Winter 2022

DOCUMENTING THE RAPIDLY EXPANDING DISTRIBUTION OF INVASIVE RAVENNA GRASS (TRIPIDIUM RAVENNAE) EASTERN IN KANSAS

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DOCUMENTING THE RAPIDLY EXPANDING DISTRIBUTION OF INVASIVE RAVENNA GRASS (*TRIPIDIUM RAVENNAE*) EASTERN IN KANSAS

A Thesis Submitted to the Graduate School
in Partial fulfillment of the Requirements
for the Degree of
Master of Science

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Pittsburg, Kansas

December 2022

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ACKNOWLEDGEMENTS

I want to thank the Department of Biology and the Graduate School at Pittsburg State University for this opportunity. I would also like to thank my fellow graduate students, who are a part of the T. M. Sperry Herbarium cohort with me, for constructive conversations and plant identification help.

Thank you to my committee, Drs. James Whitney and Cynthia Huffman, for support, feedback, and flexibility. To my advisor, Dr. Neil Snow, thank you for your wisdom and knowledge (of both the botanical and academic worlds), and having the faith to take me on as your graduate student.

I would also like to thank Michelle Fisk and Tom Baldvins of the Colorado Natural Heritage Program, for the instruction of species distribution modeling.

Thank you to Dr. Christine Rega-Brodsky, for your unwavering patience and lightning-fast email replies… but more importantly for being an incredible role model, scientist, and woman. You have helped me grow, both professionally and personally.

This research would not have been possible without the emotional support provided by my family and friends. Thank you to Claire Campbell and Zack Osborn for so much more than just accompanying me on research road trips and helping with field work. To my dear friends I have made in Pittsburg, having you in my corner is something I will always cherish. Thank you, Patrick and Marsha Ralston, for always supporting me in any way, but also for helping financially support this project.

And finally, thank you to Jennifer Gurganus, for always being my biggest fan and my greatest supporter. You always know just what to say when the world feels like it is crashing down around me.

For, Emmalee Grace.

You inspire me every day to be the best woman and person I can be.

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An Abstract of the Thesis by
Rachel A. Styers

Invasive species cause significant ecological losses in the United States where they cost approximately $21 billion dollars a year to manage (Fantle-Lepczyk et al., 2022). Early detection of new invasive species, coupled with a rapid response of management efforts, can help to slow the ecological and economic impacts caused by these habitat invaders. *Tripidium ravennae* (L.) H. Scholz (or Ravenna grass) is a tall, robust, cespitose grass known to occur in Kansas, although its distribution remained incompletely documented prior to this study. Given its known invasive tendencies, it has been declared noxious in at least six US states. Coupled with a historical search for existing specimens in Kansas, an active survey for *Tripidium ravennae* was conducted in 47 counties in eastern Kansas to properly document its distribution. The species was first recorded in Kansas in 1960 and historically documented 15 times total among eight counties within the last 62 years. In 2022, this study recorded 103 occurrences in 25 counties, representing 17 new county records. All records for Kansas after 1990 were combined to generate a species distribution model using Maximum Entropy. This model predicted substantial suitable habitat for *Tripidium ravennae* in eastern Kansas and further confirms high invasion potential for the species.

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CHAPTER I

INTRODUCTION

A nonnative species is one that has established itself in a geographical area or habitat in which it did not evolve. The movement of species into non-native habitats has many causes, including accidental or intentional anthropomorphic spread, or natural ecological spread (Bardsley & Edwards-Jones, 2006; Dehnen-Schmutz et al., 2007). Given that it did not originate in its new habitat, it sometimes thrives in the absence of the biotic pressures (i.e., predation, competition, and disease) it faced in its native habitat, a phenomenon known as biotic release (Sax et al., 2005). The lack of native predators and native ecological competitors often allows non-native or introduced species to spread and multiply, oftentimes to the imperilment of native species. As such, invasive species management is an ever-growing field in conservation.

When nonnative species have negative effects on human health, the economy, or environment, they become invasive species. Invasive species can be found across all taxonomical groups. Invasive animal and plant species usually are measured by their detrimental impacts on biological diversity and/or economic losses. Biological loss includes the decrease of native biodiversity in affected habitats, habitat loss or fragmentation of native species, negative changes in productivity and nutrient processes, and ecosystem disruption (Poland et al., 2021). Economic loss refers to the monetary loss associated with decreases in resource production, damaged habitat, decreased agricultural production, and the enormous costs often associated with the control and management of invasive species. For example, on average approximately $21 billion is being spent annually in the United States alone (Fantle-Lepczyk et al., 2022). Control methods include biological (e.g., introduced pests or animal control agents), chemical (e.g., herbicide, pesticide, poison), and physical (e.g., mechanical removal or trapping). Finally, a recent study stressed a third important impact factor associated with nonnative species is their human-health risk (Nguyen et al., 2020). Health risks include various levels of psychological effects, skin irritation, allergens, poisons, diseases, and death in extreme cases. For example, multiple mosquito species act as vectors for zoonotic diseases such as West Nile and Zika virus (Mazza & Tricarico, 2018).

Invasive plant species are significantly impacting many ecosystems globally (Baker, 1974). A greater number of Old World plant species have established in the New World as invasives compared to the inverse, and the New World has proportionately more invasive species (Shergill et al., 2018). The vectors for unintentional plant dispersal can include seeds hitching a ride in transportation vehicles, storage containers, or in transported soil (Rotherham, 2005). Intentional introductions include humans bringing plants from their native region for ornamental, culinary purposes, or for livestock forage (Dehnen-Schmutz et al., 2007). Ecologically and economically, invasive plant species ultimately can be more harmful than some species of mammals, birds, fish, or insects, because upon arrival they tend to be much less noticed (on average) than these other categories of non-natives. For example, although *Amaranthus palmeri* S. Wats. has expanded significantly northward and eastward in N. America (Kartesz, 2022) and is now one of the most problematic weeds in the Great Plains. It has been documented with a vouchered herbarium specimen for only two of the nine southeastern-most counties in Kansas. This lack of collections has occurred despite the species being abundant along roadsides, disturbed areas, and in crops such as soybeans throughout that area (N. Snow, pers. comm., Oct. 2022). The rapid spread of *A. palmeri* is due to its resistance to glyphosate and at least five other herbicides (Hygeia Analytics, 2018).

Members of the grass family, Poaceae, have a variety of economic uses. Agriculturally well-known grasses such as rice, wheat, barley, rye, corn, tef, and sugar cane are used worldwide or locally for human benefit far beyond their native ranges (Baker, 1974; Stubbendieck et al., 2017). For example, the subfamily Bambusoideae is used commercially as a substitute for wood in construction settings, particularly in Asia and South America. Bamboo is also harvested for furniture and flooring, as well as its recent popularity as a replacement for single-use plastics and paper products. Grass species also are used commonly for erosion control, such as *Agropyron cristatum* (L.) Gaertn. and *A. fragile* (Roth.) P. Candargy. Grasses also can have cultural or even spiritual connections for numerous populations worldwide. An example is the cultural relevance of Sweetgrass (*Anthoxanthum odorata* L.) within some indigenous peoples of North America (Kimmerer, 2015). Sweetgrass is not native to North America but was introduced by indigenous peoples from the lands that would become Canada (after colonization) because of its importance for cultural and ceremonial purposes (Leif & NRCS Michigan Plant Materials Program, 2010). Sweetgrass is now found in at least 40 American states (Kartez, 2022).

Members of Poaceae also have a variety of biological and ecological characteristics that make them versatile and capable of invasiveness on every continent, including Antarctica (Shaw, 2012). Grasses can be short-lived but abundant seed-producing annuals, or strongly stoloniferous or rhizomatous perennials that reproduce asexually. Grasses can have either the C_3 or C_4 photosynthetic pathway, broadening their potential adaptability to foreign environments. They regularly produce high rates of seeds, some of which are easily distributed in water, and others of which are well-adapted to wind dispersal given the presence of long hairs on the seeds or dispersal units (e.g., members of the taxonomic Tribe Andropogoneae). Seeds in grasses uniformly are relatively small and can be undetectable, making them easy to transport across geographical regions and be introduced accidentally to new areas.

Expanding from above, rhizomatous and stoloniferous stems allow for wide horizontal spread from a single "parental plant" (Stubbendieck et al., 2017). Examples of well-known invasive grasses in the United States include Cogon grass (*Imperata cylindrica* (L.) P.Beauv.), which invades low-growing forests mostly in the Southeast; Cheatgrass (*Bromus tectorum* L.), which has severely disrupted the terrestrial ecology of wide portions of the western USA (e.g., Snake River Planes of southern Idaho); and Pampas grass (*Cortaderia selloana* [Schult. & Schult. f.]), which often escapes from ornamental plantings (Stubbendieck et al., 2017).

Tripidium ravennae (L.) H. Scholz, commonly known as Ravenna grass or plume grass, is an ornamental grass native to the Mediterranean region of southern Europe, northern Africa, and the Middle East. This species can form multi-stemmed clumps up to 3-4 meters tall and 2 meters wide (Swearingen, 2018). The exact date of its introduction to the United States is unknown. The first vouchered record of Ravenna grass in America was collected in 1878, from a garden in Providence, Rhode Island. The oldest detailed record that I could confirm to be an escaped occurrence was collected in 1928 in Maricopa County, Arizona.

Now planted widely in the United States ornamentally (Figure 1), it has been documented as encroaching into non-native habitats from gardens and lawns in at least 27 states, including Kansas, where it is spreading rapidly in the eastern portions (pers. comm. C. Freeman to N. Snow, 2021; and results of this project), Oklahoma (in 19 counties), and Missouri (3 counties); Figure 1). Despite its broad distribution (Kartesz, 2022), it has been declared noxious or regulated by state law in only six states, including California, New Mexico, Oregon, Pennsylvania, Washington, and Utah. It is also considered a noxious weed by the National Park Service. A designation of "noxious" in most states requires landowner eradication or attempts thereof. In addition, a designation of noxious then forbids the sell and trade of the species in that state.

Figure 1. Characteristic ornamental planting of *Tripidium ravennae* in eastern Kansas on the campus of Pittsburg State University. The plant is approximately 3.5 meters tall.

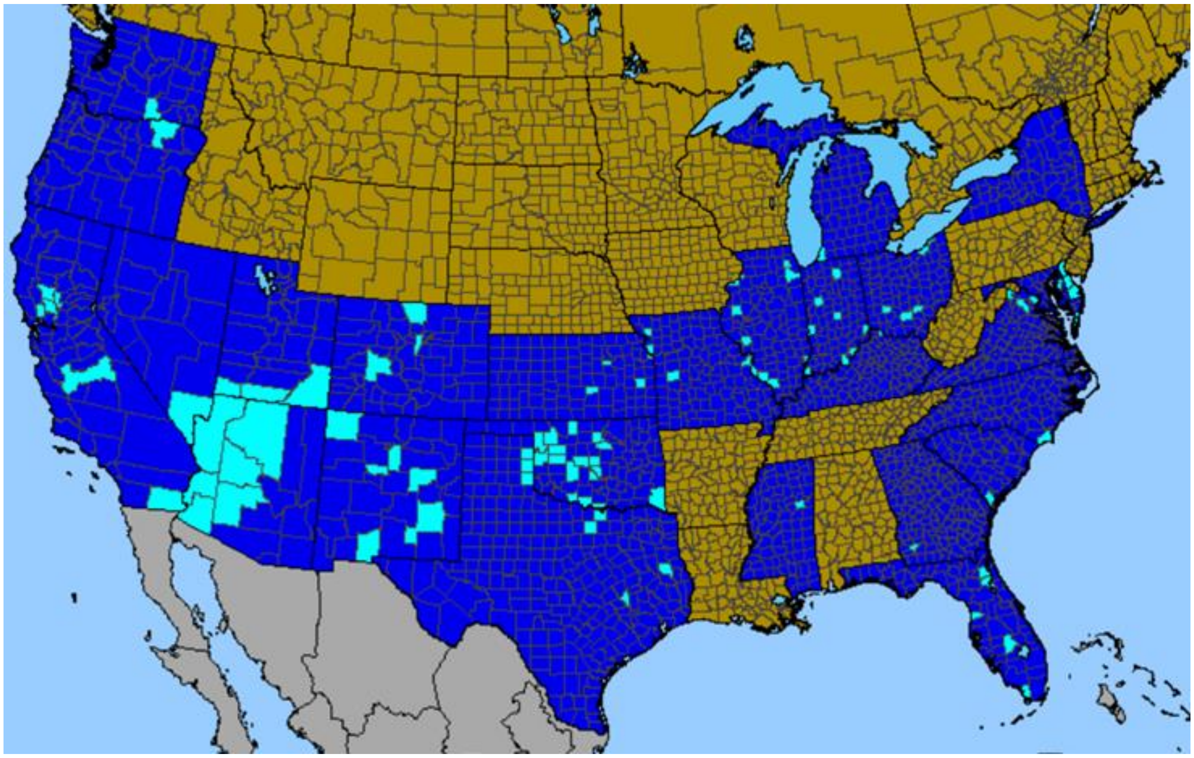

Figure 2. Distribution map of *Tripidium ravennae* based on *Biota of North America* (Kartesz 2022), prior to this study. States in dark blue represent the presence of non-native species. Light blue of individual counties represents a vouchered species presence in that county.

The nomenclatural history of *Tripidium ravennae* is extensive. The species was originally described by Linnaeus (1753) and given the name *Andropogon ravennae* L., after the town of Ravenna, in the Ravenna providence of in Northern Italy. In 1774, Linnaeus later transferred the species to the genus *Saccharum. Saccharum ravennae* (L.) L. (Linnaeus, 1774), which has been used commonly by many taxonomists (e.g., Vincent & Gardner, 2016). In 1812, Palisot de Beauvois (1812) created the combination *Agrostis ravennae* (L.) P. Beauv., but that quickly was followed up by another new combination of *Erianthus ravennae* (L.) P. Beauv., after *Agrostis* was split into five genera. Less than a decade later, a change to *Ripidium ravennae* (L.) Trin. (Trinius, 1820) was porposed; however, this name was considered taxonomically "illegitimate" due to the prior use of that name having been used by Bernhardi (1800). Scholz (2006) eventually made the new combination of *Tripidium ravennae* (L.) H. Sholz, effectively separating the species from the Old World genus of *Erianthus*, which has no legitimate presence New World as of this study (Valdés & Scholz, 2007). At the generic level, *Tripidium* species found in the New (and Old) World, exhibit three stamens instead of the two stamens present in *Erianthus*. This generic split is further supported by distinct chemical and molecular markers exhibited in both genera (Welker et al., 2019).

Subspecies or varieties of *Tripidium ravennae* have been recognized by some taxonomists, but information for these intraspecific taxa is outdated and presently unavaiable. In addition to the nominative subspecies (*T. ravennae* subsp. *ravennae*), Scholz (2006) also recognized *Tripidium ravennae* subsp. *parviflorum* (Pilg.). *Erianthus ravennae* included the subspecies *parviflorus* (Pilg.), H.Scholz), the subvariety *jamaicensis* Hack., and var. *jamaicensis* (Trin.) Hack. (WFO 2022). However, taxonomic treatments during the past sixty years in Europe (Akeroyd et al., 1993) and North America (Yatskievych, 1999; Shaw, 2012) do not recognize subspecies, so the present study will not try to differentiate among them.

Tripidium ravennae blooms in late summer and can occupy moist soils such as in ditches, marshes, and wetlands, but can tolerate a wide range of habitat conditions including open, well-drained slopes (Welker et al., 2019). As such, Yatskievych (1999) predicted accurately that it would spread in Missouri in the future. These habitat preferences are similar to those of pampas grass (*Cortaderia selloana* (Schult. & Schult. f.), for which it can be mistaken. Clear differences in leaf coloration, leaf size, and plant height, along with spikelet anatomy (Figure 3), can be used to differentiate the two species (Stubbendieck et al., 2017). More specifically, Pampas grass can have leaf blades up to 10 cm wide, whereas those of Ravenna grass usually have an average width of approximately 1.5 cm. Differences in spikelet anatomy include: 1) spikelets of *Cortaderia* usually are dioecious, so an individual plant has only pistillate (bearing only female parts) or staminate (bearing only male parts) spikelets, whereas Ravenna grass has male (stamens) and female (carpels) parts of the flowers in each floret (the small, reduced flower typical of grasses); 2) the lemmas and awns of Pampas grass are glabrous (on either sex), whereas those of Ravenna grass are distinctly scabrous, appearing rigid or spiked when magnified; and (3), the lowermost lemma of Pampas grass is 5-veined, whereas of Ravenna grass it is 1-3 veined (Figure 3).

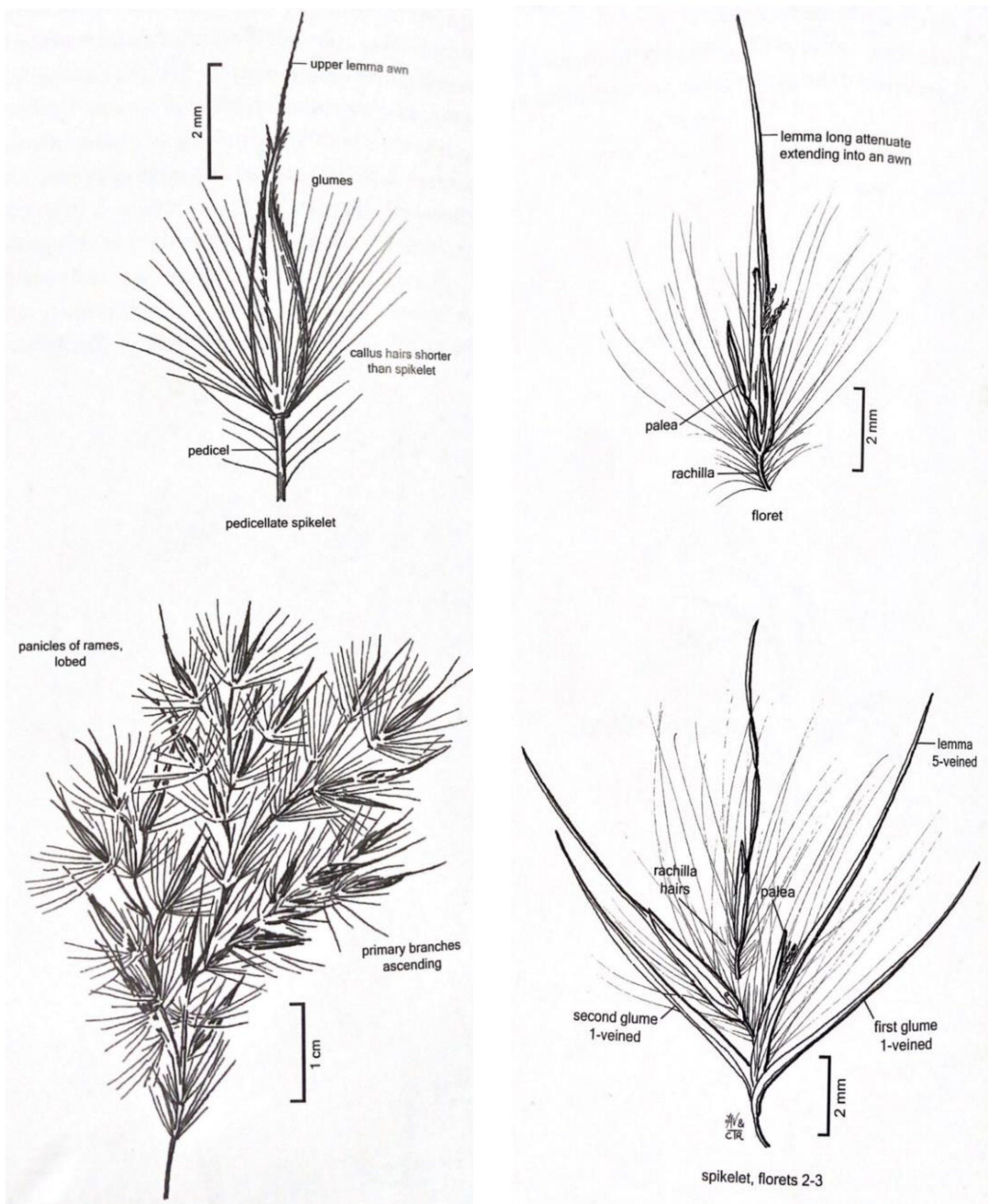

Figure 3. Illustrations of spikelet anatomy between *Tripidium ravennae* (left) and *Cortaderia selloana* (right). Images from *Grass of the Great Plains*, pages 208 (right) and 524 (left) (Stubbendieck et al., 2017).

The invasiveness of *T. ravennae* can be attributed in part due to its high seed production, wind dispersal of its lightweight and hirsute seeds, the ease at which seeds are dislodged from ornamental plantings when it is trimmed back annually, and its proficiency at germinating in disturbed habitats. Further invasiveness could also be due to the leaf blades of Ravenna grass having sharp serrated edges, and are covered in sharp, stiff hairs (botanically, these are “trichomes”), effectively preventing foraging by native fauna (Stubbendieck et al., 2017). Large monocultures replace vital forage material in some habitats, leaving less native forage for native animals (Wade, 2010).

The distribution of *T. ravennae* in Kansas was far from adequately documented prior to this study, and previously known occurrences in many counties had not been vouchered with herbarium specimens prior to this study (e.g., Crawford, Bourbon, Linn, Miami, and Johnson counties (pers. comm., C. Freeman to N. Snow., 2021). Given that many known populations lacked herbarium vouchers, its overall distribution and the approximate rate and extent of its spread in Kansas, previously was unknown.

A Species Distribution Model (SDM) analyses could help predict likely habitat requirements, occupancy, and predict additional future spread of this non-native species. A SDM using maximum entropy, or “Maxent” (Phillips et al., 2004) may be useful for developing land management considerations and techniques for *T. ravennae*, as such studies can identify important environmental variables governing the distribution of a species using presence-only data (Phillips et al., 2006). Maxent model parameters perform best when the model is tuned to a species-specific level (Radosavljevic & Anderson, 2014). Environmental variables tested should be chosen based on taxa specific requirements first, and then species-specific requirements if they are known (Merow et al., 2013).

The study has three broad objectives. A historical record search for the state of Kansas will provide previous distribution of *Tripidium ravennae,* active roadside surveys in eastern Kansas will help document the current distribution of *T. ravennae*, and a species distribution model (using Maxent) will predict the complete distribution of *T. ravennae*.

CHAPTER II

METHODS

First, a thorough review was conducted on the specimens databased for Kansas occurrence records to document when they first occurred in each county, based on online herbarium specimen data aggregators such as SEINet (2022). Data cleaning was necessary for several reasons. First, all previous synonyms of *Tripidium ravennae* were searched on SEINet and the results were merged. Taxonomic synonyms for this species include Andropogon ravennae L., Saccharum ravennae (L.) L. and Erianthus ravennae (L.) P. Beauv. The merged results had to be filtered for duplicate records given that a single digital herbarium record might be databased under more than one name, in which case duplicate records were discarded. Second, the records were filtered by keywords that would allude to an individual being a cultivated specimen, given that cultivated specimens were not of interest in the present study; such specimens likewise were discarded. The remaining specimens were checked for the accuracy of their identifications, given that some were known to be misidentified when their data were uploaded into a database.

Second, increased documentation (physical and photo vouchers) of specimens along major routes in eastern Kansas was necessary to update occurrence records and better document population sizes. Roadsides of 47 counties were surveyed in eastern

Kansas, often more than once. Predesignated paths (Figure 4) were driven before and during the blooming season (April-September) to collect additional specimens. When an individual was located, a physical specimen was collected using standard best practices. The spatial, temporal, and habitat data were collected following DarwinCore data fields (for example, see Pryer et. al., 2019). All collections were identified using keys from *Grasses of the Great Plains* (Stubbendieck et al., 2017) or *Steyermark's Flora of Missouri* vol.1 (Yatskievych, 1999). Voucher specimens for each were deposited in the Sperry Herbarium at Pittsburg State University (example, Figure 5), with data from all collections now available online through the Consortium of Northern Great Plains Herbaria website (CNGP, 2022).

Third, combined with historical records (after 1990), the additional presence data from newly collected specimens in this study provided the basis for a Species Distribution Model (SDM) analysis. Geocoordinate data (latitude and longitude) were used to help determine the environmental conditions of each locality for purposes of the Maxent species distribution modeling component of the project (details below). Collections prior to 1990 were not included because of the general lack of precise geocoordinates and the relatively few collections of the species from that time frame.

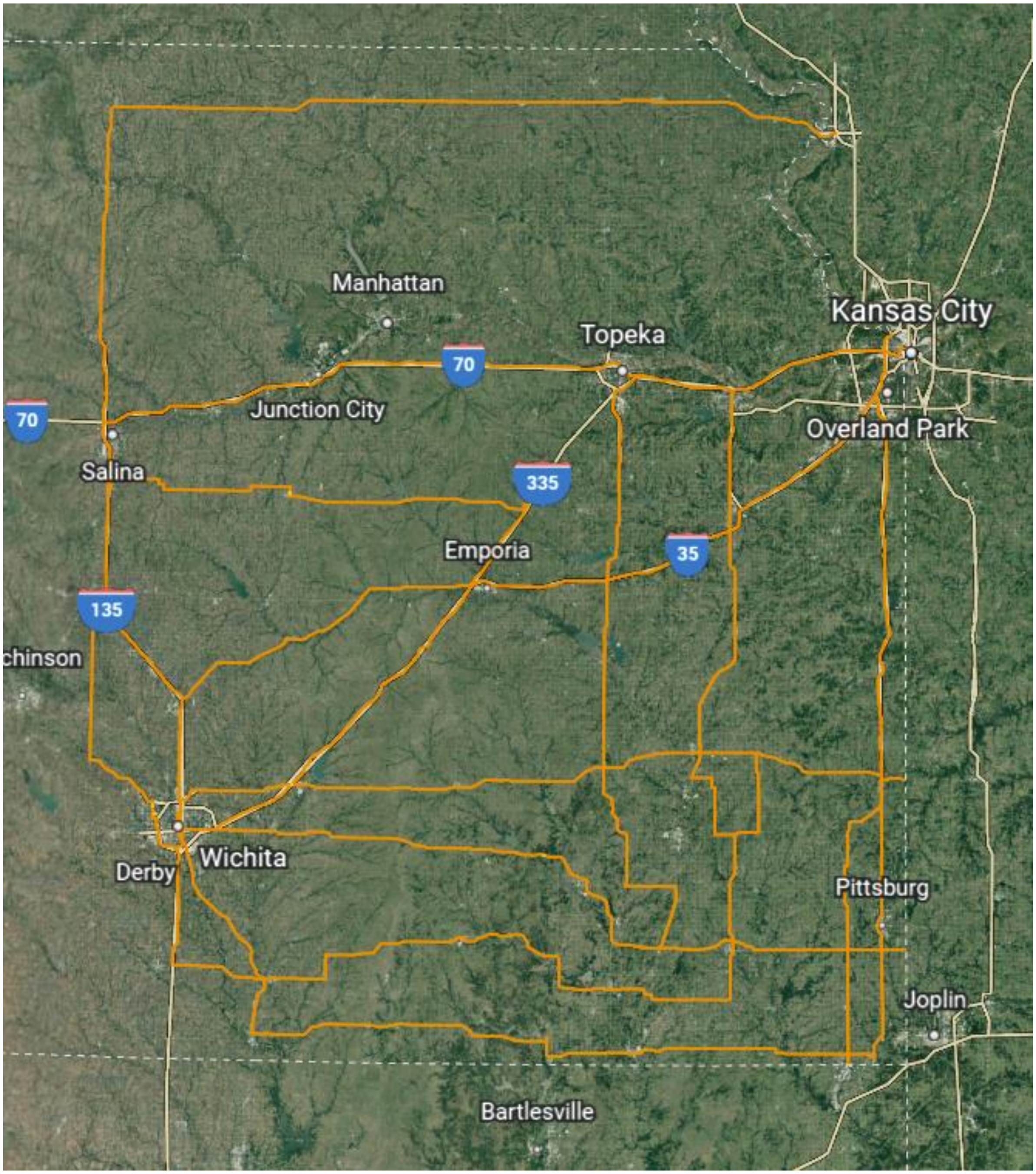

Figure 4. Survey paths driven (in yellow).

Figure 5. Characteristic/Example physical herbarium specimen of *Tripidium ravennae*.

Environmental variables (inputs) chosen for the SDM component of the study were accessed online (via Kansas Data Access & Support Center's "Kansas Geoportal") and formatted for Maxent (version 3.4.4) using ArcMap (version 10.8.2) spatial analysis tools. The environmental inputs used included: average specific humidity, average precipitation, average temperature, LiDAR elevation of plant height, and soil order (Kansas Geoportal- GIS Data Catalog, 2022).

Area under the receiver operating characteristic (ROC) curve, or AUC, was used to evaluate the performance of the Maxent model. The AUC value is a threshold-independent metric of the model's ability to discriminate presence from absence, which can help determine goodness of fit within a model. This metric can be used to eliminate variables and generate the most parsimonious model. The AUC can be a number between 0 and 1, wherein a value of ≤ 0.5 indicating that the distribution model is no better than one produced at random; a value of 0.5-0.7 showing poor performance; 0.7–0.9 showing reasonable/moderate performance; and >0.9 showing high model performance (Peterson et al., 2011). Model validation was performed by using the "Bootstrapping" function in Maxent. Twenty replications were run, and average training and test AUC values were calculated. Percent variable contributions and jackknife procedures in the Maxent program also were used to investigate and validate relative importance of environmental inputs. The resulting response curves show relationships between environmental inputs/variables and the predicted probability of the presence of *T. ravennae*.

Maxent model performance and fitness can also be evaluated by comparing threshold-dependent metrics. This is done by comparing output omission rates with the theoretically expected levels of omission. For this analysis, I used 10th percentile threshold values output by Maxent to classify at what probability the habitat is considered suitable or unsuitable for the species.

CHAPTER III

RESULTS

Database Review

Online searches for each taxonomic synonym for *Tripidium ravennae* yielded 21 occurrence records for the state of Kansas, six of which were discarded as duplicate records. The remaining 15 occurrence records, when filtered by key words on the specimens' collection labels, were all deemed to be random occurrences from escaped horticultural plantings or otherwise. Specimens with digital online photographs attached to their records were all properly identified.

The 15 records represented eight Kansas counties, with the first documented occurrence being from Harvey County in September of 1975. Two more collections were made in October of 1975, with one each in Harvey and Wyandotte Counties. The other documented counties and their years of collections (in alphabetical order) were: Anderson (1998), Douglas (2013, 2013, 2014), Geary (1998, 2002), Johnson (2006, 2013, 2014), Neosho (1998, 2000), and Shawnee (2010) (see Appendix A for collection data).

Three additional records were added during this study after being properly identified as *Tripidium ravennae,* based on their original misidentifications as *Phragmites australis* (Cav.) Trin. ex Steud. These specimens all were from Crawford County and collected in 1960, 1976, and 1979. Significantly, to the best of my knowledge, the 1960 record is the first vouchered occurrence in Kansas.

Roadside Surveys for Tripidium in eastern Kansas

Roadsides of 47 counties were surveyed in eastern Kansas, often more than once. Individuals or monoculture polygons of *Tripidium ravennae* were collected or photographically documented in 2 counties in 2022 (* = first vouchered record for that county): Allen*, Bourbon*, Butler*, Chautauqua*, Cherokee*, Cloud*, Crawford, Dickinson*, Douglas, Franklin*, Geary, Greenwood*, Johnson, Labette*, Linn*, Lyon*, Marshall*, Morris*, Neosho, Osage*, Saline*, Sedgwick*, Shawnee, Wilson*, and Wyandotte counties (Figure 6, Also see Appendix B). Of the 25 documented counties, 19 counties represent new county records, meaning that the species had never been documented previously there with a vouchered specimen.

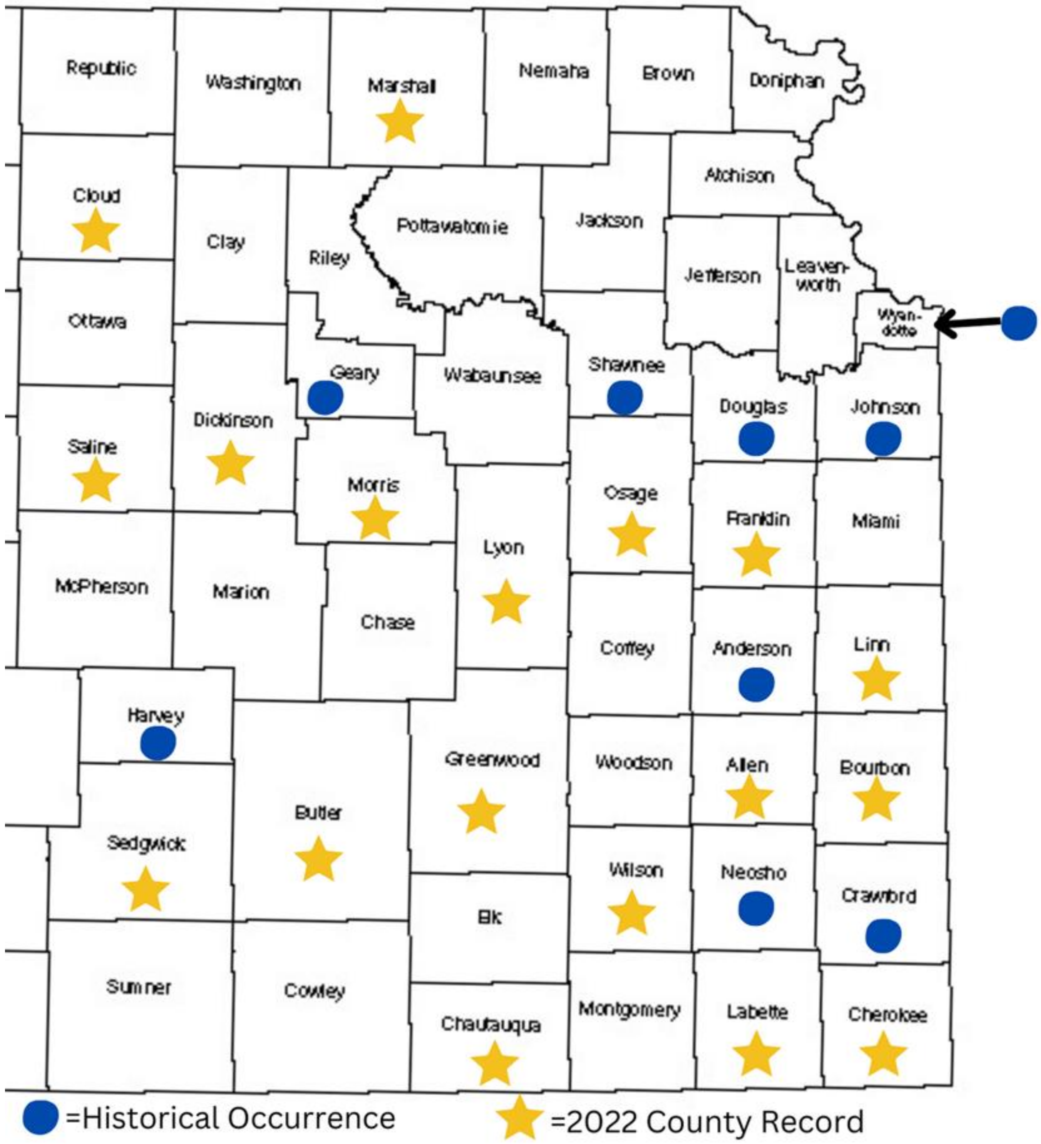

Figure 6. County level distribution of Ravenna grass in eastern Kansas.

A total of 67 physical specimens were collected between April 1st, 2022, and September 27th, 2022. Additional individuals were observed but proved inaccessible due to steep and rocky (unclimbable) bluffs, obstructions due to road construction, fence/property lines, or other dangerous situations, such as along Interstate highways, where stopping along the roadside is illegal. In these circumstances a photo voucher was taken (see Appendix C), representing a total of 27 collections. Nine additional documented occurrences were comprised of dense monocultures of *T. ravennae*, wherein individual plants of the species could not be differentiated from the others around it, and accurate counts of individual plants could not be made with confidence. Geocoordinate points were taken from around the boundaries or edges of the nine monocultures to form an occurrence polygon. Polygons were also photographed for reference (see Appendix D for maps). The combination of physical and digital vouchers for this study totaled 103 data collection sites (i.e., 94 individuals plus 9 polygon records) over 25 eastern Kansas counties (Figure 6). When combined with all historical records found in the first objective, 121 total occurrence records are documented for the state of Kansas (Table 1).

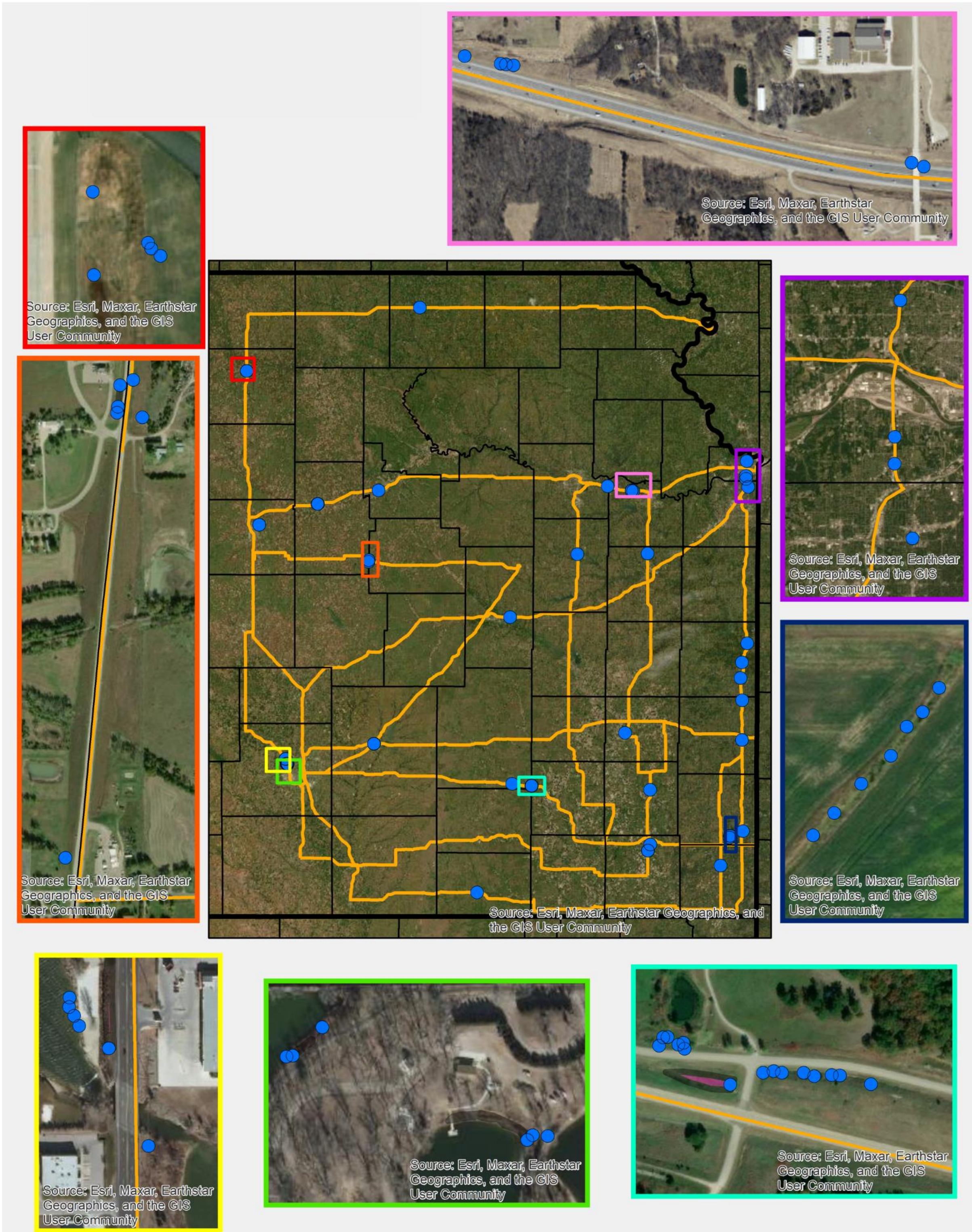

Figure 7. Occurrence records collected or observed during 2022. Extent maps' locations are indicated by color coordinated boxes on center map. Blue dots indicate a recorded occurrence in 2022.

Table 1. A current (2022) summary of historical and current occurrences of *Tripidium ravennae* in eastern Kansas counties. Green shading represents presence in that county.

Counties actively surveyed in 2022:	Historical Occurrences prior to study:	(Non-Polygon) Occurrences Documented in 2022 Study:	Polygon(s) Occurrences Documented in 2022 Study:	New Occurrence Records Found in Historical Search:	Total observations:
Allen		1			1
Anderson	1				1
Bourbon		3			3
Brown					0
Butler		5	1		6
Chase					0
Chautauqua		1			1
Cherokee		1			1
Cloud		5			5
Coffey					0
Cowley					0
Crawford		10		3	13
Dickinson		7	1		8
Doniphan					0
Douglas	3	7			10
Elk					0
Franklin		1			1
Geary	2	1	2		5
Greenwood		1			1
Harvey	2				2
Johnson	3	1			4
Labette		4			4
Leavenworth					0
Linn		3			3
Lyon		1			1
Marion					0
Marshall		1			1
McPherson					0
Miami					0
Montgomery					0
Morris		2			2
Nemaha					0
Neosho	2	1			3
Osage		2			2
Ottawa					0
Republic					0
Riley					0
Saline		3			3
Sedgwick		15	3		18
Shawnee	1		1		2
Sumner					0
Wabaunsee					0
Washington					0
Wilson		15	1		16
Woodson					0
Wyandotte	1	3			4
Totals:	**15**	**94**	**9**	**3**	**121**

Tripidium ravennae was found growing in areas of dense tall grasses, such as *Sorghum halapense* or in dense medium/short grasses such as *Setaria faberi* and *Setaria parviflora*. The species also was found growing on roadsides that appeared mowed or maintained. It was common to find the grass adjacent to a ditch (both irrigation and water control), man-made waterway (pond, reservoir, shallow stream, etc.), or other water-bearing geographic feature. However, it also was found in dry geographic features like the tops of sand berms or rocky hills.

Its occurrence in soil types proved just as varied, with the species being found in clay, clay loam, silt loam, sand, and even various sizes of rocks from pebble to river stone (i.e.,10-15 cm in diameter). Data collection sites commonly included secondary habitats such as roadside lawns, grassy road banks, and constructed wetlands, but some sites were native habitats, including prairies or wetlands.

Variations in population sizes were documented at each data collection site. Excluding monoculture polygons, 35.1% of the sites comprised more than one individual within a 2m radius of the focal (or collected) individual. Including monoculture polygons, the percentage of sites with two or more individuals increased to 40.7%. Monocultures were moderately to completely dense, excluding all other plant species in that area.

Species Distribution Modeling Using Maxent

All generated values reported are averaged over 20 replicates. Figure 8 depicts the average probability of occurrence of *T. ravennae* in eastern Kansas. Higher probability (values closer to 1) represents habitat that is most suitable for Ravenna grass, whereas lower probability (values closer to 0) represents habitat less or unsuitable (see legend on

Figure 8). The resulting Maxent model was moderate-to-highly accurate, reporting a training AUC of 0.8454 and test AUC of 0.8031, with a standard deviation of 0.0589 (Figure 9). The final model included six environmental variables (see Table 3).

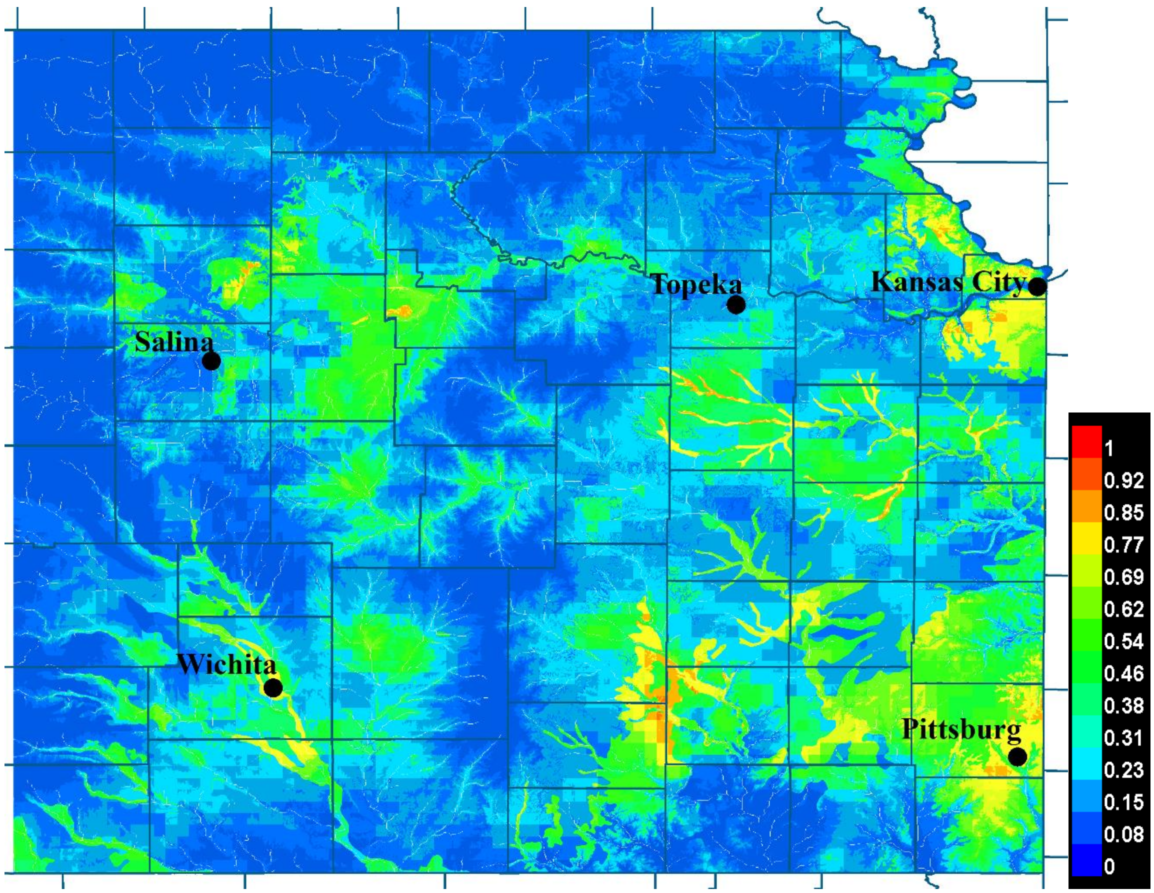

Figure 8. Maxent average probability distribution map of *Tripidium ravennae* in eastern Kansas. Values closer to one indicate higher probabilities of suitable habitat.

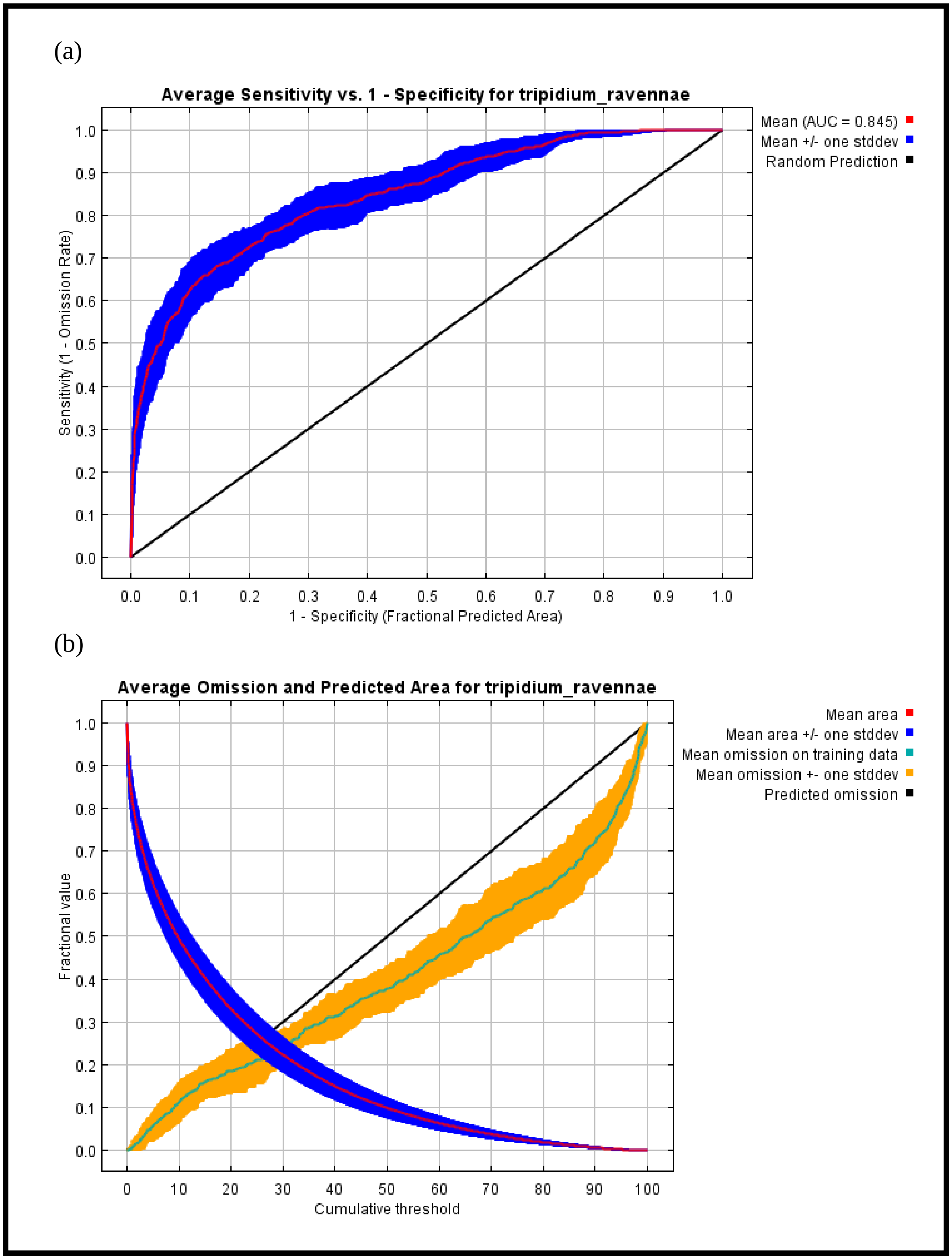

Figure 9. Graphs of relative "fitness" of the Maxent model: **(a**) Receiver operating characteristic (ROC) curve averaged over 20 replicate runs, **(b**) Training omission rate and predicted area as a function of the cumulative threshold, averaged over 20 replicate runs.

The variable *Soil Order* (See Figure 10) was the strongest predictor of Ravenna grass distribution among the replicates, showing 35.4% contribution (see Table 3). (Orders represent the highest/broadest level of classifications in the US system of soils classification.)

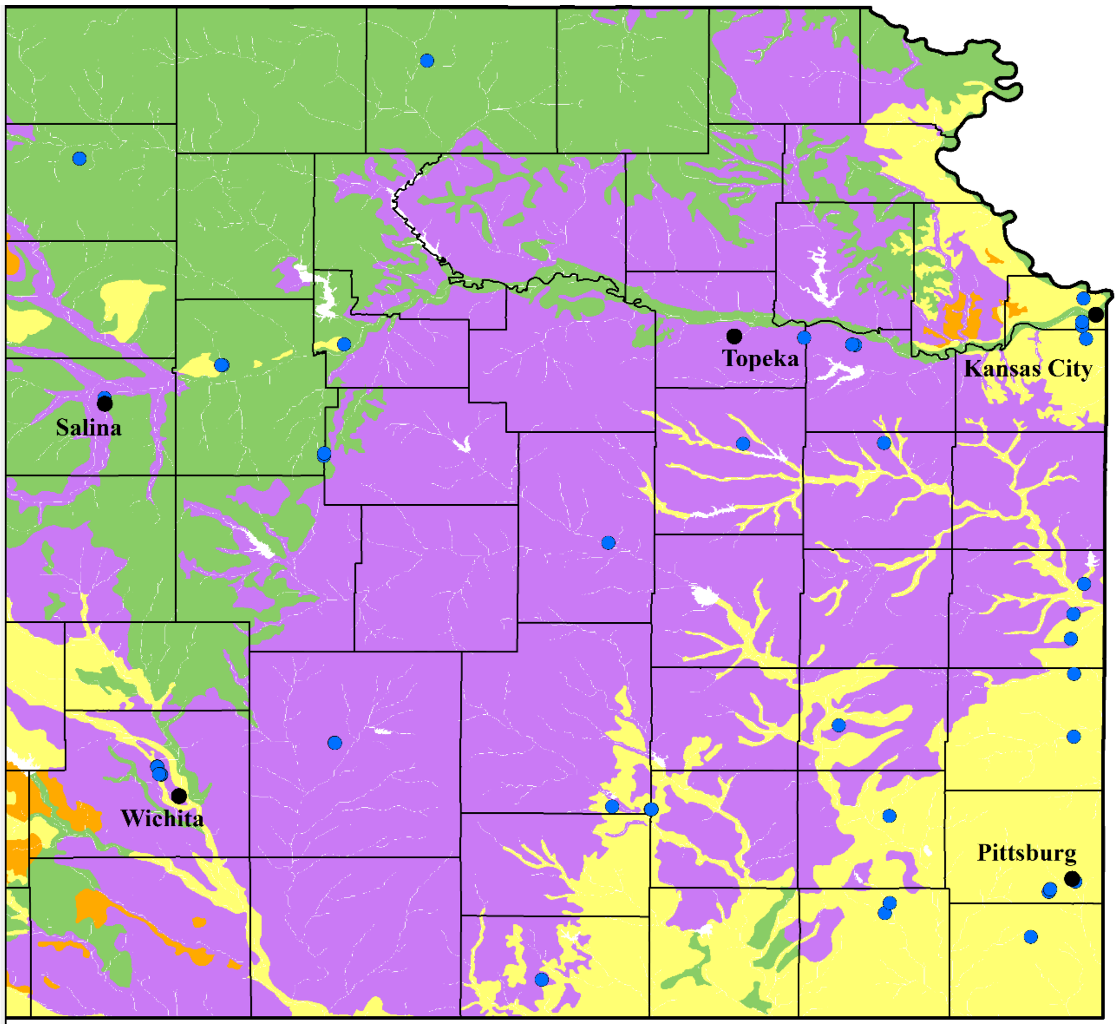

Figure 10. Collections made in eastern Kansas over map of primary soil order. Blue dots indicate recorded occurrence in 2022. Soil order is indicated by the following colors: Inceptisols= orange, Mollisols= purple, Entisols= green, Alfisols= light yellow.

The second strongest predictor was elevation at 19%. *Permutation Importance* values (shown as percentages) were calculated by measuring the drop in training AUC for each environmental variable after being randomly permuted from training presence and background data. This analysis narrowly determined that average temperature was the most important variable (20.2%), compared to soil order (18.8%), elevation (18.9%), average precipitation (18.1%), and average humidity (18.6%). Jackknife testing of variable performance determined that variable with the most useful information by itself was soil order because it created the highest gain when used in isolation. Soil order also decreased the gain the most when omitted and therefore appears to have the most information that cannot be found in the other environmental variables (see Figure 11).

Table 2. Average percent contribution and permutation importance (percentages) of environmental variables for *T. ravennae* generated by Maxent.

Variable	Percent contribution	Permutation importance
ks_soil_order	35.4	18.8
lidar_elv	19	18.9
avg_ppt	14.2	18.1
avg_temp	12.1	20.2
avg_humid	10.7	18.6
prim_rock_type	8.6	5.4

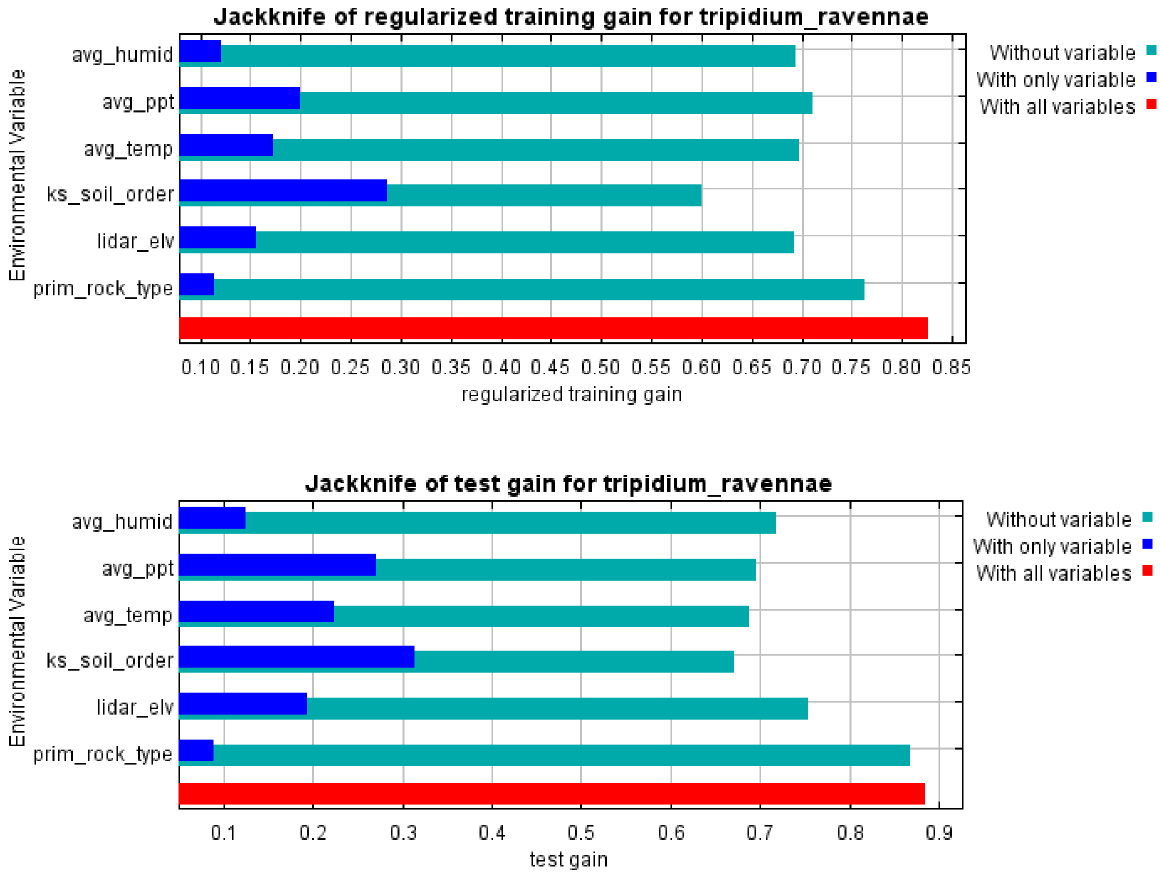

Figure 11. Results of jackknife analysis of environmental variables used in Maxent modeling of *T. ravennae* in eastern Kansas. Values shown are averages over 20 replicate runs.

Using the "10th percentile training presence logistic threshold" metric generated by Maxent (see Figure 9), a binary map can be made showing the possible suitable habitat for the species, which can be used to predict where it may spread in the future. This model assumes that suitable habitat will include at least 90% of the data used to develop the model (Phillips et al., 2006). This alternative distribution map shows that a large portion of eastern Kansas was deemed suitable for *Tripidium ravennae* (see Figure 12).

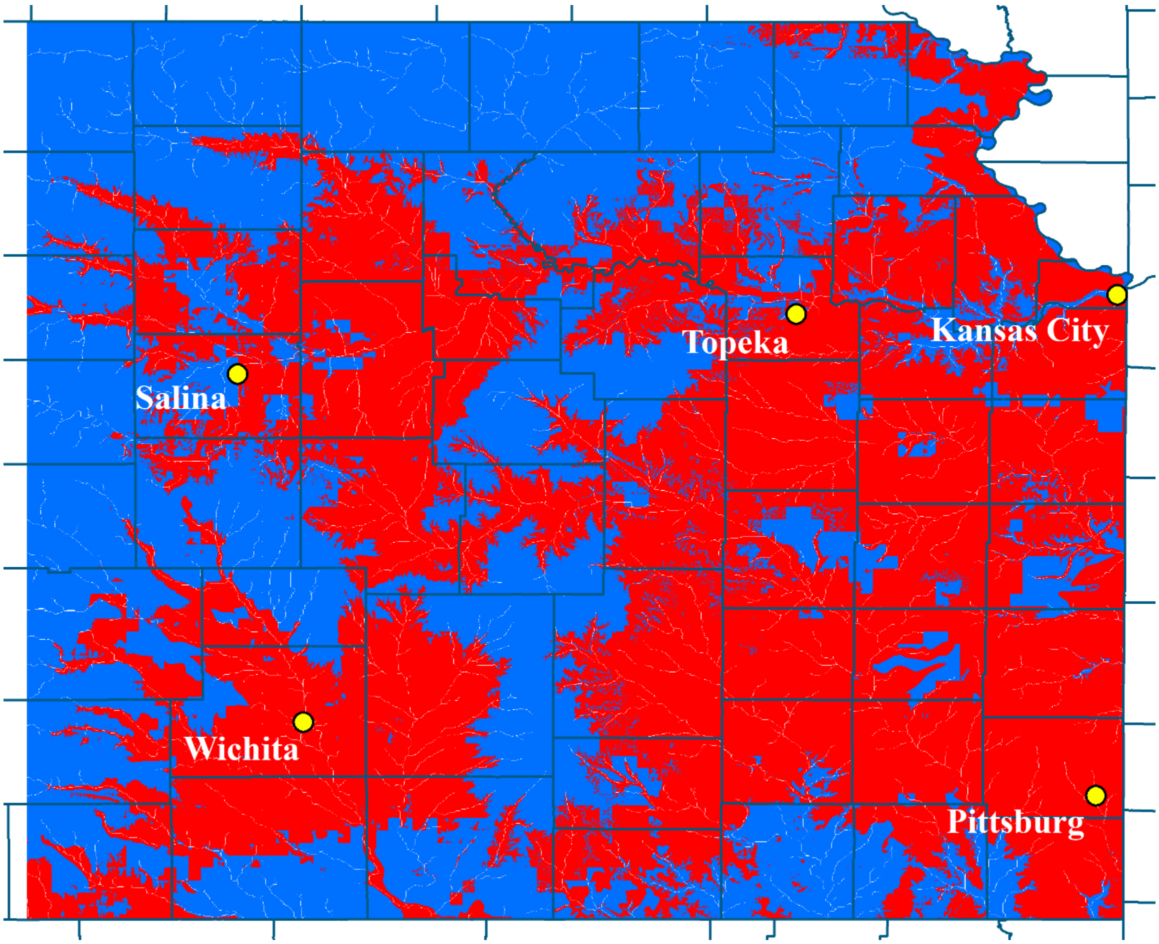

Figure 12. Habitat suitability of *Tripidium ravennae* in eastern Kansas, generated by Maxent. Red indicates suitable habitat; blue indicates non-suitable habitat.

CHAPTER IV

DISCUSSION

Invasive Species

Humans have intentionally (e.g., domesticated animals and plants) or unintentionally spread species as long as we have had the ability for long distance dispersal, especially when that dispersal began to take place across continents (Crosby, 2004). However, not all introduced species have the ability to establish in a new environment, especially when the novel environment greatly differs from that where they evolved. Those that can establish exhibit some degree (alone or together) of competitive exclusion, niche replacement, mutualism disruption, and/or behavioral or trait shifts towards native species and ultimately could contribute to the ongoing Anthropecene mass extinction event (Mooney & Cleland, 2001). The field of ecology dedicated to invasive species is relatively new but has continued to grow since its conception, which originated in the writings of Charles Elton in 1958 (*The Ecology of Invasion by Animals and Plants*).

The exponential growth in the field of invasion ecology began in the 1990's and can be explained by a combination of three reasons: (1) the negative impacts created by some invasive species are now too large to ignore; (2) the number of invasive species transported (intentionally or not) increasingly have created more ecological or economic problems; or (3) they have become so common that ecologists conducting field research began to encounter them at much higher rates than previously (Lockwood et al., 2013).

Invasive species are present at all geographical scales, from international to local. A 2017 study of the international scale concluded that annual rate of introductions of new invasive species has increased continuously over the last 200 years, with 37% of them newly recorded between 1970 and 2014 (Seebens et al., 2017). On a national scale, research has found that nonnative plant species in the United Sates were 40 times more likely than a native plant species to exhibit detectable negative impacts and be deemed invasive (Simberloff et al., 2013). In Kansas, approximately 20 percent of its plant species are nonnative. Of these, the Kansas Department of Agriculture (2022) has declared 12 plant species as “Noxious Weeds”, two of which are grasses: *Elymus repens* (L.) Gould (Quack grass) and *Sorghum halepense* (L.) Pers. (Johnson grass).

Tripidium ravennae in eastern Kansas

Historical records found have indicated that *Tripidium ravennae* first occurred in Kansas in 1960 in Crawford County (see Appendix B). The next occurrences were recorded 1975 in Harvey County, where it was collected twice, and Wyandotte County, where it was collected once. The spread of the species (prior to this study) by county, in order of first record in county is as follows:

> Crawford (1960), Harvey (1975), Wyandotte (1975), Neosho (1998), Anderson (1998), Geary (1998), Johnson (2006), Shawnee (2010), Douglas (2013).

The species remained largely overlooked or ignored until this study, with less than 20 records over the 62 years of documented occurrence in the state. The species also remains relatively undocumented for states bordering Kansas and has been documented only in 3 boarding counties total between Oklahoma and Missouri (Kartez, 2022).

An accurate rate of spread for Ravenna grass cannot be calculated at this time, due to lack of focus on this species in the past. What now is documented is that the species has spread widely across eastern Kansas from its first occurrence over 60 years ago. This study provides a baseline for future studies that may wish to document probable increases in its density or frequency in eastern Kansas.

The widespread use of the Ravenna grass as an ornamental impedes and confounds our ability to determine its natural (non-anthropogenic) spread in nature, because we cannot determine when the species was first planted ornamentally in any given county. All occurrences documented herein were escaped or wild occurrences. However, their numbers are a small percentage of the number of individual plants grown ornamentally in residential or commercial settings. For example, dozens of homes and businesses in Pittsburg have ornamental plantings of Ravenna grass, including a dozen or more on the PSU campus. More generally, Ravenna grass is widely planted as an ornamental commonly in urban areas. Each ornamental planting, like each wild individual, can act as a parental unit spreading numerous seeds each year.

Maxent Analysis

The results from the field observations in Kansas, its increasing documentation in other states, and the Maxent modelling herein indicated that Ravenna grass has high invasive potential in eastern Kansas and already is exhibiting invasiveness. It has been documented growing in multiple habitat types, including those with little to no disturbance (Gardner et al., 2016).

Maxent models also can be used to make predictive species distribution models over large spans of time (such as decades) and can be used to show how a species' distribution can change over time, as for example when adjusting to climate change (Dowling, 2015). This is done using current and predicted versions of the environmental inputs to evaluate changes in suitable habitat over time. A predictive Maxent model for *Tripidium ravennae* likely is somewhat limited at this time because of its widespread plantings as an ornamental, and because vouchered documentations for each ornamental were not entered into the modeling software.

Using the known occurrences from this study and results of the SDM, the ecological impacts caused by Ravenna grass also can be predicted. The model predicts that the most suitable habitat for *T. ravennae* in Kansas are areas with proportionately higher rainfall, lower elevations, and mollisol soils. It is also shown to grow near wetlands, ditches, and around waterways. Growth in or around waterways could have multiple impacts to multiple taxa of native species. The large clumping structure of the species, in which several dozen or more culms from a single root crown can grow out to a diameter of a meter or more (after several years of growth), could interfere with water flow or obstruct it completely in a dense enough monoculture if the flow was relatively low. *Tripidium ravennae* occurs in many different habitats, although most in this study were along roadsides due to the design of the study.

Management of Tripidium ravennae

Without foraging, or management by humans, the species could increasingly fill in all available suitable habitat in some situations, as is seen in some other grass species such as *Phragmites australis* in wetlands or *Imperata cylindrica* in terrestrial ecosystems. Dense monocultures of Ravenna grass also could promote fire, which could be devastating in riparian areas and the many dry and flat environments among prairies and rangelands in Kansas (Lambert et al., 2010).

Another useful outcome of the project could be improved management and mitigation of *Tripidium ravennae*. For example, updated records are useful for state and regional agencies that may give consideration to declaring this species noxious (as for example, in six other states), or more closely assessing the overall extent of its invasiveness.

Concerns of invasiveness apply also to the Pittsburg State University grounds, where increasingly it has been planted and manicured in recent years. I plan to meet with campus landscaping leaders and encourage them to consider taking action to prevent the further spread of this species. I also hope to encourage other local and regional decision makers such as city planners and landscapers likewise to reconsider its planting.

The most effective form of management for *Tripidium ravennae* after it is well established appears to be the mechanical removal of entire individuals. Given the height of mature stalks and more frequently the diameter of entire clumps, heavy duty machinery such as “brush hogs” are needed for mechanical removal, and in the cases of dense, large polygons, even brush hogs might be ineffective. Chemical control is used by some state agencies to control Ravenna grass, but no conclusive testing has been conducted (as of this study) to determine individual herbicide efficacy.

Another impediment for controlling the spread of Ravenna grass is that no biological control agent has been identified. When complete removal is not possible, trimming could still be a moderately effective management technique. Using a bag to wrap over matured inflorescences before trimming could help prevent the easily dislodged spikelets from spreading. Frequent mowing in areas where the plant is already widespread might be the most effective means to keep the species from growing back or propagating nearby.

Management efforts of wild or escaped Ravenna grass in eastern Kansas likely will be of limited effectiveness if ornamental plantings are not also reduced or eliminated. Requesting that homeowners remove existing plantings probably is not politically feasible. However, a ban on future sales and transport in Kansas could be enacted as a means to control its spread, as has been done for other species such as Johnson grass (*Sorghum halapense* (L.) Pers.). It is for this reason that a "Noxious Weed" designation by the Kansas Department of Agriculture would be a step in the right direction for the management of this species. Such action would prevent further ornamental planting and encourage the removal of extant ornamental plantings, particularly those on state lands such as the PSU campus. The fate of *Tripidium ravennae* in Kansas will most likely be dependent upon continued monitoring and the commencement of management efforts to eradicate the species.

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APPENDICES

Appendix A. Historical occurrence records from Kansas, collected and reviewed for thesis. Numbers in parentheses are the barcode numbers of the specimens (The complete data set for all specimens, including geocoordinates, is available at SEINet (https://swbiodiversity.org/seinet/index.php)). Specimens specifically from this thesis also can be accessed through the Consortium of Northern Great Plains Herbaria (https://ngpherbaria.org/portal/).

Anderson: Garnett, 0.5 mi N, 0.5 mi W, 8/26/1998, *Freeman 11805* (KANU 320188)

Douglas: Lawrence, W side of town, 9/2/2013, *Freeman 24824* (KANU 393301); Lawrence, 7.3 km W along E 900 Road, due N of the Clint Reservoir Dam, 9/2/2013, *Freeman 24825* (KANU 393302); Lecompton, E side of town, 9/11/2014, *Freeman 25249* (KANU 394073).

Geary: Junction City, N edge of town; Fort Riley Military Reservation, Training Unit 25, 9/19/2002, *Freeman 19508* (KANU 339021); Junction City, SW side of town immediately W of jct of I-70 & US 77, 8/25/1998, *Freeman 11803* (KANU 320186).

Harvey: E edge of Newton, 10/10/1975, *McGregor 28732* (KANU 16799); Newton, 2 mi NE, 9/1/1975, *McGregor 87839* (KANU 16801).

Johnson: De Soto, 1.5 mi S, 5 mi E, 9/27/2006, *Freeman 21948* (KANU 338710); Overland Park, 10/5/2013, *Morse 24043* (KANU 392523); Olathe, NW side of town; Ernie Miller Nature Center along KS 7, 9/24/2014, *Freeman 25273* (KANU 393505).

Neosho: 5 miles south and 2 miles west and 0.25 mile south of Erie, 9/25/2000, *Holland 9992* (KSP033451); St Paul, ca 3 mi SE, 8/23/1998, *Holland 9498* (KANU 323538).

Shawnee: Topeka, Big Shunga Park, 11/10/2010, *Hansen 388* (KANU 394023).

Wyandotte: 0.5 mi E Turner exit on I-70, 10/13/1975, *Brooks 11862* (KANU 16800).

Appendix B. Primary collections data for voucher specimens collected for the thesis in eastern Kansas in 2022, sorted by county. Numbers in parentheses are the barcode numbers of the specimen. (The complete data set for all specimens, including geocoordinates, is available from the Consortium of Northern Great Plains Herbaria: https://ngpherbaria.org/portal/)

Allen: Iola, adjacent to N bound side of Hwy 169, ca. 1450 m SW of NW Minnesota Rd Exit, 9/13/2022 (flowering), *Styers 311* (KSP046554).

Bourbon: 2 km S of Prescott on N bound side of 69 Hwy, 8/28/2022 (flowering), *Styers 294* (KSP046537); Fort Scott, ca. 115m SE of Intersection of Hwy 69 and E South St, 9/3/2022 (flowering), *Styers 296* (KSP046539); Fort Scott, ca. 105m SE of Intersection of Hwy 69 and E South St., 9/3/2022 (flowering), *Styers 297* (KSP046540).

Butler: El Dorado, ca. 45m SW of Hwy 254 and SW Boyer Rd Intersection, on NE corner of "L"-shaped protected wetland, 9/13/2022 (flowering), *Styers 312* (KSP046555); El Dorado, ca. 60 m SW of Hwy 254 and SW Boyer Rd Intersection, on SW corner of "L"-shaped wetland, 9/13/2022 (flowering), *Styers 313* (KSP046556); El Dorado, ca. 110 m S of Hwy 254 and SW Boyer Rd Intersection, on SE side of "L"-shaped wetland, 9/13/2022 (flowering), *Styers 314* (KSP046557); El Dorado, ca. 90 m SW of Hwy 254 and SW Boyer Rd Intersection, on SE side of "L"-shaped wetland, 9/13/2022 (flowering), *Styers 315* (KSP046558); El Dorado, ca. 95 m SSW of Hwy 254 and SW Boyer Rd Intersection, on SW side of "L"-shaped wetland, 9/13/2022 (flowering), *Styers 316* (KSP046559).

Chautauqua: Summit, 5 m N of W bound side of Hwy 166, ca. 1 km W of Rd. 14 intersection, 9/9/2022 (bud), *Styers 304* (KSP046547).

Cherokee: Skidmore, Adjacent to Hwy 7 on E side, 4/15/2022 (flowering), *Styers 245* (KSP046489).

Cloud: S of Concordia, ca. 20m S of Hwy 81 and Airport Park Junction., 8/5/2022 (bud), *Styers 271* (KSP046514); S of Concordia, ca. 42m S of Hwy 81 and Airport Park Junction. 8/5/2022 (bud), *Styers 272* (KSP046515); S of Concordia, ca. 44m SE of Hwy 81 and Airport Park Junction, 8/5/2022 (bud), *Styers 273* (KSP046516); S of Concordia, ca. 40m SE of Hwy 81 and Airport Park Junction, 8/5/2022 (flowering), *Styers 274* (KSP046517); S of Concordia, ca. 39m SSE of Hwy 81 and Airport Park Junction, 8/5/2022 (flowering), *Styers 275* (KSP046518).

Crawford: Pittsburg, 150m SW from front gate of Pittsburg State Univ. Natural History Reserve, 1053 S. 180th street, 4/1/2022 (flowering), *Styers 243* (KSP046487); Pittsburg, 150m SW from front gate of Pittsburg State Univ. Natural History Reserve, 1053 S. 180th street, 5/1/2022 (flowering), *Styers 246* (KSP046490); Baker, S of E 530th Ave, 1/4 mi E of S 180th St., 5/1/2022 (sterile), *Styers247* (KSP04649); Baker, SE of intersection of E 530th St. and S 180th St., ca. 275m W of E 180th St. and 100m S of E 530th St., 9/23/2022 (flowering), *Styers 320* (KSP046563); Baker, E of intersection of E 530th St. and S 180th St. , ca. 290 m W of E 180th St. and 90 S of E 530th St., 9/23/2022 (flowering), *Styers 321* (KSP046564); Baker, E of intersection of E 530th St. and S 180th St., ca. 300 m W of E 180th St. and 75m S of E 530th St., 9/23/2022 (flowering), *Styers 322* (KSP046565); Baker, E of intersection of E 530th St. and S 180th St., ca. 310 m W of E 180th St. and 65 m S of E 530th St., 9/23/2022 (flowering), *Styers 323* (KSP046566); Baker, E of intersection of E 530th St. and S 180th St., ca. 320 m W of E 180th St. and 50 m S of E 530th St. 9/23/2022 (flowering); *Styers 324* (KSP046567); Baker, E of intersection of E 530th St. and S 180th St., ca. 335 m W of E 180th St. and 35 m S of E 530th St., 9/23/2022 (flowering), *Styers 325*(KSP046568); Pittsburg, ca. 60 m directly E of S Joplin St. and E Forest St. intersection, 9/23/2022 (flowering), *Styers 326* (KSP046569).

Dickinson: W of Abilene, ca. 12m N of Hwy 70 (Westbound), 450m E of Flag Rd. overpass, 8/5/2022 (bud), *Styers 283* (KSP046526); W of Abilene, ca. 5m N of Hwy 70 (Westbound) 465m E of Flag Rd. overpass, 8/5/2022 (bud), *Styers 284* (KSP046527); W of Abilene, ca. 5m S of Hwy 70 (eastbound) 775m E of Flag Rd. overpass, behind guardrail SE of railroad overpass, 8/5/2022 (flowering), *Styers 285* (KSP046528); Herrington, downward slope of hillside at junction of Hwys 77 and 56, 9/10/2022 (flowering), *Styers 305* (KSP046548); Herrington, adjacent to S bound side of Hwy 77, ca. 215 m S of E Helen St., 9/10/2022 (flowering), *Styers 307* (KSP046550); Herrington, adjacent to S bound side of Hwy 77, ca. 40 m N of Commercial Dr., 9/10/2022 (flowering), *Styers 308* (KSP046551); Herrington, adjacent to S bound side of Hwy 77, ca. 50 m N of Commercial Dr., 9/10/2022 (flowering), *Styers 309* (KSP046552).

Douglas: Kanwaka, adjacent to N side of W bound lane of I-70, immediately E of E800 Rd. overpass, 8/15/2022 (bud), *Styers 289* (KSP046532); Kanwaka, adjacent to N side of W bound lane of I-70, immediately W of E800 Rd overpass, 8/15/2022 (bud), *Styers 290* (KSP046533); Kanwaka, Adjacent to N side of W bound exit lane to rest stop off I-70, W of Hwy 40 overpass, 8/15/2022 (flowering), *Styers 291* (KSP046534); Kanwaka, adjacent to N side of W bound lane of I-70, Approx, 715m W of E800 Rd overpass, 8/15/2022 (bud), *Styers 292* (KSP046535); Kanwaka, adjacent to N side of W bound lane of I-70, Approx, 725m W of E800 Rd overpass, 8/15/2022 (bud), *Styers 293* (KSP046536); Kanwaka, adjacent to N side of W bound lane of I-70, Approx, 825 m W of E800 Rd overpass, 8/15/2022 (bud), *Styers 317* (KSP046560); Kanwaka, adjacent to N side of W bound lane of I-70, Approx, 890 m W of E800 Rd overpass, 8/15/2022 (flowering), *Styers 318* (KSP046561).

Franklin: Hayes, adjacent to N bound exit to Stafford Rd, off Hwy 59, ca. 65m NE of exit. 8/15/2022 (bud), *Styers 288* (KSP046531).

Geary: Junction City, ca. 50m W of S Spring Valley Rd overpass on Hwy 70, east bound, 8/5/2022, (flowering), *Styers 286* (KSP046529).

Greenwood: Salt Springs, Adjacent to E bound side of Hwy 400, ca. 265 m E of Aa Rd., 9/27/2022 (flowering), *Styers 336* (KSP046579).

Johnson: Overland Park, within exit loop of 63rd Street exit onto Metcalf Ave., 9/3/2022 (flowering), *Styers 301* (KSP046544).

Labette: Parsons, ca. 190 m E of Hwy 59 on S side of 22000 Rd., 8/7/2022 (flowering), *Styers 279* (KSP046522); Parsons, ca. 197 m E of Hwy 59 on S side of 22000 Rd., 8/7/2022 (bud), *Styers 280* (KSP046523); Parsons, ca. 10m NNE of Main St. and N 11th St. Junction. 8/7/2022 (bud), *Styers 281* (KSP046524); Parsons, ca. 13m NE of Main St. and N 11th St. Junction, 8/7/2022 flowering), *Styers 282* (KSP046525).

Linn: Potosi, 4 mi N of Prescott on North-bound side of Hwy 69, 8/28/2022 (bud), *Styers 295* (KSP046538); Potosi, 1.1 mi. after Pleasanton exit on Hwy 69 on N bound side of road, 9/3/2022 (flowering), *Styers 298* (KSP046541); Valley, ca. 15 m W of N bound side of Hwy 69, ca. 95 m N of E 1800 Rd overpass, 9/4/2022 (flowering), *Styers 303* (KSP046546).

Lyon: Emporia, 5m N of roadside on Hwy 35 Southbound, ca. 760m E of Rd. R1 overpass,8/4/2022 (bud), *Styers 269* (KSP046512).

Marshall: Marysville, 4m N of westbound edge of Hwy 36, 450m W of 11th Rd., 8/5/2022 (bud), *Styers 270* (KSP046513).

Morris: Herrington, adjacent to N bound side of Hwy 77, ca. 200 m S of E Helen St., 9/10/2022 (flowering), *Styers 306* (KSP046549); Herrington, ca. 30 m W of N bound side of Hwy 77 and 50 m N of Commercial Dr., 9/10/2022 (flowering), *Styers 310* (KSP046553).

Neosho: Ca. 2 mi N of Erie, adjacent to Prairie Ridge golf course service road, at junction of Hwy 59 and Hwy 146. 8/12/2022 (flowering), *Styers 287* (KSP046530).

Osage: Fairfax, adjacent to S bound side of Hwy 75, ca. 650 m S of W 197th St and Hwy 75 intersection, 8/15/2022 (bud), *Styers 319* (KSP046562); US Hwy 75, 5.3 road miles S of intersection with US Hwy 56, ca. 18.3 road miles south of Topeka, 05/16/2022 (sterile), *Snow 11561*.

Saline: Salina, ca. 35m S of E Iron Ave., W of Smokey Hill River Bridge, 8/5/2022 (flowering), *Styers 276* (KSP046519); Salina, ca. 25m S of E Iron Ave., W of Smokey Hill River Bridge, 8/5/2022 (bud), *Styers 277* (KSP046520); Salina, ca. 13m S of E Iron Ave., W of Smokey Hill River Bridge. 8/5/2022 (bud), *Styers 278* (KSP046521).

Sedgwick: Wichita, 4m west of N Ridge Road, off S-bound edge. 1.1 mi S of Hwy 96 junction, 7/23/2022 (flowering), *Styers 249* (KSP046493); Wichita, 40m W of S bound side of N Ridge Road, 1 mi S of Hwy 96 junction, 7/23/2022 (flowering), *Styers 250* (KSP046494); Wichita, 40m W of S bound side of N Ridge Road, 1 mi S of Hwy 96 junction, 7/23/2022 (flowering), *Styers 251* (KSP046495); Wichita, 40m W of S bound side of N Ridge Road, 1 mi S of Hwy 96 junction, 7/23/2022 (flowering), *Styers 252* (KSP046496); Wichita, 40m W of S bound side of N Ridge Road, 1 mi S of Hwy 96 junction, 7/23/2022 (flowering), *Styers 253* (KSP046497); Wichita, Adjacent to N Ridge Rd. , ca. 200m N of N Westwind Bay St., 7/23/2022 (flowering), *Styers 254* (KSP046498); Wichita, ca. 10 m S of W 21st. St., ca. 400m E of N Ridge Rd., 9/25/2022 (flowering), *Styers 327* (KSP046570); Wichita, ca. 25 m S of W 21st. St., ca. 415m E of N Ridge Rd., 9/25/2022(flowering), *Styers 328* (KSP046571); Wichita, ca. 30 m S of W 21st. St., ca. 420m E of N Ridge Rd., 9/25/2022 (flowering), *Styers 329* (KSP046572); Wichita, ca. 75 m SE of W 21st St. and N North Shore Blvd intersection, 9/25/2022 (flowering), *Styers 330* (KSP046573); Wichita, ca. 80 m ESE of W 21st St. and N North Shore Blvd intersection, 9/25/2022 (flowering), *Styers 331* (KSP046574); Wichita, ca. 80 m SE of W 21st St. and N North Shore Blvd intersection, 9/25/2022 (flowering), *Styers 332* (KSP046575); Wichita, ca. 120 m S of W 21st ST. and 215 m E of N North Shore Blvd., 9/25/2022 (flowering), *Styers 333* (KSP046576); Wichita, ca. 115 m S of W 21st ST. and 220 m E of N North Shore Blvd., 9/25/2022 (flowering), *Styers 334* (KSP046577); Wichita, ca. 110 m S of W 21st ST. and 235 m E of N North Shore Blvd., 9/25/2022 (flowering), *Styers 335* (KSP046578).

Wilson: New Albany, adjacent to Hwy 400 on N side, 4/1/2022 (flowering), *Styers 244* (KSP046488); New Albany, SW of intersection of Allen Rd and Old Hwy 96, 4/1/2022 (flowering), *Styers 248* (KSP046492); Fall River, Adjacent to N side of 10th street, ca. 80m W of Allen Rd., 7/25/2022 (sterile), *Styers 255* (KSP046499); Wilson Fall River, ca. 5 m N of 10th St., ca. 85m W of Allen Rd., 7/25/2022 (sterile), *Styers 256* (KSP046500); Fall River, ca. 8m N of 10th street, ca. 80m W of Allen Rd., 7/25/2022 (sterile), *Styers 257* (KSP046501); Fall River, ca. 15m N of 10th street, ca. 90m W of Allen Rd., 7/25/2022 (flowering), *Styers 258* (KSP046502); Fall River, ca. 15m N of 10th street, ca. 95 m W of Allen Rd., 7/25/2022 (sterile), *Styers 259* (KSP046503); Fall River, ca. 5m N of 10th street, ca. 100m W of Allen Rd., 7/25/2022 (sterile), *Styers 260* (KSP046504); Fall River, ca. 120m E of Allen Rd. and 10m S of 10th St., 7/25/2022 (sterile), *Styers 261* (KSP046505); Fall River, ca. 85m E of Allen Rd., 5m S of 10th St., 7/25/2022 (sterile), *Styers 262* (KSP046506); Wilson Fall River, ca. 75m E of Allen Rd., 6m S of 10th St., 7/25/2022 (sterile), *Styers 263* (KSP046507); Fall River, ca. 70m E of Allen Rd., 5m S of 10th St., 7/25/2022 (sterile), *Styers 264* (KSP046508); Fall River, ca. 65m E of Allen Rd., 6m S of 10th St., 7/25/2022 (sterile), *Styers 265* (KSP046509); Fall River, ca. 10m SE of Allen Rd. and 10th St. junction, 7/25/2022 (sterile), *Styers 266* (KSP046510); Fall River, ca. 15m SE of Allen Rd. and 10th St. junction, 7/25/2022 (sterile), *Styers 267* (KSP046511).

Wyandotte: Kansas City, adjacent to N bound side of I635, Approx 100 m N of Douglas Ave. Overpass, 9/3/2022 (flowering), *Styers 299* (KSP046542); Kansas City, adjacent to S bound side of I635, immediately N of Georgia Ave. Overpass, 9/3/2022 (flowering), *Styers 300* (KSP046543); Kansas City, adjacent to S bound side of I635, immediately N of Shawnee Dr Overpass, 9/3/2022 (flowering), *Styers 302* (KSP046545).

Appendix C. Photographic vouchers of recorded *Tripidium ravennae* occurrences for study. (Each record is labeled by its collection number, county, latitude, longitude, and date of collection.)

Styers 250
Sedgwick Co.
37.7457292, -97.4266611
07/23/2022

Styers 255
Wilson Co.
37.6189086, -95.9601459
07/25/2022

Styers 256
Wilson Co.
37.6189086, -95.9601459
07/25/2022

Styers 257
Wilson Co.
37.6188658, -95.9602192
07/25/2022

Styers 259
Wilson Co.
37.6189036, -95.960557
07/25/2022

Styers 260
Wilson Co.
37.618799, -95.9606169
07/25/2022

Styers 261
Wilson Co.
37.6186353, -95.9590396
07/25/2022

Styers 262
Wilson Co.
37.6183479, -95.9586394
07/25/2022

Styers 263
Wilson Co.
37.6184255, -95.9583084
07/25/2022

Styers 264
Wilson Co.
37.6186146, -95.9585258
07/25/2022

Styers 265
Wilson Co.
37.6186346, -95.9588087
07/25/2022

Styers 266
Wilson Co.
37.6184749, -95.9588949
07/25/2022

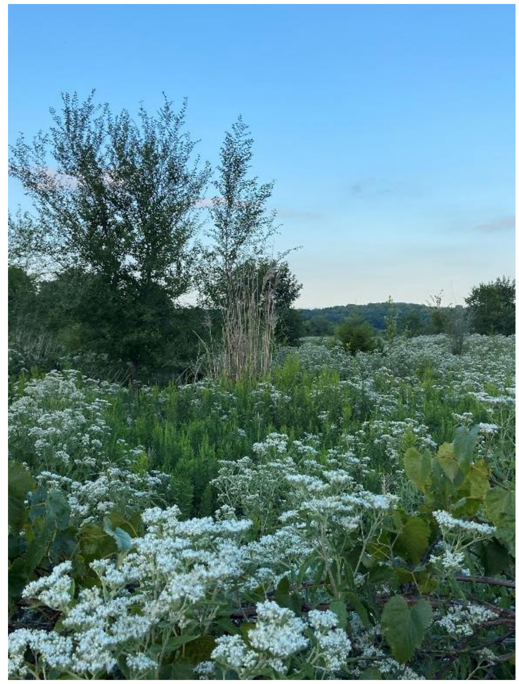
Styers 267
Wilson Co.
37.6186454, -95.9590279
07/25/2022


Styers 299
Wyandotte Co.
39.0670012, -94.6793517
09/03/2022


Styers 300
Wyandotte Co.
39.1357719, -94.6762508
09/03/2022

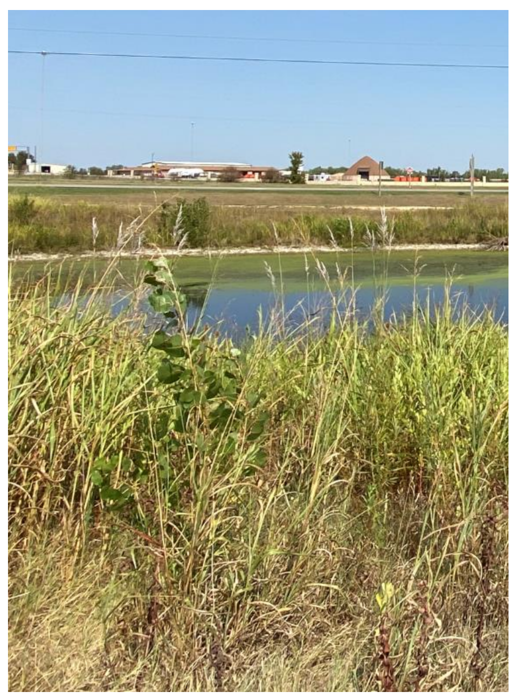

Styers 301
Johnson Co.
39.0159201, -94.6681759
09/03/2022

Styers 302
Wyandotte Co.
39.0529062, -94.6806563
09/03/2022



Styers 303
Linn Co.
38.287924, -94.6733995
09/04/2022

Styers 312
Butler Co.
37.8164083, -96.8990856
09/13/2022



Styers 313
Butler Co.
37.8164083, -96.8990856
09/13/2022

Styers 314
Butler Co.
37.8159408, -96.8989924
09/13/2022

Styers 315
Butler Co.
37.8158426, -96.8990929
09/13/2022

Styers 316
Butler Co.
37.8161293, -96.8992715
09/13/2022

Styers 327
Sedgwick Co.
37.7230823, -97.4214098
09/25/2022

Styers 328
Sedgewick Co.
37.7229487, -97.4213438
09/25/2022

Styers 329 (infl. shown in red boxes)
Sedgewick Co.
37.7229357, -97.4213159
09/25/2022

Snow 11561
Osage Co.
38.704, -95.68655
05/16/2022

Appendix D. Monoculture polygons recorded during 2022 study. Extent maps' locations are indicated by color coordinated dots on center map. All extent maps are shown in same scale (1:1,500).