0.00%	0.00%	0.00%
11371_2	0	0	0	214	0.00%	0.00%	0.00%
11371_3	0	0	0	1160194	0.00%	0.00%	0.00%

APPENDIX M: CANOPY COVER ESTIMATES (AREA AND PERCENT COVER) FOR EASTERN MASSASAUGA (EMR) ELEMENT OCCURRENCES (EOS) IN THE BARRY COUNTY STUDY REGION FOR 2011. (NOTE: EO_ID SPLIT INDICATES INDIVIDUAL SOURCE FEATURES/LOCATIONS THAT COMPRISE EACH EO. CELLS HIGHLIGHTED IN RED INDICATE AREAS WITH CANOPY ESTIMATES GREATER THAN 50% AND POTENTIAL AREAS FOR HABITAT MANAGEMENT FOR EMRS.)

2011							
EO_ID split	Forest (m^2)	Shrub (m^2)	Total Canopy	Total EO Area	Percent Cover Forest	Percent Cover Shrub	Percent Cover All Canopy
12835_6	488	484	972	1957	24.94%	24.73%	49.67%
12835_2	424	388	812	1957	21.67%	19.83%	41.49%
19833_2	488	316	804	1957	24.94%	16.15%	41.08%
12835_1	1856	1120	2976	7826	23.72%	14.31%	38.03%
19833_7	196	412	608	1957	10.02%	21.05%	31.07%
19832_1	1124	1296	2420	7828	14.36%	16.56%	30.91%
19833_6	132	468	600	1957	6.75%	23.91%	30.66%
19833_1	480	64	544	1957	24.53%	3.27%	27.80%
19833_4	192	280	472	1957	9.81%	14.31%	24.12%
17113_3	5168	29840	35008	145238	3.56%	20.55%	24.10%
19833_10	1232	604	1836	7828	15.74%	7.72%	23.45%
12751_4	172	284	456	1957	8.79%	14.51%	23.30%
19832_2	172	284	456	1957	8.79%	14.51%	23.30%
19835_2	1080	1296	2376	11132	9.70%	11.64%	21.34%
19836_1	1080	1296	2376	11132	9.70%	11.64%	21.34%
19833_3	808	1940	2748	13424	6.02%	14.45%	20.47%
19835_9	120	268	388	1958	6.13%	13.69%	19.82%
12751_1	108	272	380	1957	5.52%	13.90%	19.42%
19834_1	108	272	380	1957	5.52%	13.90%	19.42%
19833_8	1644	3356	5000	27675	5.94%	12.13%	18.07%
12835_4	216	1832	2048	13425	1.61%	13.65%	15.26%
19835_4	64	216	280	1957	3.27%	11.04%	14.31%
19836_3	64	216	280	1957	3.27%	11.04%	14.31%
19833_5	36	988	1024	7828	0.46%	12.62%	13.08%
17113_2	116	132	248	1957	5.93%	6.75%	12.67%
19837	5160	1908	7068	57283	9.01%	3.33%	12.34%
19835_1	5160	1908	7068	57283	9.01%	3.33%	12.34%
12835_10	7676	21112	28788	241808	3.17%	8.73%	11.91%
12751_2	664	616	1280	11472	5.79%	5.37%	11.16%
19834_2	664	616	1280	11472	5.79%	5.37%	11.16%

7666	51736	34100	85836	782674	6.61%	4.36%	10.97%
19835_7	0	300	300	2818	0.00%	10.65%	10.65%
19835_6	41260	10928	52188	501029	8.24%	2.18%	10.42%
12751_3	1640	4436	6076	61051	2.69%	7.27%	9.95%
2383	760	2092	2852	31310	2.43%	6.68%	9.11%
12751_5	1508	512	2020	32735	4.61%	1.56%	6.17%
19832_3	1508	512	2020	32735	4.61%	1.56%	6.17%
19835_10	98916	4656	103572	2540556	3.89%	0.18%	4.08%
12835_8	12	48	60	2862	0.42%	1.68%	2.10%
19835_3	0	156	156	7828	0.00%	1.99%	1.99%
19836_2	0	156	156	7828	0.00%	1.99%	1.99%
17113_1	4	28	32	1957	0.20%	1.43%	1.64%
19833_9	0	16	16	1957	0.00%	0.82%	0.82%
19835_5	288	208	496	125251	0.23%	0.17%	0.40%
19836_4	288	208	496	125251	0.23%	0.17%	0.40%

APPENDIX N: CANOPY COVER ESTIMATES (AREA AND PERCENT COVER) FOR EASTERN MASSASAUGA (EMR) ELEMENT OCCURRENCES (EOS) IN THE BARRY COUNTY STUDY REGION FOR 2014. (NOTE: EO_ID SPLIT INDICATES INDIVIDUAL SOURCE FEATURES/LOCATIONS THAT COMPRISE EACH EO. CELLS HIGHLIGHTED IN RED INDICATE AREAS WITH CANOPY ESTIMATES GREATER THAN 50% AND POTENTIAL AREAS FOR HABITAT MANAGEMENT FOR EMRS.)

2014							
EO_ID split	Forest (m^2)	Shrub (m^2)	Total Canopy	Total EO Area	Percent Cover Forest	Percent Cover Shrub	Percent Cover All Canopy
12835_6	524	468	992	1957	26.78%	23.91%	50.69%
12835_2	444	400	844	1957	22.69%	20.44%	43.13%
19833_2	488	308	796	1957	24.94%	15.74%	40.67%
12835_1	1856	1132	2988	7826	23.72%	14.46%	38.18%
19832_1	1120	1280	2400	7828	14.31%	16.35%	30.66%
19833_7	200	384	584	1957	10.22%	19.62%	29.84%
19833_6	116	464	580	1957	5.93%	23.71%	29.64%
19833_1	496	64	560	1957	25.34%	3.27%	28.62%
12751_4	168	312	480	1957	8.58%	15.94%	24.53%
19832_2	168	312	480	1957	8.58%	15.94%	24.53%
17113_3	5132	29968	35100	145238	3.53%	20.63%	24.17%
19833_10	1244	604	1848	7828	15.89%	7.72%	23.61%
19833_4	164	264	428	1957	8.38%	13.49%	21.87%
19835_2	1112	1312	2424	11132	9.99%	11.79%	21.78%
19836_1	1112	1312	2424	11132	9.99%	11.79%	21.78%
19833_3	808	1952	2760	13424	6.02%	14.54%	20.56%
12751_1	108	280	388	1957	5.52%	14.31%	19.83%
19834_1	108	280	388	1957	5.52%	14.31%	19.83%
19835_9	108	268	376	1958	5.52%	13.69%	19.20%
19833_8	1652	3300	4952	27675	5.97%	11.92%	17.89%
12835_4	216	1836	2052	13425	1.61%	13.68%	15.28%
19835_4	76	220	296	1957	3.88%	11.24%	15.13%
19836_3	76	220	296	1957	3.88%	11.24%	15.13%
19833_5	36	996	1032	7828	0.46%	12.72%	13.18%
19837	5184	1952	7136	57283	9.05%	3.41%	12.46%
19835_1	5184	1952	7136	57283	9.05%	3.41%	12.46%
12835_10	7848	21164	29012	241808	3.25%	8.75%	12.00%
17113_2	100	128	228	1957	5.11%	6.54%	11.65%
7666	51616	34092	85708	782674	6.59%	4.36%	10.95%
19835_7	0	308	308	2818	0.00%	10.93%	10.93%

12751_2	612	616	1228	11472	5.33%	5.37%	10.70%
19834_2	612	616	1228	11472	5.33%	5.37%	10.70%
19835_6	41288	10900	52188	501029	8.24%	2.18%	10.42%
12751_3	1624	4416	6040	61051	2.66%	7.23%	9.89%
2383	772	2112	2884	31310	2.47%	6.75%	9.21%
12751_5	1668	508	2176	32735	5.10%	1.55%	6.65%
19832_3	1668	508	2176	32735	5.10%	1.55%	6.65%
19835_10	99188	4588	103776	2540556	3.90%	0.18%	4.08%
12835_8	12	48	60	2862	0.42%	1.68%	2.10%
19835_3	0	152	152	7828	0.00%	1.94%	1.94%
19836_2	0	152	152	7828	0.00%	1.94%	1.94%
17113_1	4	28	32	1957	0.20%	1.43%	1.64%
19833_9	0	16	16	1957	0.00%	0.82%	0.82%
19835_5	272	220	492	125251	0.22%	0.18%	0.39%
19836_4	272	220	492	125251	0.22%	0.18%	0.39%

APPENDIX O: CANOPY COVER ESTIMATES (AREA AND PERCENT COVER) FOR EASTERN MASSASAUGA (EMR) ELEMENT OCCURRENCES (EOS) IN THE BARRY COUNTY STUDY REGION FOR 2017. (NOTE: EO_ID SPLIT INDICATES INDIVIDUAL SOURCE FEATURES/LOCATIONS THAT COMPRISE EACH EO. CELLS HIGHLIGHTED IN RED INDICATE AREAS WITH CANOPY ESTIMATES GREATER THAN 50% AND POTENTIAL AREAS FOR HABITAT MANAGEMENT FOR EMRS.)

2017							
EO_ID split	Forest (m^2)	Shrub (m^2)	Total Canopy	Total EO Area	Percent Cover Forest	Percent Cover Shrub	Percent Cover All Canopy
12835_5	3012	0	3012	7826	38.49%	0.00%	38.49%
12835_1	996	720	1716	7826	12.73%	9.20%	21.93%
1542_3	1892	4064	5956	31305	6.04%	12.98%	19.03%
12835_10	21832	18416	40248	241808	9.03%	7.62%	16.64%
19838	7992	11864	19856	125219	6.38%	9.47%	15.86%
1542_1	7992	11864	19856	125219	6.38%	9.47%	15.86%
17113_3	4608	16700	21308	145238	3.17%	11.50%	14.67%
7666	78572	18912	97484	782674	10.04%	2.42%	12.46%
1542_2	3472	2408	5880	48898	7.10%	4.92%	12.03%
2383	2892	12	2904	31310	9.24%	0.04%	9.27%
12835_4	4	1028	1032	13425	0.03%	7.66%	7.69%
12835_7	12	1620	1632	23125	0.05%	7.01%	7.06%
12835_3	24	532	556	13520	0.18%	3.93%	4.11%
12835_6	0	64	64	1957	0.00%	3.27%	3.27%
12835_8	12	32	44	2862	0.42%	1.12%	1.54%