Fall 12-2023

Vulnerabilities of Greater Prairie Chicken and Tier 1 At-risk Species in Nebraska Caused by Grassland Transition to Woody Dominance

Robert Peterson
University of Nebraska-Lincoln

VULNERABILITIES OF GREATER PRAIRIE CHICKEN AND TIER 1 AT-RISK SPECIES IN NEBRASKA CAUSED BY GRASSLAND TRANSITION TO WOODY DOMINANCE

By

Robert B. Peterson

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Agronomy

Under the Supervision of Professor Dirac Twidwell

Lincoln, Nebraska

December, 2023

VULNERABILITIES OF GREATER PRAIRIE CHICKEN AND TIER 1 AT-RISK SPECIES IN NEBRASKA CAUSED BY GRASSLAND TRANSITION TO WOODY DOMINANCE

Robert B. Peterson, M.S.

University of Nebraska, 2023

Advisor: Dirac Twidwell

Woody plant encroachment is a global threat and has been transitioning grasslands to woody dominance at a biome scale. This threat is present in the Great Plains grassland biome which is currently experiencing grassland biome collapse as the alternative woody biome advances northwest. Nebraska, which contains the most intact temperate grassland in the world, is currently at the front lines of this large-scale transition making this state's management decisions vital for the remaining grasslands and the species which rely on these ecosystems. In this study, we assess the vulnerability of Greater Prairie Chicken and Tier 1 at-risk species in Nebraska caused by the threat of grassland transition to woody dominance. Chapter one focuses on the threat of the advancing woody biome to Greater Prairie Chicken in Nebraska, utilizing two measurements to quantify risk. Chapter two utilizes participatory scenario planning integrated with Tier 1 at-risk species assessments to assess statewide and regional vulnerability to Tier 1 species listed in Nebraska's Natural Legacy project caused by the threat of grassland lost to woody dominance. Overall, the findings show that Greater Prairie Chicken, and Tier 1 at-risk species found in Nebraska have become increasingly vulnerable to this threat. These results highlight

the need for adaptive management strategies to mitigate the risk of woody encroachment and subsequent grassland transition to woody dominance.

DEDICATION

To my late father, Keith A. Peterson, for instilling in me an appreciation and admiration for rangeland ecosystems, and a strong work ethic from a young age.

ACKNOWLEDGEMENTS

This research would not have been possible without the assistance of numerous individuals and organizations. First, I would like to recognize my advisor, Dr. Dirac Twidwell, for investing his time in my growth from a student into a young professional. His mentorship toward the development of this thesis and his deep knowledge and passion for rangeland science has been inspirational. I would also like to thank my committee members, Dr. Dave Wedin, and Dr. Gwendwr Meredith for their direction and encouragement throughout my time here. Their perspectives helped to develop a well-rounded thought process throughout the development of this research.

I am extremely thankful to have had the opportunity to work with members of the Twidwell lab and staff at the University of Nebraska. I would especially like to thank Dr. Dillon Fogarty for his invaluable support during a myriad of challenging times, whether that be providing company during the throes of a global pandemic or providing guidance through the many challenging aspects of my thesis. I would like to thank Dr. Dan Uden for technical support and direction while working with large spatial datasets. I would also like to thank Dr. Sam Kady for sharing her technical expertise in figure creation and coding. A big thanks to current and past members of the Twidwell Lab, including Connor Barns, Allison Ludwig, Dan Bauloye, Dr. Reinhard Schultz, and Dr. Tori Donavan, for assistance and company during our lab meetings and conference trips.

This research would not have been possible without Nebraska's conservation community and our agency partners. I would like to thank the Rainwater Basin Joint

Venture, especially Andy Bishop, Greg Brinkman, Roger Grosse, and Dana Varner for sharing of data and expertise. I would like to thank the Nebraska Game and Parks Commission for funding this research and the staff for their support in data and direction in various planning and assessment processes, especially Mellissa Penella, Kristal Stoner, John Laux, T.J. Walker, Scott and Cassidy Wessel, Adam Kester, Matt Steffl, and Scott Luedtke. I would also like to thank staff at Nebraska's Natural Resource Conservation Service, especially Jeff Nichols, and Neil Dominy for their support and direction throughout various projects taken on throughout my time here.

I would like to extend gratitude to my undergraduate advisors at Concordia University Nebraska, including Dr. Jen Fruend, Dr. Joel Helmer, and Dr. Joe Gubanyi, for sparking my interest in natural and geospatial systems and setting a high standard for my work at the beginning of my college career. I would also like to thank Ben Wheeler for being a consistent mentor throughout my life, inviting me to partake in a variety of learning opportunities, including controlled burns, discussions during bird surveys or hunting trips, and taking part in events like the Loup trex.

Most importantly, I would like to thank my roommates and my family. My many roommates for providing me a place to live during a difficult transitional period in my life. My mom, for supporting my career path, encouraging me during difficult times, and constantly reminding me to take care of my physical and mental health. My siblings for being some of my best friends, giving me direction during the hard times and celebrating my successes during the good times. My nephews and nieces, for reminding me of the

curious and stubborn child I once was and still am today, which allowed me to overcome the fear of taking this next step in my career path.

GRANT INFORMATION

This research was funded by the Nebraska Game & Parks Commission W-125-R-1.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INCREASED VULNERABILITY OF GREATER PRAIRIE CHICKEN POPULATIONS IN NEBRASKA TO GRASSLAND BIOME COLLAPSE

ABSTRACT

A common objective in biodiversity conservation is preventing species from becoming small and isolated, which is of great concern for the Greater Prairie Chicken (*Tympanuchus cupido;* GRPC), an iconic grassland species in North America. Grasslands have become the most endangered ecosystem in North America which has caused great reductions to GRPC habitat, greatly reducing their range, and causing large portions of their population to become small and isolated. Here we utilize a vulnerability framework, created to manage risk in the face of large-scale threats, to assess the vulnerability of GRPC populations in Nebraska to the large-scale grassland threat of the advancing alternative woody biome state. The objective of this study was to assess changes in vulnerability of GRPC in Nebraska to the threat of the advancing alternative woody biome state. We assessed these changes by combining GRPC abundance data in Nebraska and early warning for woody transition data in Great Plains. First, we measured the proximity of GRPC populations to the advancing alternative woody biome state in 1990, 2000, 2010, 2020. Second, we visualized areas of high GRPC abundance and calculated the proportion of GRPC populations vulnerable to current and future expansion of the alternative woody biome state. The results indicate that the advancing woody biome has heightened GRPC vulnerability in the past 30 years, and areas with top GRPC abundances have become more vulnerable from current and to future woody biome

expansion. These findings demonstrate how ecological monitoring data can be utilized to assess risk to species and ecosystems allowing for strategic adaptive management to reduce vulnerability.

INTRODUCTION

A common goal in species conservation is to reduce habitat fragmentation to prevent populations from becoming small and isolated (Wu, 2013; Wilson et al., 2016). Species populations that become disjunct are not only expected to be more vulnerable due to environmental and demographic stochasticity, but also experience reductions in genetic diversity which results in decreased fitness and local adaptation abilities (Lande & Barrowclough, 1987; Bruna, 2004; Honnay, 2008). In an era of unprecedented global change, adaptation to proactive conservation management is vital for the persistence of intact ecosystems and the biodiversity they support (Glick et al., 2011). Vulnerability frameworks were created for this purpose and have been used to manage risk in the face of large-scale threats including climate change, woody encroachment, and annual grass invasion (Glick et al., 2011; Twidwell et al., 2021; Maestas et al., 2022). This framework takes a holistic approach, considering three components: sensitivity, exposure, and adaptive capacity (Glick et al., 2011). Sensitivity refers to characteristics that influence the degree that a stressor has on a system (Glick et al., 2011; Maestas et al., 2022). Exposure is the extent to which the change is affecting a system (Glick et al., 2011; Maestas et al., 2022) . Sensitivity and exposure combine to form risk. Adaptive capacity is the ability of influencing factors such as humans to adapt by reducing sensitivity or exposure (Glick et al., 2011; Maestas et al., 2022). This framework can be applied to any ecological system that is at risk of an unprecedented change. Here, we apply the vulnerability framework to the Greater Prairie Chicken (*Tympanuchus cupido*, here after GRPC) system in Nebraska.

GRPCs are considered an umbrella species and an indicator species in the Great Plains grassland ecosystem (Poiani et al., 2001; Hovick et al., 2015). They require intact treeless prairies with a diversity of microhabitats provided by heterogeneity within grassland landscapes (Poiani et al., 2001; Fuhlendorf et al., 2017). This species once had a vast range, occupying tall and mixed grasslands in the Great Plains region of the United States and Canada, as well as the Midwest and East Coast regions of the United States (Svedarsky et al., 2000). However, the United States has since lost at-least 82% of the tallgrass prairie (Samson et al., 2004). This has pushed this species to the peripherals of its range into the mixed and short grass prairies. Their current range has been reduced to the Great Plains and small portions of the Midwest, with their main populations occurring in Kansas, Nebraska, and South Dakota (Svedarsky et al., 2000). This habitat loss has led to GRPCs being listed as near-threatened nationally (BirdLife International, 2020).

The GRPC's remaining habitat has been greatly reduced and fragmented by large-scale threats including grassland transition to woody dominance and row-crop agriculture conversions (Briggs et al., 2005; Engle et al., 2008; USDA NRCS, 2021). These stressors represent the top two drivers of grassland loss in the Great Plains and are occurring at similar rates (USDA NRCS, 2021). Unlike stressors that reduce habitat quality (e.g., overgrazing), woody encroachment and row-crop conversion eliminate grassland habitats which are crucial for stable GRPC populations (Niemuth, 2000). The difference in these stressors lies in the degree to which they affect GRPCs. It is well documented that GRPCs are highly sensitive to minimal amounts of woody cover (Merrill, et al., 1999; Niemuth, 2000; McNew et al., 2012). In contrast, GRPCs thrive in grasslands that are

20% to 30% cropland followed by population declines past this land-cover threshold (Svedarsky et al., 2000). Therefore, in this study, we explore the threat of woody expansion because GRPCs are more sensitive to this change, and the remaining GRPC habitat is susceptible to this threat.

In Nebraska, recent research shows increasing GRPC population trends since 1980 throughout the most intact temperate grassland region in the world, the Sandhills (Scholtz & Twidwell, 2022; Berger et al., 2023). This region along with other grasslands in Nebraska are home to stable and growing populations of GRPC (Svedarsky et al., 2000; Berger et al., 2023). These relatively intact grasslands are all experiencing local woody encroachment making them vulnerable to transitioning to woody dominance in the future (Fogarty et al., 2020; 2022). They are also at the forefront of the advancing alternative woody biome state, where, once within this state, grasslands become the exception rather than the rule (Folke et al., 2004; Walker & Meyers, 2004; Engle et al., 2008). GRPC populations found in grassland islands within the alternative woody biome state have become small and isolated from habitat fragmentation (Svedarsky et al., 2003; Bouzat et al., 2008). This has instigated extreme decreases in this species range and has caused great reductions to other prairie chicken subspecies and species, including the critically endangered Atwater prairie chicken (*Tympanuchus cupido attwateri*) which is currently found in small grassland islands in southern Texas, and the vulnerable lesser prairie chicken (*Tympanuchus pallidicinctus*) which is found in the southern Great Plains (Svedarsky et al., 2003; Morrow et al., 2004). As woody expansion encroaches into the remaining GRPC strongholds, high sensitivity paired with heightened exposure elevates the risk of these populations becoming small and isolated in the future (Svedarsky et al., 2000; Engle et al., 2008; McNew et al., 2012; Twidwell et al., 2021).

In this study, our objective is to determine how GRPC vulnerability has changed throughout time. To meet this objective, we combined the most comprehensive GRPC abundance dataset for the state of Nebraska (RWBJV & NGPC, 2021) and the early warning for woody transitions dataset for the Great Plains (Uden et al., 2019; Twidwell et al., 2022). We determined changes in vulnerability by: (1) measuring the proximity of GRPC populations to the advancing alternative woody biome state in 1990, 2000, 2010, and 2020, and (2) by visualizing areas of high GRPC abundance and calculating the proportion of GRPC abundance vulnerable to current and future expansion of the alternative woody biome state.

METHODS

The Nebraska Natural Legacy Project

The Nebraska Natural Legacy Project was established as Nebraska's state wildlife action plan in 2005 (Schneider et al., 2011). The goals of the Nebraska Natural Legacy Project are (1) to reverse the decline of at-risk species, (2) recover currently listed species and allow for their de-listing, (3) keep common species common, and (4) conserve natural communities (Schneider et al., 2011). This plan outlines four prairie ecoregions that occur within Nebraska, United States. These prairie ecoregions are all experiencing woody encroachment which leads to grassland transition to a woody dominant state (Fogarty et al., 2020). Each of these unique grasslands also serve as habitat for GRPCs which are currently listed as a Tier 2 at-risk species in the revision of the at-risk species for the Nebraska State Wildlife action plan (Schneider et al., 2011; 2018). The remaining grasslands within Nebraska serve as key strongholds for nationwide GRPC populations and the conservation of these grasslands are vital for GRPCs persistence in the future (Svedarsky et al., 2000).

Focal Study Area and Datasets

In this study, we combine Nebraska GRPC abundance data (RWBJV & NGPC, 2021) and early warning for woody transitions data (Uden et al., 2019; Twidwell et al., 2022). The GRPC abundance data overlays the whole state of Nebraska (RWBJV & NGPC, 2021; Figure 1.1A). This grass-dominated state is found in the central portion of the Great Plains biome. It is approximately 200,000 square kilometers and contains some of the most intact temperate grasslands found throughout North America, and the world (Scholtz & Twidwell, 2022). The grassland plant community throughout Nebraska is largely driven by a longitudinal precipitation gradient (Epstein et al., 1998), generally with tallgrass prairies in the eastern portion, mixed-grass prairies in the central portion, and shortgrass prairies in western portion of the state (Schneider et al., 2011). The early warning for woody transitions data extends the whole Great Plains (Uden et al., 2019; Twidwell et al., 2022; Figure 1.1A). The Great Plains is a temperate grassland biome found in the central portion of the United States. This dataset has a spatial extent of about 2,000,000 square kilometers, extended over 10 states (Figure 1.1A). It has an annual temporal extent of 30 years ranging from 1990 to 2020.

The GRPC abundance dataset was created to monitor GRPCs across the state of Nebraska (RWBJV & NGPC, 2021). It was created using a long-term sampling protocol which was established in 2019. Sampling for this data was coordinated by Nebraska Game and Parks Commission. Here, 216 sections were randomly selected to be surveyed annually. To ensure samples were collected across a spectrum of landscape conditions, they were divided evenly between the four Natural Legacy Project prairie ecoregions (Schneider et al., 2011) and further subdivided between nine descriptive landscape categories (bins) within each ecoregion. Bins were created by stratifying percent canopy cover, and percent grass into equal thirds equaling nine bins for each ecoregion. The randomly selected sections were surveyed if landowner permission was granted. If landowner permission was not granted, the nearest section was selected within the same ecoregion and bin until a section was found where permission was granted. Surveying occurred between March 20th and April 30th, 30 minutes before sunrise and 90 minutes after sunrise in weather that was mostly clear skies (≤ 50 CC) with light winds (≤ 12 mph). Observers surveyed GRPCs by navigating within approximately 200 meters of all portions of the assigned section. Surveyors documented all the GRPCs they observed. If the GRPCs were observed displaying on a lek, the GPS location and the total number of individuals observed was recorded. If other GRPCs were observed (flushed, flying, etc.), the total number of individuals was recorded. Data collection is expected to continue annually for the foreseeable future.

GRPC abundances were modeled for the State of Nebraska using generalized linear mixed models and Poisson regression (Rhodes et al., 2009). Variables were selected for the model using Akaike's Information Criterion (AIC) corrected for small sample size to assess the fit of the data. Multivariate data used in this model included: grassland and woodland landscape data acquired from Missouri Resource Assessment Partnership (MoRAP, 2021), average precipitation for a 30-year period (1981 - 2010) acquired from PRISM Climate Group data (PRISM Climate Group, 2021), and standard deviation digital elevation models acquired from U.S Geological Survey Digital Elevation Models (USGS, 1999). The GRPC abundance model for Nebraska was created by the Rainwater Basin Joint Venture, and the Nebraska Game and Parks Commission.

We used the early warning for woody transitions dataset to delineate the alternative woody and grassy states in the Great Plains (Uden et al., 2019; Twidwell et al., 2022). This dataset shows the grassy and woody alternative states and the transition between them in the Great Plains (Uden et al., 2019; Twidwell et al., 2022). This data is used as an early warning metric to detect woody transitions in grasslands. It was used to quantify changes in the alternative woody biome state over time. It utilizes spatial covariance between the proportional cover of the perennial forbs and grass functional group and the tree functional group from the RAP 2.0 dataset (Uden et al., 2019; Jones et al., 2020; Allred et al., 2021; Twidwell et al., 2022). For this study, we used the large-scale woody transition data with resolution of 240 meters and a 139 x 139 pixel moving window in 1990, 2000, 2010, and 2020 to represent each decade that data was available (visualizations of data are available at https://conservation-maps.wlfw.org) (Uden et al., 2019; Twidwell et al., 2022).

Using the early warning for woody transitions dataset, we created a biome boundary that distinguished the alternative woody and grassy states for 1990, 2000, 2010, and 2020. We applied a threshold to the continuous woody transition dataset to create a binomial dataset that categorized the alternative woody and grassy biome states for each year. Pixels with a value less than this threshold represented a woody biome state, while pixels with a value greater than this threshold represented a grassy biome state. We selected the largest intact tract of woodland to represent the woody biome state. This woody biome state consistently occupied the southeastern portion of the Great Plains and expanded northwest at various rates throughout the years. We removed islands of alternative states within each biome to create two spatially discrete woody and grassy biomes, separated by a biome boundary. The biome boundary was smoothed using the "PAEK" algorithm within the "smooth line" tool in arcPro. This resulted in a biome boundary that delineated the alternative woody and grassy states for the years 1990, 2000, 2010, and 2020 (Figure 1.1A).

Analysis

Decadal Change in GRPC Vulnerability

The first measure used to assess changes in vulnerability of GRPCs was the proximity of GRPC populations to the alternative woody biome state in 1990, 2000, 2010, and 2020. We calculated the distance of each GRPC abundance pixel to the alternative woody biome boundary for each decadal year. Next, we removed marginal land by removing every pixel with a GRPC abundance value less than one. This yielded a raster-stack where each pixel contains a GRPC abundance value and a distance value for each decadal year. We used density plots to examine the distribution of GRPC population proximity to the woody biome state for each of the four decades (Figure 1.1B-E).

We also calculated the proximity of the alternative woody biome state to top GRPC abundances within Nebraska for 1990, 2000, 2010, and 2020. Using the GRPC abundance data, we extracted six intervals representing incremental decreases in the top percentages of GRPC abundance. These six intervals included the top: 5%, 5% to 10%, 10% to 15%, 15% to 25%, 25% to 35%, and 35% to 50%. We used a density plot to examine distance distributions between these intervals and the advancing woody biome for each decadal year (Figure 1.2).

Vulnerability of GRPC to Future Expansion of the Woody Biome State

The second indicator of GRPC vulnerability included measuring when Nebraska population strongholds are going to experience the pressures of the collapsing grassland biome and advancement of the woody biome state. We calculated GRPC abundance occurring in the alternative grassy and woody biome states for the year 2020, and for eight future scenarios representing woody biome expansion. Each future scenario represented an additional 25 kilometers of western woody biome expansion from the 2020 biome boundary, with the final scenario reaching 200 kilometers westward (Figure 1.3). The results visualized vulnerable populations to continued expansion of the alternative woody biome (Figure 1.3), and the proportion of relative GRPC abundance occurring in the alternative woody and grassy biome states in 2020 and each of the eight future scenarios (Figure 1.4).

RESULTS

The alternative woody biome state has continuously advanced northwest over the Great Plains, increasing the vulnerability of GRPC populations in Nebraska. In 1990, the median distance between GRPC populations in Nebraska and the alternative woody biome boundary was 669 km (range: 304, 954) (Figure 1.1A and 1.1B). By 2000 the alternative woody biome advanced 258 km northwest where it reached Nebraska's southeast border and had a median proximity of 411 km (range: -19, 740) to GRPC populations in this state (Figure 1.1A and 1.1C). The woody biome state advanced 246 km northwest between 2000 to 2010 where it reached the northern boundary of Nebraska and continued to envelop GRPC populations resulting in a median proximity of 165 km (range: -188, 194) (Figure 1.1A and 1.1D). The woody biome continued to advance westward over the state of Nebraska moving 65 km from 2010 to 2020. In 2020, the median proximity of the advancing woody biome boundary to GRPC populations in Nebraska was 99 km (range: -257, 352) (Figure 1.1A and 1.1E).

The severity of GRPC vulnerability was intensified as the alternative woody biome state advanced closer to the areas containing the highest GRPC abundances compared to areas containing lower GRPC abundances. In 2020, the area containing the top 5% of GRPC abundance had a median distance of 19 km (range -211, 81) (Figure 1.2). The subsequent lower abundance interval representing the area containing the top

5% to 10% of GRPC abundance had a median distance of 34 km (range -219, 138) (Figure 1.2). The next lower abundance interval representing the area containing the top 10% to 15% of GRPC abundance had a median distance of 37 km (range -220, 144) (Figure 1.2). The lowest abundant interval, representing the area containing 35% to 50% of GRPC abundance had a median distance of 88 km (range -228, 304) (Figure 1.2).

Coupled with the increased proximity of the advancing woody biome state to top GRPC abundances, there were differences in the shape of the density curve indicating increased proximity of the advancing woody biome state to all segments of areas containing higher GRPC abundances. As the top abundance intervals decrease the distribution curve gets wider with a longer and fatter tail (Figure 1.2). In 2020, the highest abundant interval containing the top 5% of GRPC abundance had a proximity range of 292 km (-211, 81) (Figure 1.2). The next highest abundant interval representing the area where the top 5% to 10% of GRPC abundance occur had a proximity range of 357 km (-219, 138) (Figure 1.2). The subsequent interval representing the area where the next 10% to 15% of GRPC abundance occur had a proximity range of 364 km (-220, 144) (Figure 1.2). The lowest abundance interval, which contains fringe GRPC populations where the top 35% to 50% of GRPC abundance occur had a range of 533 km (-288, 305) (Figure 1.2).

GRPC abundance is not uniformly distributed throughout the state of Nebraska. There are higher abundances occupying the central portion of Nebraska compared to other regions that contain marginal or disjunct populations (Figure 1.3). As the woody biome advances, it will affect GRPC populations differently based on the habitat quality and residing abundance. In 2020, the woody biome state was at the frontlines of areas with major prairie chicken abundances (Figure 1.3). If the alternative woody biome state advances 100 km west, the highest abundant GRPC areas will begin to be enveloped, reducing and fragmenting vital GRPC population strongholds (Figure 1.3). By the time the alternative woody state advances and additional 200 km westward, it will have enveloped intact high abundant GRPC habitat, and will be encroaching on increasingly marginal GRPC habitat (Figure 1.3).

Changes in the proportion of the GRPC population abundance in Nebraska found in the alternative grassy and woody biome states also indicate heightened vulnerability. In 2020, 81% of the GRPC abundance was found in a grassy state, and 19% was found in the alternative woody state (Figure 1.4). When the woody biome advanced 100 km west, 47% of GRPC abundance was found within the alternative woody biome state (Figure 1.4). After the woody biome state advanced 200 km west, approximately 73% of GRPC abundance was found within the alternative woody biome state (Figure 1.4). This indicates heightened vulnerability to GRPCs in Nebraska, given the potential trajectory of future grassland lost to woody dominance.

DISCUSSION

One of the main objectives when conserving GRPCs is preventing the population from becoming small and isolated (Svedarsky et al., 2003). The failure of meeting this objective has been the demise of other prairie chicken species and subspecies, including the extinct Heath Hen (*Tympanuchus cupido cupido*), the federally endangered Attwater's

Prairie-Chicken (*Tympanuchus cupido attwateri*), and the vulnerable Lesser Prairie Chicken (*Tympanuchus pallidicinctus*) (Svedarsky et al., 2000; Morrow et al., 2004). It has also greatly affected GRPC populations found in the once desirable tallgrass prairie habitat (Svedarsky et al., 2003). Currently, Nebraska's remaining grasslands constitute a key population stronghold for stable GRPC populations (Svedarsky et al., 2000). Concerningly, the results from this study indicate that Nebraska GRPC populations have become increasingly vulnerable to the advancing woody biome state. This vulnerability is influenced by high sensitivity to woody cover (Niemuth, 2000; McNew et al., 2012) and increased proximity to the advancing woody biome. Compounding this issue, the areas containing the highest abundances of GRPCs are more susceptible to becoming disjunct because they are closer in proximity to the alternative woody biome state compared to areas containing lower abundances. If the woody biome state continues to advance westward, key GRPC population strongholds will be the first to be impacted, creating disjunct populations.

This species' high vulnerability is of further concern because the advancing woody biome in the Great Plains has yet to be inhibited by grassland conservation management activity. Although, local management has been successful at conserving remnant grasslands adequate for disjunct GRPC populations (Niemuth, 2000; Niemuth, 2003), there has yet to be an effort successful at halting or reducing the advancing alternative woody state at the biome scale (USDA-NRCS, 2021). If no change is made, we expect the alternative woody biome state to continue its trajectory, transitioning

Nebraska's remaining grasslands, leaving local remnant grasslands and disjunct GRPC populations in areas where local management is sustained.

Halting the advancing woody biome state, and consequently reducing the vulnerability of intact high abundant GRPC habitat will require expansion of our adaptive capacity through proactive woody encroachment management (Glick et al., 2011; Twidwell et al., 2021). We can enhance management by implementing the Working Lands for Wildlife grassland conservation framework (Twidwell et al., 2021; USDA-NRCS, 2021). This framework promotes defending core grasslands and grassland species strongholds from woody encroachment and subsequent woody transitions through early detection and prevention strategies (Twidwell et al., 2021; USDA-NRCS, 2021). Once these areas are protected we can begin growing the core areas by restoring early-invaded grasslands (Twidwell et al., 2021; USDA-NRCS, 2021; Maestas et al., 2022). This management tactic allocates resources for more effective management due to the hysteretic nature of grassland lost to woody dominance (Bielski et al., 2021), and by streamlining management to the most abundant areas where there is cultural will to conserve our remaining grasslands (USDA-NRCS, 2021).

One limitation of this study was the lack of temporal GRPC abundance data. We only had GRPC abundance data derived from surveys taken in 2020 and 2021. Previous grassland disruptions and transitions that occurred in the past 30 years likely disrupted and changed GRPC abundance patterns throughout the state. While comparing congruent years of abundance data to vegetation monitoring data would have provided valuable insights into the relationships between GRPC populations and grassland lost to the advancing woody biome state, it is not necessary for this study because we are still analyzing a change occurring within historical GRPC habitat, and how this change affects current abundances. This limitation provides a basis for future studies as abundance data and vegetation data become available.

CONCLUSION

In this study, a vulnerability framework was applied to the GRPC populations in Nebraska concerning the large-scale threat of the advancing alternative woody biome state. We found that GRPC populations in Nebraska are becoming increasingly vulnerable from (1) increased proximity of the alternative woody biome to GRPC populations in the past 30 years, and from (2) top GRPC abundant areas becoming at-risk to current and future woody biome expansion. This methodology can serve as an example for assessing the risk of other species and ecosystems to different stressors as monitoring data becomes available. Future studies that focus on GRPC conservation should continue to monitor the vulnerability of these populations to woody expansion. This study could be expanded by analyzing risk to other large-scale GRPC and grassland threats such as cropland cultivation. By proactively conserving GRPCs by protecting and managing vulnerable high-abundant populations, we can work toward mitigating the threats posed by grassland loss, aiding in the survival and resilience of GRPCs and other grassland obligate species in their last remaining habitat strongholds.

LITERATURE CITED

Allred, B. W., Bestelmeyer, B. T., Boyd, C. S., Brown, C., Davies, K. W., Duniway, M. C., … Uden, D. R. (2021). Improving Landsat predictions of rangeland fractional cover with multitask learning and uncertainty. *Methods in Ecology and Evolution*, *12,* 841-849. https://doi.org/10.1111/2041-210X.13564

Baird, J., Plummer, R., Haug, C., & Huitema, D. (2014). Learning effects of interactive decision-making processes for climate change adaptation. *Global Environmental Change*, *27*(1), 51–63. https://doi.org/10.1016/j.gloenvcha.2014.04.019

Berger, D. J., Lusk, J. J., Powell, L. A., & Carroll, J. P. (2023). Exploring Old Data with New Tricks: Long-Term Monitoring Indicates Spatial and Temporal Changes in Populations of Sympatric Prairie Grouse in the Nebraska Sandhills. *Diversity*, *15*(1). https://doi.org/10.3390/d15010114

Bielski, C. H., Scholtz, R., Donovan, V. M., Allen, C. R., & Twidwell, D. (2021). Overcoming an "irreversible" threshold: A 15-year fire experiment. *Journal of Environmental Management*, *291*(April), 112550. https://doi.org/10.1016/j.jenvman.2021.112550

BirdLife International. (2020). *Tympanuchus cupido, Greater Prairie-Chicken* (Vol. 8235). https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T22679514A177901079.en%0ACopyright:

Bruna, E. M. (2004). Ecology: Biological impacts of deforestation and fragmentation. In Burley, J. (Ed.), *Encycolpedia of Forest Sciences.* Academic Press, Washington, DC, 85-90.

Engle, D. M., Coppedge, B. R., & Fuhlendorf, S. D. (2008). From the Dust Bowl to the Green Glacier: Human Activity and Environmental Change in Great Plains Grasslands. In Van Auken, O. W. (Ed.), *Western North American Juniperus Communities* (Vol. 196, pp. 253–271). Springer New York. https://doi.org/10.1007/978-0-387-34003-6_14

Epstein H. E., Lauenroth W. K., Burke, I. C., & Coffin D. P. (1998). Regional productivities of plant species in the Great Plains of the United States. Plant Ecology, 134, 173-195. https://doi.org/10.1023/A:1009732800810

Fogarty, D. T., Allen, C. R., & Twidwell, D. (2022). Incipient woody plant encroachment signals heightened vulnerability for an intact grassland region. *Journal of Vegetation Science*, *33*(6). https://doi.org/10.1111/jvs.13155

Fogarty, D. T., Peterson, R. B., & Twidwell, D. (2022). Spatial patterns of woody plant encroachment in a temperate grassland. *Landscape Ecology*, *37*(11), 2835–2846. https://doi.org/10.1007/s10980-022-01511-y

Fogarty, D. T., Roberts, C. P., Uden, D. R., Donovan, V. M., Allen, C. R., Naugle, D. E., Jones, M. O., Allred, B. W., & Twidwell, D. (2020). Woody plant encroachment and the sustainability of priority conservation areas. *Sustainability (Switzerland)*, *12*(20), 1–15. https://doi.org/10.3390/su12208321

Fuhlendorf, S. D., Hovick, T. J., Elmore, R. D., Tanner, A. M., Engle, D. M., & Davis, C. A. (2017). A hierarchical perspective to woody plant encroachment for conservation of prairie-chickens. *Rangeland Ecology and Management*, *70*(1), 9–14. https://doi.org/10.1016/j.rama.2016.08.010

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., & Holling C. S. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics, 35*(1), 557-581.

Glick, P., Stein, B., & Edlson N. (2011). Scanning the conservation horizon: a guide to climate change vulnerability assessment. Washington D.C., USA

Honnay, O. (2008). Genetic Drift. In Fath, B. (Ed.), *Encyclopedia of ecology, 2*, 114-117. https://doi.org/10.1016/B978-0-444-63768-0.00616-8

Hovick, T. J., Dwayne Elmore, R., Fuhlendorf, S. D., & Dahlgren, D. K. (2015). Weather constrains the influence of fire and grazing on nesting greater prairie-chickens. *Rangeland Ecology and Management*, *68*(2), 186–193. https://doi.org/10.1016/j.rama.2015.01.009

Jones, M. O., Allred, B. W., Naugle, D. E., Maestas, J. D., Donnelly, P., Metz, L. J., … Mclver, J. D. (2018). Innovation in rangeland monitoring: Annual, 30 m, plant functional type percent cover maps for U.S. rangelands, 1984-2017. Ecosphere, 9(9), e02430. 10.1002/ecs2.2430

Lande, R., & Barrowclough, G. (1987). Effective population size, genetic variation, and their use in population management. In Soule, M. (Ed.), Viable Populations for Conservation, 87 - 124. Cambridge, Cambridge University Press.

Maestas, J. D., Porter, M., Cahill, M., & Twidwell, D. (2022). Defend the core: Maintaining intact rangelands by reducing vulnerability to invasive annual grasses. *Rangelands*, *44*(3), 181–186. https://doi.org/10.1016/j.rala.2021.12.008

[MoRAP] Missouri Resource Assessment Partnership. (2021). Ecological mapping systems of Nebraska. University of Missouri. Columbia, Missouri, USA

Morrow, M. E., Rossignol, T. A., & Silvy, N. J. (2004). Federal listing of prairie grouse: lessons from the Attwater's prairie-chicken. Wildlife Society Bulletin, 32, 112-118. https://doi.org/10.2193/0091-7648(2004)32[112:FLOPGL]2.0.CO;2

McNew, L. B., Prebyl, T. J., & Sandercock, B. K. (2012). Effects of rangeland management on the site occupancy dynamics of prairie-chickens in a protected prairie preserve. *Journal of Wildlife Management*, *76*(1), 38–47. https://doi.org/10.1002/jwmg.237

Niemuth, N. D. (2000). Land Use and Vegetation Associated with Greater Prairie-Chicken Leks in an Agricultural Landscape. *The Journal of Wildlife Management*, *64*(1), 278. https://doi.org/10.2307/3803000

Niemuth, N. D. (2003). Identifying landscapes for Greater Prairie Chicken translocation using habitat models and GIS: A case study. Wildlife Society Bulletin (1973-2006), 31(1), 145-155.

Poiani, K. A., Merrill, M. D., & Chapman, K. A. (2001). Identifying conservation-priority areas in a fragmented minnesota landscape based on the umbrella species concept and selection of large patches of natural vegetation. *Conservation Biology*, *15*(2), 513–522. https://doi.org/10.1046/j.1523-1739.2001.015002513.x

PRISM Climate Group. (2021). PRISM gridded climate dataset for the conterminous United States. Oregon State University. Corvallis, Oregon, USA. http://prism.oregonstate.edu

[RWBJV & NGPC] Rainwater Basin Joint Venture & Nebraska Game and Parks Commission. (2021). Nebraska State-wide Grouse Models.

Rhodes, J. R., McAlpine C. A., Zuur, A. F., Smith, G. M., & Ieno, E. N. (2009). GLMM applied on the spatial distribution of koalas in a fragmented landscape. Mixed Effects Models and Extensions in Ecology with R. *Statistics for Bilogy and Health.* Springer, New York, NY, USA. https://doi.org/10.1007/978-0-387-87458-6_21

Samson, F. B., Knopf, F. L., & Ostlie, W. R. (2004). *Great Plains ecosystems: past, present, and future*. *32*(1), 6–13.

Scholtz, R., & Twidwell, D. (2022). The last continuous grasslands on Earth: Identification and conservation importance. *Conservation Science and Practice*, *4*(3), 1–20. https://doi.org/10.1111/csp2.626

Society, W. (2018). *Land-Use Patterns Surrounding Greater Prairie-Chicken Leks in Northwestern Minnesota Author (s): Michael D . Merrill , Kim A . Chapman , Karen A . Poiani and Brian Winter Published by : Wiley on behalf of the Wildlife Society Stable URL : http://www.jst*. *63*(1), 189–198.

Svedarsky, W. D., Westemeier, R. L., Robel, R. J., Gough, S., & Toepher, J. E. (2000).

Status and management of the greater prairie-chicken Tympanuchus cupido pinnatus in North America. *Wildlife Biology*, *6*(4), 277–284. https://doi.org/10.2981/wlb.2000.027

Svedarsky, W. D., Toepfer, J. E., Westemeier, R. L., & Robel, R. J. (2003). Effects of management practices on grassalnd birds: Greater Prairie-Chicken. Northern Prairie Wildlife Research Center, Jamestown, ND.

Twidwell, D., Fogarty, D., & Weir, J. (2021). Reducing Woody Encroachment in Grasslands. *Oklahoma Cooperative Extension Service*, *E-1054*.

Twidwell, D., Uden, D. R., Roberts, C. P., Allred, B. W., Jones, M. O., Naugle, D. E., & Allen, C. R. (2022). Mapping Panarchy to Improve Visualization of Complex Environmental Change. Gunderson, L. H., Allen, C. R., & Garmestani, A (eds). *Applied Panarchy: Applications and Diffusion across Disciplines.* Island Press, Washington DC, p 136.

Uden, D. R., Twidwell, D., Allen, C. R., Jones, M. O., Naugle, D. E., Maestas, J. D., & Allred, B. W. (2019). Spatial Imaging and Screening for Regime Shifts. *Frontiers in Ecology and Evolution*, *7*(October), 1–16. https://doi.org/10.3389/fevo.2019.00407

[USDA NRCS] United States Department of Agriculture Natural Resources Conservation Service. (2021). *A framework for conservation action in the Great Plains Grasslands Biome: Working lands for wildlife*. 1–21. https://wlfw.rangelands.app/assets/greatPlainsFramework.pdf

[USGS] United States Geological Survey. (1999). National Elevation Dataset: 1 arc second (30-meter). Department of Interior, U.S. Geological Survey, EROS data Center. Sioux Falls, South Dakota, USA.

Walker, B., & Meyers, J. A. (2004). Thresholds in ecological and social-ecological systems: a developing database. *Ecology and Society, 9*(2). http://www.ecologyandsociety.org/vol9/iss2/art3/

FIGURES

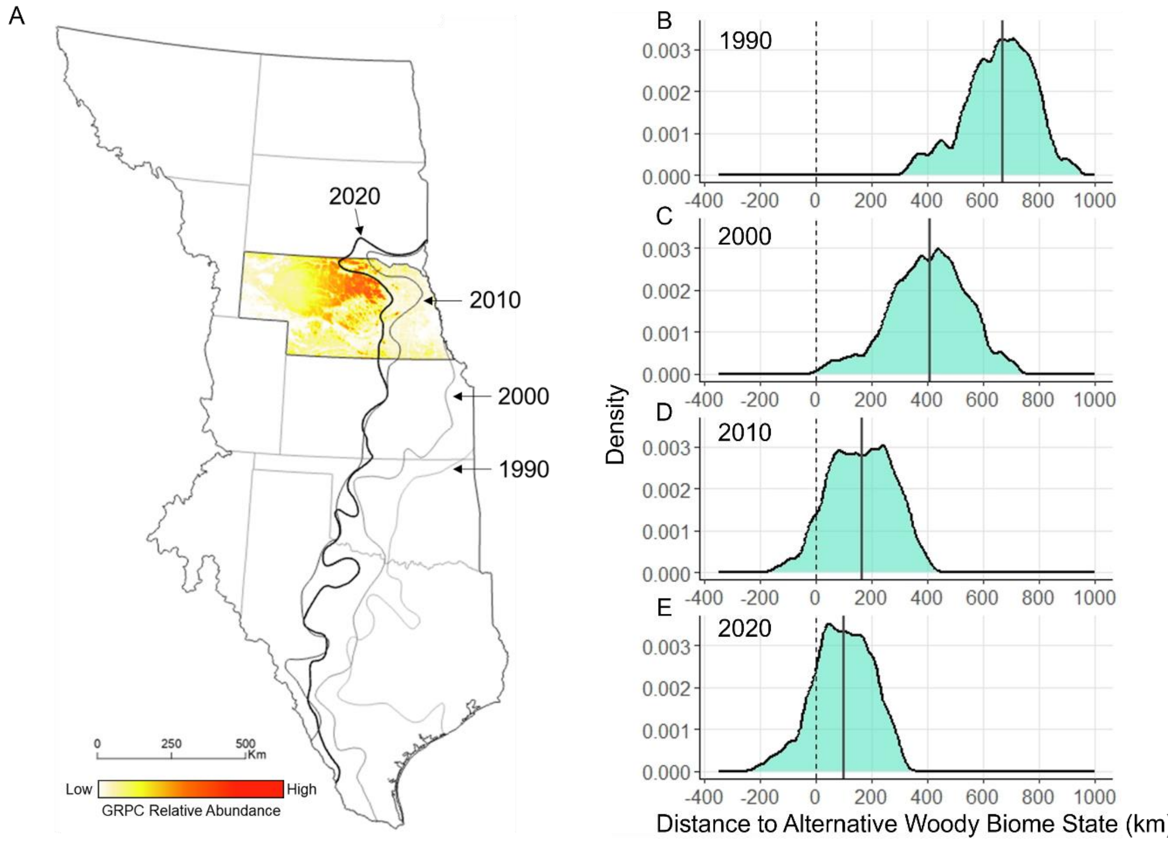


Figure 1.1 GRPC population abundances relative to changes in the location of the boundary separating alternative grassy:woody biome states in the Great Plains. **A** The boundary location is shown for each decade and based on results from Uden et al. (2019). **B-E** Increasing exposure of GRPC populations to grassland biome collapse and the advancement of the alternative woody biome state between each decade from 1990 – 2020. Shown are density plots demonstrating the distance distributions of GRPC populations in Nebraska. Distance distributions represent the distance to the boundary separating alternative grassy:woody biome states in the Great Plains for each decade from 1990 – 2020.

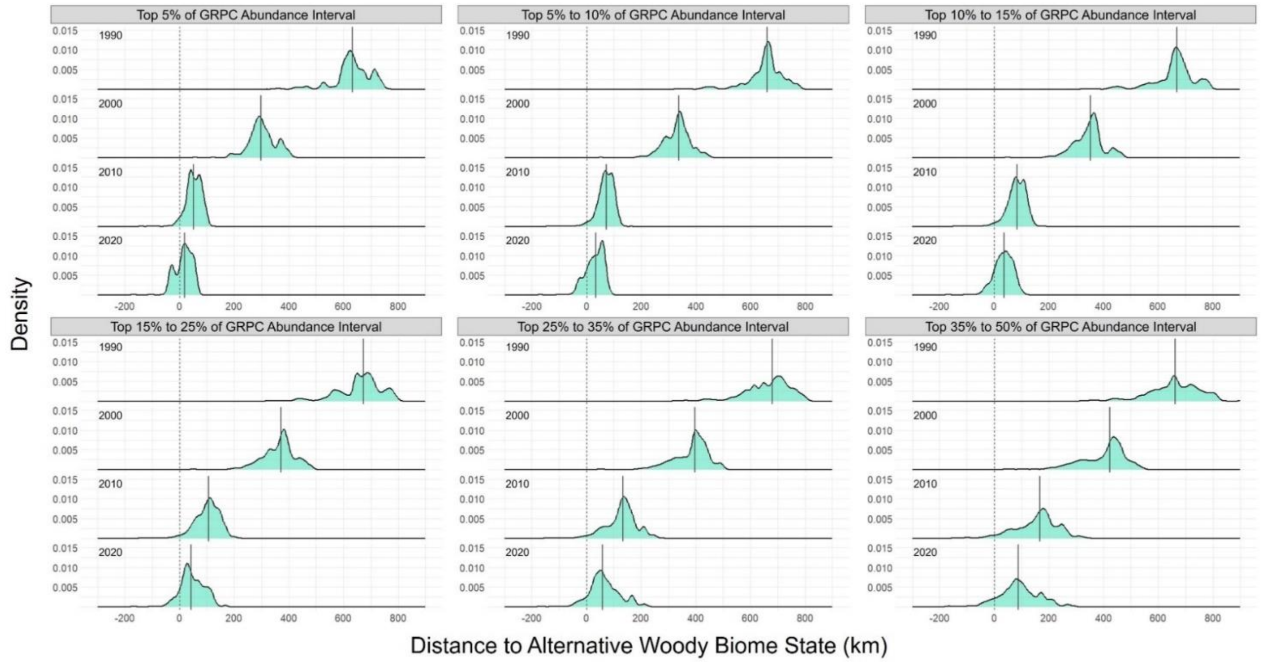


Figure 1.2 Increasing exposure to areas containing top greater prairie chicken population abundances to grassland biome collapse and the advancement of the alternative woody biome state from 1990 – 2020. Shown are density plots demonstrating distance distributions for six intervals of greater prairie chicken population abundances in Nebraska. Distance distributions represent the distance to the boundary separating alternative grassy:woody biome states in the Great Plains for each decade from 1990 – 2020. The six intervals represent incremental decreases in top percentages of greater prairie chicken abundance in Nebraska.

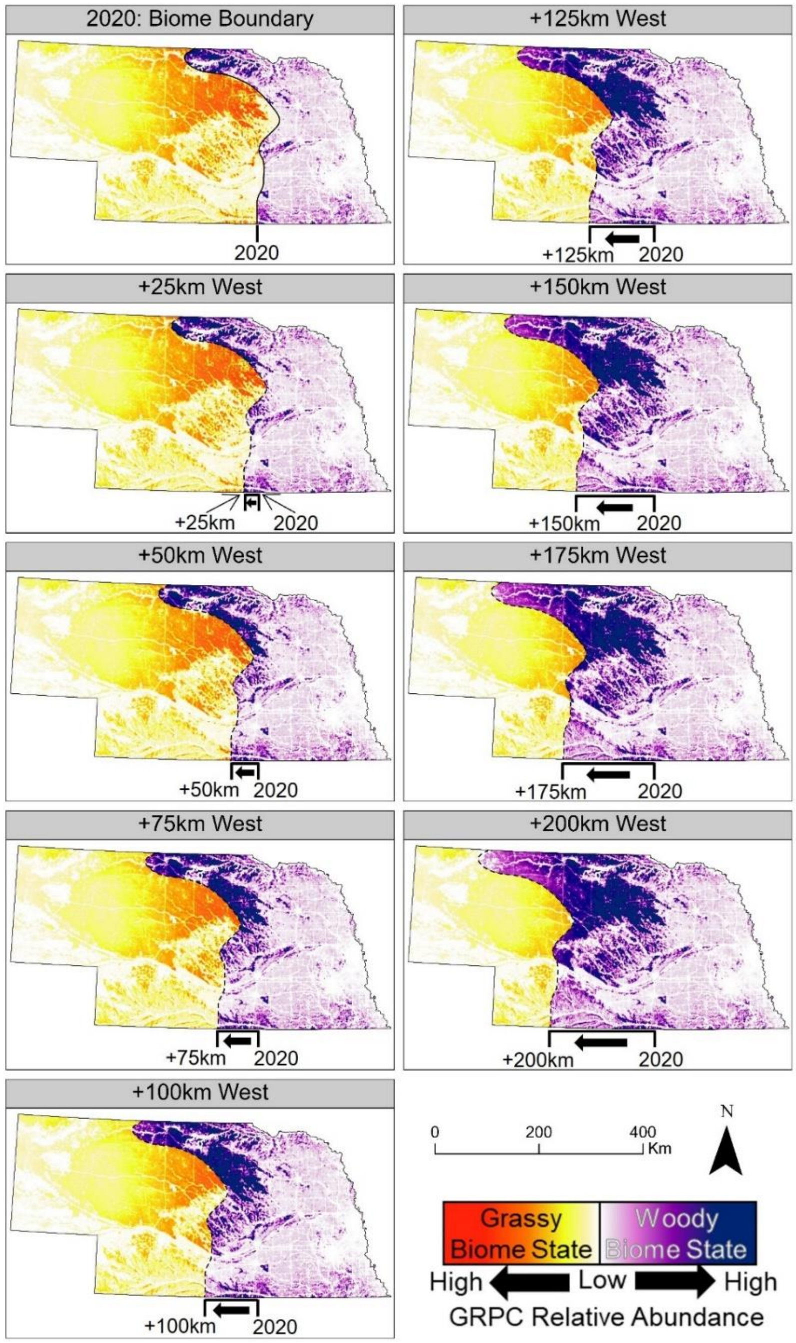


Figure 1.3 Visualizations showing the proportion of Nebraska's greater prairie chicken populations increasingly vulnerable, defined as populations located within the woody

biome state, to future scenarios of advancement for the alternative woody biome state (shown for multiple 25-km distance intervals).

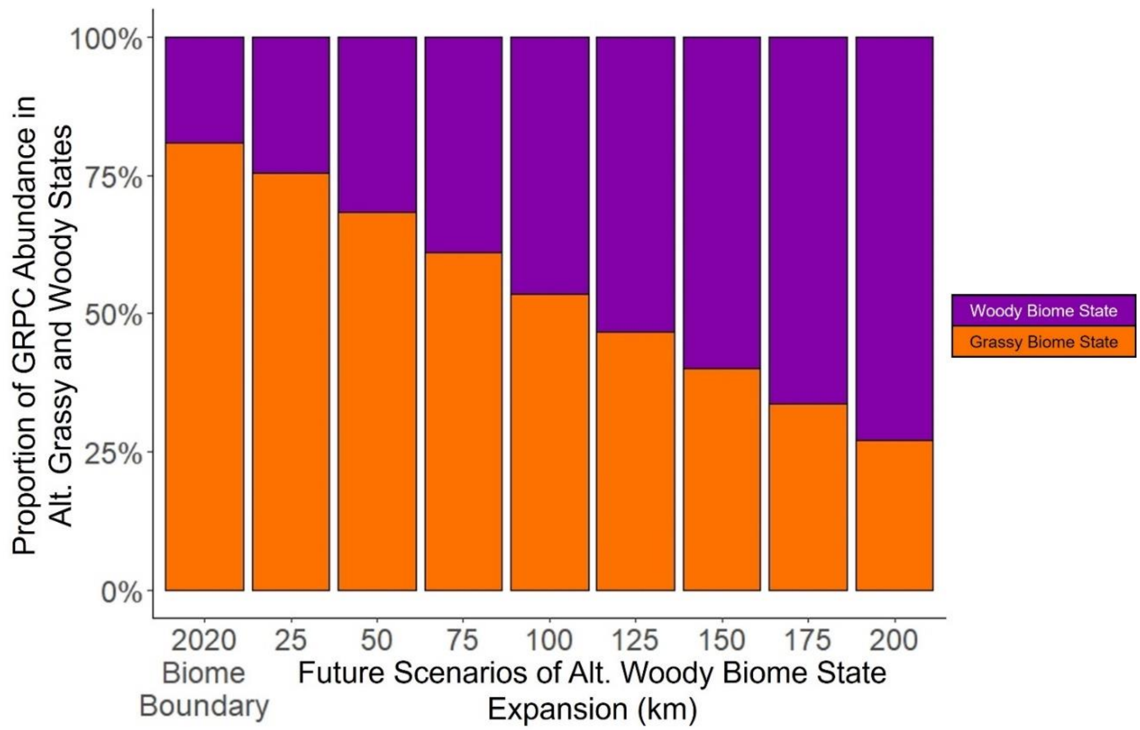


Figure 1.4 Summary of the proportion of GRPC populations in Nebraska, increasingly vulnerable, defined as populations located within the woody biome state, to future scenarios of advancement for the alternative woody biome state (shown for multiple 25-km distance intervals).

CHAPTER 2: PARTICIPATORY SCENARIO PLANNING TO ASSESS VULNERABILITY OF NEBRASKA'S TIER 1 AT-RISK SPECIES

ABSTRACT

Grasslands are one of the most imperiled ecosystems in the world and are under threat from grassland transition to woody dominance. This threat impacts multiple functions supported by grassland ecosystems, directly and indirectly affecting biodiversity. Nebraska is currently at the forefront of this large-scale threat, making it imperative to examine the vulnerability of Nebraska's biodiversity and at-risk species to this threat. In this study, we integrate participatory scenario planning with a Tier 1 at-risk species assessment to determine vulnerability of Tier 1 species listed in the Nebraska Natural Legacy Project to the threat of grassland transition to woody transition. The data obtained from this assessment were expected results from perceptions of conservation professionals. We dissect the results by examining statewide sensitivity, identifying ecoregion tipping points, and determining ecoregion proximity to these tipping points in 1990, 2022, 2050 with continued management, and 2050 without continued management. The findings show that Tier 1 at-risk species were expected to be vulnerable to the threat of grassland transition to woody dominance in Nebraska. Overall, Tier 1 at-risk species were highly sensitive to this threat. A common tipping point emerged between 7 of the 8 ecoregions where small negative impacts combine to form a larger widespread negative impact. The proximity to these tipping points varied, but each ecoregion was at a point where at least 25% of species were expected to be negatively impacted. Five of eight ecoregions were not expected to reduce or stabilize this threat in the future given

continued woody encroachment management. Results from this study should assist in the management decision making process, considering tradeoffs resulting from these decisions.

INTRODUCTION

Grasslands are one of the most imperiled ecosystems in the world (Carbutt, 2022; Suttie, et al., 2005), and one of the most endangered ecosystems in North America (Samson & Knopf, 1994). In the Great Plains, grasslands have been greatly reduced and largely fragmented from land use conversions (cultivation, human development) and woody plant encroachment leading to a woody transition (Samson et al., 2004; Fogarty et al., 2020b). As the remaining grasslands continue to shrink from these threats, we anticipate shifts and changes in grassland ecosystem services that we have come to rely on (Bengtsson et al., 2019; Twidwell et al., 2021). These shifts have already been observed in grassland biodiversity, with grassland birds being reduced by more than 60% since the 1970s (Rosenberg et al., 2019).

The United States has lost approximately 93,000 km^2 of grasslands to agriculture conversions from 1982 to 1997 and a comparable amount to woody transitions (Samson et al., 2004; Twidwell et al., 2021). These large-scale threats are still looming today and are converting grasslands at similar rates (NRCS, 2021). Many of the remaining grasslands escaped cultivation because they are better suited as grazing lands due to climate, soil, and topographic conditions (Olimb & Robinson, 2019). For example, in the Great Plains, tall grass prairies have lost at least 82% of grasslands to row crop conversions, while short and mixed grass prairies which are less conducive to row crops have lost 30% (Samson & Knopf, 1994). However, many of the remaining grasslands are still experiencing woody encroachment, leaving them vulnerable to transitioning into woody dominance (Fogarty et al., 2020b, 2022).

Grassland lost to woody dominance has been a green glacier, converting the Great Plains grassland biome to an alternative woody state as it moves northwest through the biome (Engle et al., 2008). It has been driven by fire exclusion brought about by European settlement and was accelerated by encroachment from tree plantings (Engle et al., 2008; Jones et al., 2020). The increase in woody dominance results in major changes in many ecosystem services supported by grasslands, including reductions in food production (Fuhlendorf et al., 2008; Anadon et al., 2014) and freshwater supply (Jackson et al., 2005; Zou et al., 2018), and increases in of large wildfire risk (Donovan et al., 2020) and vector-borne diseases (Loss et al., 2021). These changes indirectly and directly impact biodiversity, affecting species that reside in or near grassland ecosystems (Ratajczak et al., 2012). Nebraska is currently at the front line of this large-scale transition (Engle et al., 2008), making management decisions vital for the remaining grasslands and ecosystem services and biodiversity they support.

Given the notable declines already observed in grassland birds (Rosenberg et al., 2019), it becomes imperative to examine the future of other at-risk species residing in and around remaining grasslands. There are 119 species listed as Tier 1 at-risk species in Nebraska's state wildlife action plan (Schneider et al, 2018). Although some species' threats are well defined, there are many in which direct or indirect risks are unknown (Schneider et al., 2018). As grasslands, which are the primary historical landscape in Nebraska, remain vulnerable to woody transitions, it is vital that we assess how this change will impact species that are already at-risk. By doing so, we can make informed and impactful decisions in conservation management concerning grassland lost to woody dominance.

Participatory scenario planning allows us to advise conservation planning in the face of an unpredictable future (Peterson et al., 2003). Instead of focusing on a single potentially accurate trajectory, scenarios provide a variety of plausible futures adding more resiliency to the decision-making process given the unknown (Bennett et al., 2003; Peterson et al., 2003). Starting out in the business field, participatory scenario planning approaches have been integrated into the conservation field due to the complex and unpredictable nature of ecological systems (Bennett et al., 2003; Peterson et al., 2003).

We integrated participatory scenario planning with Tier 1 at-risk species impact assessments to help advise policy by considering tradeoffs (Bennet, 2017). Like all natural systems, grasslands are complex, and threats to grasslands cause many direct and indirect impacts to supporting ecosystem services and biodiversity (Proctor & Larson, 2005). Tier 1 at-risk species encompass a wide spectrum of habitats, ranging from terrestrial and aquatic to diverse ecological niches such as grasslands, woodlands, forests, and areas in between (Schneider et al., 2011; 2018). By assessing the impact of multiple plausible future scenarios of a grassland threat on Tier 1 at-risk species we can output well rounded tradeoffs that could occur when considering management decisions to mitigate a threat.

Here, we conducted a collaboratively led participatory scenario planning exercise to explore the future of Tier 1 at-risk species given variable levels of grassland lost to woody dominance. This exercise integrated participatory scenario planning with Tier 1 at-risk species assessments using the recently developed Integrative Ecosystem Service Analysis Tool (IESAT) (Fogarty et al., 2020a). Similar methods have been used by global sustainability initiatives such as the Millennium Ecosystem Assessment (MEA) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (MEA, 2003; IPBES, 2016). Our approach, occurs at a smaller ecoregion scale allowing for the integration of local stakeholder knowledge and perspectives into the larger-scale decision-making processes (Oteros-Rozas et al., 2015; Kok et al., 2017; Allen et al., 2018; Caceres-Escobar et al., 2019).

The objective of this assessment was to assess the vulnerability of Tier 1 at-risk species in Nebraska to the threat of grassland transition to woody dominance. We assessed sensitivity at the statewide level by summarizing varying levels of grassland lost to woody transition's impact (1) on Tier 1 at-risk species and by (2) outlining some of the most and least sensitive Tier 1 at-risk species, and (3) by assessing impact on taxonomic groups of Tier 1 at-risk species. Next, we scale it down to an ecoregion level where we assessed sensitivity by quantifying regional Tier 1 at-risk species tipping points. We quantified the estimated proximity of each ecoregion to these tipping points. We assessed future proximity to these tipping points with continued management and without management.

METHODS

Nebraska Natural Legacy Project

The Nebraska Natural Legacy Project was established as Nebraska's state wildlife action plan in 2005 (Schneider et al., 2011). The goals of this plan include: (1) reverse the decline of at-risk species, (2) recover currently listed species and allow for their de-listing, (3) keep common species common, and (4) conserve natural communities (Schneider et al., 2011). The natural legacy project takes a two-pronged approach, focusing on habitats and selected individual species (Schneider et al., 2011). Priority habitat conservation was centered around four grassland ecoregions, which were further broken down into biologically unique landscapes (BULs) (Schneider et al., 2011). BULs were delineated based on known occurrences of at-risk species, and a broad array of common species (Schneider et al., 2011). At-risk species were listed based upon a two-tiered approach. Tier 1 species were globally, or nationally at-risk, and Tier 2 species were only at-risk in Nebraska and apparently stable in other states (Schneider et al., 2011; 2018).

Participatory Scenario planning approach

We held a day long workshop in October 2022, where we invited knowledgeable professionals in regional biodiversity and habitat management around Nebraska to participate in a Tier 1 at-risk species assessment. This assessment followed a participatory scenario-planning approach to evaluate the impact of grassland lost to woody dominance on Nebraska's Tier 1 at-risk species (Schneider et al., 2011; 2018; Oteros-Rozas et al., 2015). We modified an approach outlined by Peterson et al., (2003) tailored for the goals of this study. This approach included the following steps: (1)

identification of a focal issue and scenario development, (2) identification of study ecoregions, (3) identification of regional expert panels, (4) Tier 1 at-risk species questionnaire, (5) peer-review and discussion of results, (6) follow-up assessment, and (7) data analysis and visualization.

1. Identification of a Focal Issue and Scenario Development

We chose from the top two drivers of grassland loss in the great plains which includes cropland cultivation, and grassland lost to woody dominance (USDA NRCS, 2021). In the last 20 years, these two threats have been converting grasslands at similar rates (USDA NRCS, 2021). Many grasslands in Nebraska have escaped cultivation because soil and topographic conditions make them better suited as grazing lands (Olimb & Robinson, 2019). All the remaining grasslands in Nebraska are experiencing woody encroachment leaving them vulnerable to transitioning to woody dominance (Fogarty et al., 2020b, 2022). This led us to choose grassland lost to woody dominance as the focal issue for this participatory scenario planning exercise.

We developed six scenarios to represent plausible futures of grassland lost to woody dominance (table 2.2). These scenarios were tied to narratives of change and aimed to provide a snapshot of grassland landscapes in the future. To construct these six plausible future scenarios, we used the bounded range of variation framework (Moritz et al., 2013; Twidwell et al., 2018). This framework involved considering extreme values representing the largest and lowest plausible proportions of grasslands transitioning to woody dominance and then creating evenly spaced intervals within this range. Each interval represents a plausible future scenario, and each scenario is relative to the assumption that each ecoregion's rangeland was 100% intact grassland.

2. Identification of Study Ecoregions

We collaborated with leadership in the Nebraska Game and Parks commission to define eight ecoregions encompassing a diverse selection of remaining grasslands across Nebraska (Figure 2.1, Table 2.1). To accomplish this, we utilized both individual BULs and groups of BULs from the Nebraska Natural Legacy Project (Schneider et al., 2011), as well as ecoregions from the Great Plains Grassland Initiative (GPGI) (USDA NRCS, n.d.; Figure 2.1, Table 2.1). GPGI is part of the Natural Resource Conservation Service's (NRCS) working lands for wildlife framework which outlines the last remaining iconic grassland regions for priority conservation in the Great Plains Biome (USDA NRCS, n.d.; 2021). We used GPGI regions as broader grassland regions that overlayed multiple BULs. We exclusively selected terrestrial BULs that contained grasslands (Fogarty et al., 2020b; Schneider et al., 2011), and we grouped BULs together if they were in close proximity and contained similar ecological characteristics.

3. Identification of Expert Panel

Collaborating with leadership within the Nebraska Game and Parks commission, we designated a leader for each ecoregion. These ecoregion leaders recruited an expert panel comprising of up to five people. Each expert panel consisted of local personnel that were knowledgeable about biodiversity and conservation management in their specific ecoregion. Each panel worked together to complete the Tier 1 at-risk species questionnaire for their ecoregion. We had a total of 25 regional experts who attended this workshop, with representation from five different conservation organizations.

4. Tier 1 at-risk Species Questionnaire

A Tier 1 at-risk species questionnaire was developed using a rapid prototyping approach to estimate impact to Tier 1 at-risk species given the specified scenario. Included in this questionnaire were Tier 1 at-risk species found in the specific ecoregion listed in either the 2011 Nebraska Natural Legacy Project (Schneider et al., 2011) or the 2018 revision of at-risk species for the Nebraska Natural Legacy Project (Schneider et al., 2018). For GPGI regions, we compiled all Tier 1 species that were found in terrestrial BULs containing grasslands within each respective GPGI region. Tier-1 species included in the 2018 natural legacy plan were added in a follow-up virtual questionnaire sent after the workshop. Species from each version were included in this study per request of regional experts since species removed were still species of concern and could be reintroduced to the list. Each expert panel worked together to assess each scenario of grassland lost to woody transition's impact on each Tier 1 at-risk species found in their respective ecoregion.

Impact to Tier 1 species was estimated using a 7-point global rating of change scale, ranging from extreme negative impact (-3) to extreme positive impact (3) (Kamper et al., 2013; Table 2.3). Participants also rated the confidence of their estimates using a 5-point scale, ranging from no confidence to extreme confidence. The questionnaires were administered to each team online using Qualtrics software (See appendix A for an example of the Questionnaire).

5. Peer Review and Discussion

Response data gathered from each questionnaire was compiled and summarized in real time using the Integrative Ecosystem Service Analysis Tool (IESAT) (Fogarty et al., 2020a). This tool streamlined the process, enabling rapid assessment of Tier 1 at-risk species impact outcomes. IESAT is a data visualization tool that uses response data from Qualtrics to generate visualizations aimed at facilitating participatory ecosystem service assessments. Impact outcomes for each Tier 1 at-risk species within each scenario were calculated and visualized for each ecoregion.

The real-time results were examined during the peer-review and discussion segment of this workshop. Using the IESAT online platform, workshop organizers were able to compare the impact that grassland lost to woody transition has on Tier 1 at-risk species for each ecoregion. The purpose of the peer-review and discussion portion was to break down the results, identifying areas of agreement, disagreement, and uncertainty while building knowledge based on different perspectives and reasoning.

6. Follow-up Questionnaire

The follow-up questionnaire was used to gather participants consensus from the peer-review discussions, and to glean further local knowledge on each ecoregion. Two questions used a 7-point Likert scale, and two questions used a 5-point Likert scale. We also posed a question to get each participant's estimate of the proportion of each ecoregion's rangeland that has been or will be transitioned to woody dominance in the following timeframes and conditions: pre-settlement era, 1990, 2022, 2050 with continued woody encroachment management, and 2050 without woody encroachment management (See Appendix B for follow-up questionnaire). This research was approved by an Institutional Review Board (IRB).

7. Data Analysis and Visualization

Using the results from the tier 1 species questionnaire, we summarized vulnerability of Nebraska's Tier 1 at-risk species to the threat of grassland lost to woody dominance. We begin by summarizing sensitivity of Tier 1 at-risk species by calculating the mean impact expected for each species across each ecoregion (Table 2.4). Then we determined the proportion of species expected to experience positive impacts (>0), negative impacts (<0), and no impacts (0) in each scenario of grassland lost to woody transition (Figure 2.2A). Additionally, we analyzed the proportion of Tier 1 at-risk species expected to experience different degrees of negative impact such as slight (-1), moderate (-2), or extreme (-3), for each scenario of grassland lost to woody dominance (Figure 2.2B).

We determined when Tier 1 at-risk species became negatively impacted and counted the number species beginning to receive negative impacts at each point of grassland lost to woody transition (Figure 2.3). To conceptually illustrate the timeframe of grassland transition woody dominance, we used a curve function commonly used to represent woody invasions in grasslands (Robert et al., 2018). By using the percentage of grassland lost to woody transition, we determined where along the curve Tier 1 at-risk species became negatively impacted and how many became negatively impacted at each of these points.

The sensitivity of Tier 1 at-risk taxa was summarized by calculating the mean impact of each species across each ecoregion and then grouping these species into taxonomic groups. We followed classifications provided by the Nebraska Natural Legacy Project to create six distinct taxonomic groups (Schneider et al., 2018; Tables 2.5 - 2.10). We combined mollusks, crustaceans, and fish into a freshwater species group due to the limited representation in each of these taxonomic groups (Table 2.6). Then, we calculated the proportion positive impacts (>0), negative impacts (<0), and no impacts (0) expected for each Tier 1 species within each taxonomic group (Figure 2.4). Additionally, we determined the proportion of each taxonomic group expected to experience each degree of negative impact, including slight (-1), moderated (-2), and extreme (-3) degrees for each scenario of grassland lost to woody transition (Figure 2.5).

Regional data visualizations were created to assess the sensitivity of Tier 1 at-risk species at an ecoregion level (Figure 2.6 and Table 2.11). These depicted the impact on Tier 1 at-risk species for each scenario of grassland lost to woody transition within each ecoregion. We also quantified the proportion of species reaching or surpassing each degree of negative impact, and highlighted when these values reached 25%, 50%, and 75% for each scenario of grassland lost to woody dominance within each ecoregion (Table 2.11).

To assess the proximity of ecoregions to the tipping points, we created a data visualization depicting the expected impacts on Tier 1 at-risk species for the scenario closest to the mean estimates of grassland lost to woody transition in 1990, 2022, 2050 with continued management, and 2050 without continued management for each ecoregion (Figure 2.7). Finally, we quantified the estimated trajectory of grassland lost to woody transition for each ecoregion, between each timeframe and condition (Figure 2.8). We created a visualization depicting these trajectories (Figure 2.8).

RESULTS

Statewide Sensitivity

Based on the results from this workshop comprised of independent teams of regional experts, Tier 1 at-risk species were expected to exhibit high sensitivity to grassland lost to woody dominance. In the scenario where 10% of grasslands were lost to woody transition, 59% of Tier 1 species were expected to be negatively impacted (Figure 4A). By the scenario where 50% of grasslands were lost to woody transition, 90% of species were expected to be negatively impacted, of these negative impacts 55% percent were expected to be moderate or extreme negative impacts (Figure 2.2). As grasslands were lost to woody transition, the severity of impacts on Tier 1 at-risk species exacerbates (Figure 4A and 4B).

While high sensitivity of Tier 1 at-risk species was expected at lower levels of grassland lost to woody dominance, there was more variance in the impact response at these lower levels when compared to higher levels. For instance, at 5% grassland lost to woody transition, more species were expected to be unaffected or positively impacted than negatively impacted (Figure 2.3). However, at this low level, 35 Tier 1 at-risk species were expected to become negatively impacted (Figure 2.5). When 10% of grasslands were lost to woody dominance, 19 more species were expected to become negatively impacted (Figure 2.5). At the point where 75% of grasslands were lost to woody transition, only 3 species were expected to become negatively impacted (Figure 2.5). These results indicate that many Tier 1 species were expected to begin experiencing negative impacts at low levels grassland lost to woody transition.

Although Tier 1 species were expected to be sensitive to grassland lost to woody transitions, expected impact still varied across individual species. For instance, the Colorado Butterfly Plant (*Gaura neomexicana coloradensis*) displayed the highest sensitivity and was expected to experience moderate negative impacts (-2) when 5% of grasslands were lost to woody transition, and extreme negative impacts (-3) when 10% of grasslands were lost to woody dominance (Table 2.4). Four additional Tier 1 at-risk species were expected to reach extreme negative impacts (-3) when 25% of grasslands were lost to woody transition (Table 2.4). There were five Tier 1 species that were expected to be unaffected or positively impacted throughout each scenario of grassland lost to woody transition, including four mammals and one plant species (Table 2.4).

The same trend of high sensitivity was observed when Tier 1 at-risk species were separated into taxonomic groups. All groups, except for mammals, were expected to experience nearly 100% negative impacts in the scenario where 50% of grasslands were lost to woody transition (Figure 2.4). The taxonomic groups expected to be the most sensitive were Tier 1 at-risk Plants, Insects, and Birds (Figure 2.4). The least sensitive group were Tier 1 at-risk mammals (Figure 2.4). While some mammals received positive impacts to each scenario of change, negative impacts outweighed positive impacts when 25% of grasslands were lost to woody dominance (Figure 2.4). Participants expressed an averaged high level of confidence in the estimated impact for birds compared to all the other taxonomic groups, which received an averaged moderate confidence rating.

Ecoregion Analysis

Based on the results from this workshop comprised of independent teams of regional experts, many of the ecoregions shared a common tipping point where widespread negative impacts become expected for Tier 1 at-risk species (Figure 2.6; Table 2.11). This point occurred in the scenarios representing 10% to 25% of grassland lost to woody transition (Table 2.11). After this point the transition gains momentum and Tier 1 at-risk species were unable to cope with further grassland loss and transition to woody dominance. When 25% of grasslands were lost to woody transition, the majority of Tier 1 at-risk species were expected to be negatively impacted in all ecoregions except the Northeast Prairie BULs ecoregion (Table 2.11). This ecoregion lagged, but when 50% of the grasslands were lost to woody transitions, 75% of Tier 1 at-risk species were expected to be negatively impacted (Table 2.11).

While many of the ecoregions share common tipping points where widespread negative impacts were expected for Tier 1 species, ecoregions have experienced varying levels of woody transitions and therefore, differ in proximity to the expected tipping point. In 2022, all eight ecoregions were expected to have lost enough grassland to woody dominance to negatively impact at least 25% of Tier 1 at-risk species (Figure 2.7 & 2.8; Table 2.11). Four of these eight ecoregions were expected to be at the point where at least 50% of Tier 1 at-risk species were expected to be negatively impacted (Figure 2.7 & 2.8; Table 2.11). The Loess Canyons were nearing 50% of grassland lost to woody transition, where 75% of Tier one species were expected to be negatively impacted of which, 55% were moderately or extremely negatively impacted (Figure 2.7 & 2.8; Table 2.11).

While all of the ecoregions were expected to be at or past the tipping point where at least 25% of species were expected to be negatively impacted, adaptive capacity allows us to manage this risk, impeding, halting, or reducing grassland lost to woody transition in the future (Bielski et al., 2021; Vallury et al., 2022). In 30 years with continued woody encroachment management, two of eight ecoregions were expected to reduce woody dominance resulting in grassland restoration, and one ecoregion was expected to halt the threat resulting in grassland stabilization (Figure 2.7 & 2.8). The Sandhills Prairie ecoregion was expected to reduce woody transitions by 3%, closer to the point where 25% of Tier 1 species were negatively impacted, and the Loess Canyons BUL was expected to reduce woody dominance by 22%, closer to the point where 50% of Tier 1 species were negatively impacted (Figure 2.7 & 2.8; Table 2.11). In 30 years without woody encroachment management, seven of eight ecoregions were expected to lose more grasslands to woody transition than what was expected with management (Figure 2.8 & 2.9; Table 2.11). The Rainwater Basin BUL was expected to stabilize at 10% grassland lost to woody dominance in the future regardless of management.

DISCUSSION

The results from this participatory scenario planning assessment found that Tier 1 at-risk species were expected to be sensitive to the threat of grassland transition to woody dominance. It also found that common tipping points emerged among ecoregions where sensitivity to the threat became apparent and widespread negative impacts to Tier 1 at-risk species became expected. However, ecoregions displayed varying levels of exposure as each ecoregion has experienced different levels of grassland lost to woody dominance, varying in proximity to the tipping points. Nevertheless, each ecoregion was expected to be at the point where at least 25% of Tier 1 at-risk species were expected to be negatively impacted. The ability to combat this threat varies among ecoregions where three of eight ecoregions were expected to reduce or stabilize grassland lost to woody dominance by 2050 given continued grassland management, and the remaining five ecoregions were expected to continue to lose grasslands to woody dominance.

Overall, Tier 1 at-risk species were expected to be highly sensitive to relatively low levels of grassland lost to woody dominance. However, there was more variance at low levels than high levels of grassland loss. For instance, when 5% of grasslands were lost, there were more positive impacts and no impacts than negative impacts (Figure 2.2A). One common explanation for the positive impacts at low levels was the increase in landscape heterogeneity. It is also important to note that when 5% of grassland was lost was to woody dominance, 35 Tier 1 at-risk species were expected to experience negative impacts (Figure 2.3). The positive impacts and no impacts quickly diminished as the transition gained momentum, and negative impacts, as well as the severity of negative impacts quickly exacerbated (Figure 2.2; Figure 2.4).

Results also showed common tipping points across each ecoregion where Tier 1 at-risk species were expected to experience widespread negative impacts. This result was not expected since ecoregions were experiencing different levels of grassland lost to woody dominance. We hypothesized teams' perception of impact would be different given what they have experienced and observed (Bennet et al., 2003; Cencini et al., 2012). This expectation only held true for the Northeast ecoregion which had delayed tipping points. This ecoregion team explained this result by expressing that this ecoregion had more woody obligate Tier 1 at-risk species because it had more historical woody cover than other ecoregions, creating lower sensitivity to the threat of grassland lost to woody dominance.

One common goal of ecosystem service assessment frameworks, and specifically this Tier 1 at-risk species assessment is to aid in the environmental decision-making process (Bennet, 2017). This requires the recognition and the consideration of tradeoffs based on multiple services or in this case Tier 1 at-risk species (MEA, 2003; Bennet et al., 2017). Here, tradeoffs became apparent as there were Tier 1 species that were positively impacted through various, or all levels of grassland lost to woody dominance, but there were overwhelmingly more negatively impacted species than positively impacted species. One example where tradeoffs were apparent was in the mammal functional group of Tier 1 at-risk species. This group contained many woodland obligate species and generalists including many bats and rodents, but the group was still overwhelmingly negatively impacted by grassland transitions to woody dominance. This guides management objectives to focus on mitigating woody encroachment which causes grassland transition to woody dominance.

The results from this Tier 1 at-risk species assessment reflect the importance of adaptive woody encroachment management throughout Nebraska's remaining grasslands. In 2050 with continued management, only two ecoregions were predicted to restore grassland that was lost to woody transition (Figure 2.8). Although continued management reduces the amount of grassland lost to woody dominance when compared to no management, five of the eight ecoregions were still not expected to reduce or stabilize woody transitions in the future under this condition (Figure 2.8). Since many Tier 1 at-risk species were expected to become negatively impacted at low levels of grassland lost to woody dominance it will be important to integrate a framework focused on proactively stabilizing intact grasslands and then growing these grasslands after stabilization is reached (Twidwell et al., 2021; USDA-NRCS, 2021).

Ecology is complex (Proctor & Larson, 2005) and species abiding in ecological systems do not fit into groups with homogeneous habitat needs, but a spectrum requiring different needs throughout stages of life (Fuhlendorf & Engle, 2001). This complexity is compounded by the considerable number of Tier 1 at-risk species, many of which are rare (Schneider et al., 2011, 2018), which makes gathering empirical evidence regarding their population change and habitat requirements time consuming and exceptionally challenging (Petit & Valiere, 2006). This combined with the uncertainty of an unprecedented change enhances the unknown futures of these species. Here lies the functionality of participatory scenario planning approaches like this Tier 1 at-risk species assessment. In this study, we utilized local ecological knowledge to summarize the impact of grassland lost to woody dominance on 92 Tier 1 at-risk species. Where, despite not all being classified as grassland obligate or even terrestrial species, they are overwhelmingly expected to exhibit high sensitivity to the threat of grassland transition to woody dominance.

Tier 1 at-risk species encompass a wide spectrum of habitats, ranging from terrestrial and aquatic to diverse ecological niches such as grasslands, woodlands, forests, and areas in between (Schneider et al., 2011; 2018). Even with these diverse niches, Tier 1 at-risk species were overwhelmingly expected to be negatively impacted by grassland transition to woody dominance. Not only does this threat cause direct impacts to grassland obligate species, it also indirectly impacts other ecosystem dwellers. For instance, freshwater species were expected to be overwhelmingly negatively impacted. This was justified by regional experts because of the reduced quality and quantity of water in aquatic systems that's associated with woody encroachment into grasslands which is supported in the literature (Jackson et al., 2005; Zou et al., 2018).

This study followed frameworks that integrated participatory scenario planning with ecosystem service assessments such as the MEA and the IPBES (MEA, 2003; IPBES, 2016). These large-scale assessments have used a top-down approach evaluating a threat's impact to vague global ecosystem services to drive change at the local level (Kok et al., 2017). This approach is criticized because vague ecosystem services lack integration of local knowledge and perspectives, and only have implicit connections to biodiversity and ecosystem services (Reyers et al., 2013; Kok et al., 2017). Our study was adapted from large-scale global ecosystem service assessments to fit a bottom-up approach assessing impact of a large-scale threat on discrete Tier-1 species at smaller ecoregion scales to drive change at a larger statewide level.

The results from this Tier 1 at-risk species assessment were meant to better inform conservation planners on the vulnerability of Nebraska's Tier 1 at-risk species caused by the threat of grassland transition to woody dominance through integration of stakeholder-based knowledge. When interpreting these results, one should consider both perceived impact, and confidence in this impact (Robertson et al., 2003; see Appendix C for confidence rankings). These results were not meant to replace the need for empirical evidence concerning the impact on species, but to aid in decision making given what has not been empirically studied. This study could be furthered by considering more threats to grasslands, including row crop cultivation and urbanization. It can also serve as an example for other ecological systems experiencing unprecedented change. We propose that the results from this assessment will help inform policy and management regarding the threat of grassland transition to woody dominance and its expected impact on Tier 1 at-risk species.

LITERATURE CITED

Anadon, J. D., Sala, O. E., Turner, B. L. II, & Bennet, E. M. (2014). Effect of woody-pant encroachment on livestock production in North and South America. Proc Natl Acad Sci, 111, 12948-12953. https://doi.org/10.1073/pnas.1320585111

Allen, C. R., Birge, H. E., Angeler, D. G., Arnold, C. A., Chaffin, B. C., DeCaro, D. A., … Gunderson, L. (2018). Quantifying uncertainty and trade-offs in resilience assessments. *Ecology and Society*, *23*(1), art3. https://doi.org/10.5751/ES-09920-230103

Bengtsson, J., Bullock, J. M., Egoh, B., Everson, C., Everson, T., O'Connor, T., … Lindborg, R. (2019). Grasslands—More important for ecosystem services than you might think. *Ecosphere*, *10*(2). https://doi.org/10.1002/ecs2.2582

Bennett, E., Carpenter, S., Peterson, G., Cumming, G., Zurek, M., & Pingali, P. (2003). Why global scenarios need ecology. *Frontiers in Ecology and the Environment*, *1*(6), 322–329. https://doi.org/10.1890/1540-9295(2003)001[0322:WGSNE]2.0.CO;2

Bielski, C. H., Scholtz, R., Donovan, V. M., Allen, C. R., & Twidwell, D. (2021). Overcoming an "irreversible" threshold: A 15-year fire experiment. *Journal of Environmental Management*, *291*, 112550. https://doi.org/10.1016/j.jenvman.2021.112550

Caceres-Escobar, H., Kark, S., Atkinson, S. C., Possingham, H. P., & Davis, K. J. (2019). Integrating local knowledge to prioritise invasive species management. *People and Nature*, *1*(2), 220–233. https://doi.org/10.1002/pan3.27

Carbutt, C. (2022). The Imperiled Alpine Grasslands of the Afrotropic Realm. In *Imperiled: The Encyclopedia of Conservation* (pp. 243–255). Elsevier. https://doi.org/10.1016/B978-0-12-821139-7.00012-X

Cecconi, F., Cencini, M., Falcioni, M., Vulpiani, A. (2012). Predicting the future from the past: An old problem from a modern perspective. *American Journal of Physics, 80*, 1001-1008. https://doi.org/10.1119/1.4746070

Donovan, V. M., Wonkka, C. L. Wedin, D. A., Twidwell, D. (2020). Land-use type as a driver of large wildfire occurrence in the U.S. Great Plains. *Remote Sensing, 12*(11), 1889. https://doi.org/10.3390/rs12111869

Engle, D. M., Coppedge, B. R., & Fuhlendorf, S. D. (2008). From the Dust Bowl to the Green Glacier: Human Activity and Environmental Change in Great Plains Grasslands. In Van Auken, O. W. (Ed.), *Western North American Juniperus Communities* (Vol. 196, pp. 253–271). Springer New York. https://doi.org/10.1007/978-0-387-34003-6_14

Fuhlendorf, S. D., Archer, S. A., Smeins, F., Engle, D. M., & Taylor. A. T. Jr. (2008). The Combined Influence of Grazing, Fire, and Herbaceous Productivity on Tree-Grass Interactions. In Van Auken, O. W. (Ed.), *Western North American Juniperus*

Communities (Vol. 196, pp. 253–271). Springer New York. https://doi.org/10.1007/978-0-387-34003-6_14

Fuhlendorf, S. D., & Engle, D. M. (2001). Restoring Heterogeneity on Rangelands: Ecosystem Management Based on Evolutionary Grazing Patterns: We propose a paradigm that enhances heterogeneity instead of homogeneity to promote biological diversity and wildlife habitat on rangelands grazed by livestock, *BioScience, 51*(8), 625-632. https://doi.org/10.1641/0006-3568(2001)051[0625:RHOREM]2.0.CO;2

Fogarty, D., Burback, C., & Saltzman, C. (2020a). *Integrative ecosystem service analysis tool.* https://ecoserve-app.com

Fogarty, D. T., Peterson, R. B., & Twidwell, D. (2022). Spatial patterns of woody plant encroachment in a temperate grassland. *Landscape Ecology*, *37*(11), 2835–2846. https://doi.org/10.1007/s10980-022-01511-y

Fogarty, D. T., Roberts, C. P., Uden, D. R., Donovan, V. M., Allen, C. R., Naugle, D. E., … Twidwell, D. (2020b). Woody Plant Encroachment and the Sustainability of Priority Conservation Areas. *Sustainability*, *12*(20), 8321. https://doi.org/10.3390/su12208321

Glick, P., Stein, B., & Edlson N. (2011). Scanning the conservation horizon: a guide to climate change vulnerability assessment. Washington D.C., USA

IPBES. (2016). The methodological assessment report on scenarios and models of biodiversity and ecosystem services. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany

Jackson, R. B., Jobbagy, E. G., Avissar, R., Baidya Roy, S., Barrett, D. J., Cook, C. W., … Murray, B. C. (2005). Trading water carbon with biological carbon sequestration. *Science, 310*(5756), 1944-1947. DOI: 10.1126/science.1119282

Jones, M. O., Naugle, D. E., Twidwell, D., Uden, D. R., Maestas, J. D., & Allred, B. W. (2020). Beyond Inventories: Emergence of a New Era in Rangeland Monitoring. *Rangeland Ecology & Management*, *73*(5), 577–583. https://doi.org/10.1016/j.rama.2020.06.009

Kamper, S. J., Maher, C. G., & Mackay G. (2013). Global rating of change scales: A review of strengths and weaknesses and considerations for design. *Journal of Manual & Manipulative Therapy, 17*(3), 163-170. https://doi.org/10.1179/jmt.2009.17.3.163

Kok, M. T. J., Kok, K., Peterson, G. D., Hill, R., Agard, J., & Carpenter, S. R. (2017). Biodiversity and ecosystem services require IPBES to take novel approach to scenarios. *Sustainable Science, 12*, 177-181. https://doi.org/10.1007/s11625-016-0354-8

Loss, S. R., Noden, B. H., & Fuhlendorf, S. D. (2022). Woody plant encroachment and the ecology of vector-borne diseases. *Journal of Applied Ecology, 59*, 420-430. https://doi.org/10.1111/1365-2664.14083

Maestas, J. D., Porter, M., Cahill, M., & Twidwell, D. (2022). Defend the core: Maintaining intact rangelands by reducing vulnerability to invasive annual grasses. *Rangelands*, *44*(3), 181–186. https://doi.org/10.1016/j.rala.2021.12.008

[MEA] Millennium Ecosystem Assessment. (2003). Ecosystems and human well-being: a framework for assessment. Island Press, Washington, DC, USA.

Moritz, M. A., Hurteau, M. D., Suding, K. N., & D'Antonio, C. M. (2013). Bounded ranges of variation as a framework for future conservation and fire management: Bounded ranges of variation. *Annals of the New York Academy of Sciences*, *1286*(1), 92–107. https://doi.org/10.1111/nyas.12104

Olimb, S. K., & Robinson, B. (2019). Grass to grain: Probabilistic modeling of agricultural conversion in the North American Great Plains. *Ecological Indicators*, *102*, 237–245. https://doi.org/10.1016/j.ecolind.2019.02.042

Oteros-Rozas, E., Martín-López, B., Daw, T. M., Bohensky, E. L., Butler, J. R. A., Hill, R., … Vilardy, S. P. (2015). Participatory scenario planning in place-based social-ecological research: Insights and experiences from 23 case studies. *Ecology and Society*, *20*(4), art32. https://doi.org/10.5751/ES-07985-200432

Peterson, G. D., Cumming, G. S., & Carpenter, S. R. (2003). Scenario Planning: A Tool for Conservation in an Uncertain World. *Conservation Biology*, *17*(2), 358–366. https://doi.org/10.1046/j.1523-1739.2003.01491.x

Petit, E., & Valiere, N. Population size with noninvasive capture-mark-recapture data. *Conservation Biology, 20*(4), 1062-1073. https://doi.org/10.1111/j.1523-1739.2006.00417.x

Proctor, J. D., & Larson, B. M. H. (2005). Ecology, Complexity, and Metaphor. *BioScience, 55*(12), 1065-1068. https://doi.org/10.1641/0006-3568(2005)055[1065:ECAM]2.0.CO;2

Ratajczak, Z., Nippert, J. B., & Collins, S. L. (2012). Woody encroachment decreases diversity across North American grasslands and savannas. *Ecology*, *93*(4), 697–703. https://doi.org/10.1890/11-1199.1

Reyers, B., Briggs, R., Cumming, G. S., Elmqvist, T., Hejnowicz, A. P., & Polasky. (2013). Getting the measure of ecosystem services: a social-ecological approach. *Frontiers in Ecology and the Environment, 11*, 268-273. https://doi.org/10.1890/120144

Roberts, C. P., Uden, D. R., Allen, C. R., & Twidwell, D. (2018). Doublethink and scale mismatch polarize policies for an invasive tree. *PLoS ONE, 13(3).* https://doi.org/10.1371/journal.pone.0189733.

Robertson, M. P., Villet, M. H., Fairbanks, D. H. K., Henderson, L., Higgins, S. I., Hoffmann, J. H., … Zimmermann, H. G. A proposed prioritization system for the management of invasive alien plants in South Africa. South African Journal of Science, 99, 37-43. http://hdl.handle.net/10204/2098

Rosenberg, K. V., Dokter, A. M., Blancher, P. J., Sauer, J. R., Smith, A. C., Smith, P. A., … Marra, P. P. (2019). Decline of the North American avifauna. *Science*, *366*(6461), 120–124. https://doi.org/10.1126/science.aaw1313

Samson, F. B., Knopf, F. L., & Ostlie, W. R. (2004). Great Plains ecosystems: Past, present, and future. *Wildlife Society Bulletin*, *32*(1), 6–15. https://doi.org/10.2193/0091-7648(2004)32[6:GPEPPA]2.0.CO;2

Samson, F. B., & Knopf, F. L. (1994). Prairie conservation in North by Fred. *BioScience*, *44*(6), 418–421.

Schneider, R., Fritz, M., Jorgensen, J., Schainost, S., Simpson, R., Steinauer, G., & Rothe-Groleau, C. (2018). *Revision of the Tier 1 and 2 Lists of Species of Greatest Conservation Need: A Supplement to the Nebraska Natural Legacy Project State Wildlife Action Plan.* The Nebraska Game and Parks Commission. https://outdoornebraska.gov/wp-content/uploads/2023/03/NE-SWAP-SGCN-Revision-Supplemental-Document-2018-Final_edited-1.pdf

Schneider, R., Stoner, K., Steinauer, G., Panella, M., & Humpert, M. (2011). *The Nebraska Natural Legacy Project: State Wildlife Action Plan.* (2nd ed.). The Nebraska Game and Parks Commission. https://outdoornebraska.gov/wp-content/uploads/2023/03/NebraskaNaturalLegacyProject2ndEdition.pdf

Suttie, J. M., Reynolds, S. G., & Batello C. (2005). *Grassalnds of the World*. Food and Agriculture Organization of the United Nations.

Twidwell, D., Fogarty, D., & Weir, J. (2021). Reducing Woody Encroachment in Grasslands. *Oklahoma Cooperative Extension Service*, *E-1054*.

Twidwell, D., Wonkka, C. L., Bielski, C. H., Allen, C. R., Angeler, D. G., Drozda, J., … Roberts, C. P. (2018). The perpetual state of emergency that sacrifices protected areas in a changing climate. Conservation Biology, 32(4), 757-973. https://doi.org/10.1111/cobi.13099

[USDA-NRCS] United States Department of Agriculture Natural Resource Conservation Service. (2021). *A framework for conservation action in the Great Plains Grasslands Biome.* Working Lands for Wildlife, USDA-NRCS. https://wlfw.rangelands.app

[USDA-NRCS] United States Department of Agriculture Natural Resource Conservation Service. (n.d.). *Nebraska Great Plains Grassland Initiative*. https://www.nrcs.usda.gov/conservation-basics/conservation-by-state/nebraska/nebraska-great-plains-grassland-initiative

Vallury, S., Smith, A. P., Chaffin, B. C., Nesbitt, H. K., Lohani, S., Gulab, S., … Allen, C. R. (2022). Adaptive capacity beyond the household: a systematic review of empirical social-ecological research. Environmental Research Letters, 17(6). https://doi.org/10.1088/1748-9326/ac68fb

Wilson, M. C., Chen, X., Corlett, R. T., Didham, R. K., Ding, P., Holt, R. D., … Yu, M. (2016). Habitat fragmentation and biodiversity conservation: key findings and future challenges. *Landscape Ecology 31*, 219-227. https://doi.org/10.1007/s10980-015-0312-3

Wu, J. (2013). Key concepts and research topics in landscape ecology revisited: 30 years after the Allerton Park workshop. *Landscape Ecology 28*, 1-11. https://doi.org/10.1007/s10980-012-9836-y

Zou, C., Twidwell, D., Bielski, C., Fogarty, D. T., Mittelstet, A. R., Starks, P. J., … Acharya, B. S. (2018). Impact of eastern redcedar proliferation on water resources in the Great Plains USA - current state of knowledge. Water, 10(12), 1768. https://doi.org/10.3390/w10121768

FIGURES

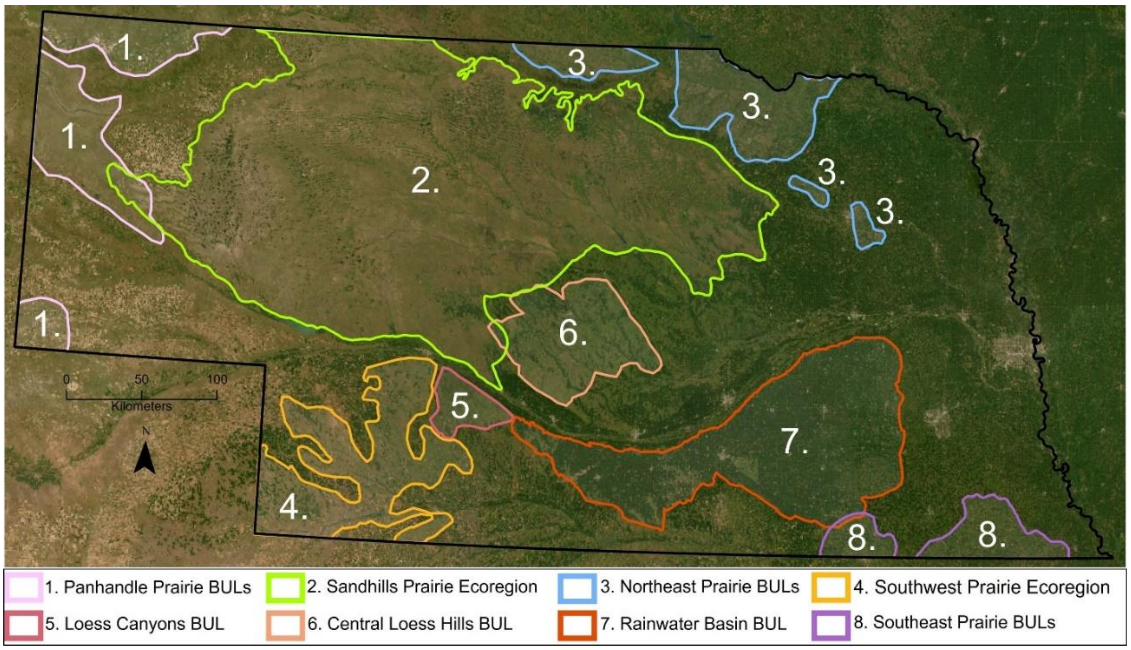


Figure 2.1 Map showing the eight study ecoregions across Nebraska. Study ecoregions were created using terrestrial BULs that contained grasslands from Nebraska's Natural Legacy Project (Fogarty et al., 2020b; Schneider et al., 2011) and regions from the Great Plains Grassland Initiative (USDA-NRCS, n.d.). BULs were grouped if they were in close proximity and contained similar ecological characteristics. See table 2.1 ecoregion discriptions.

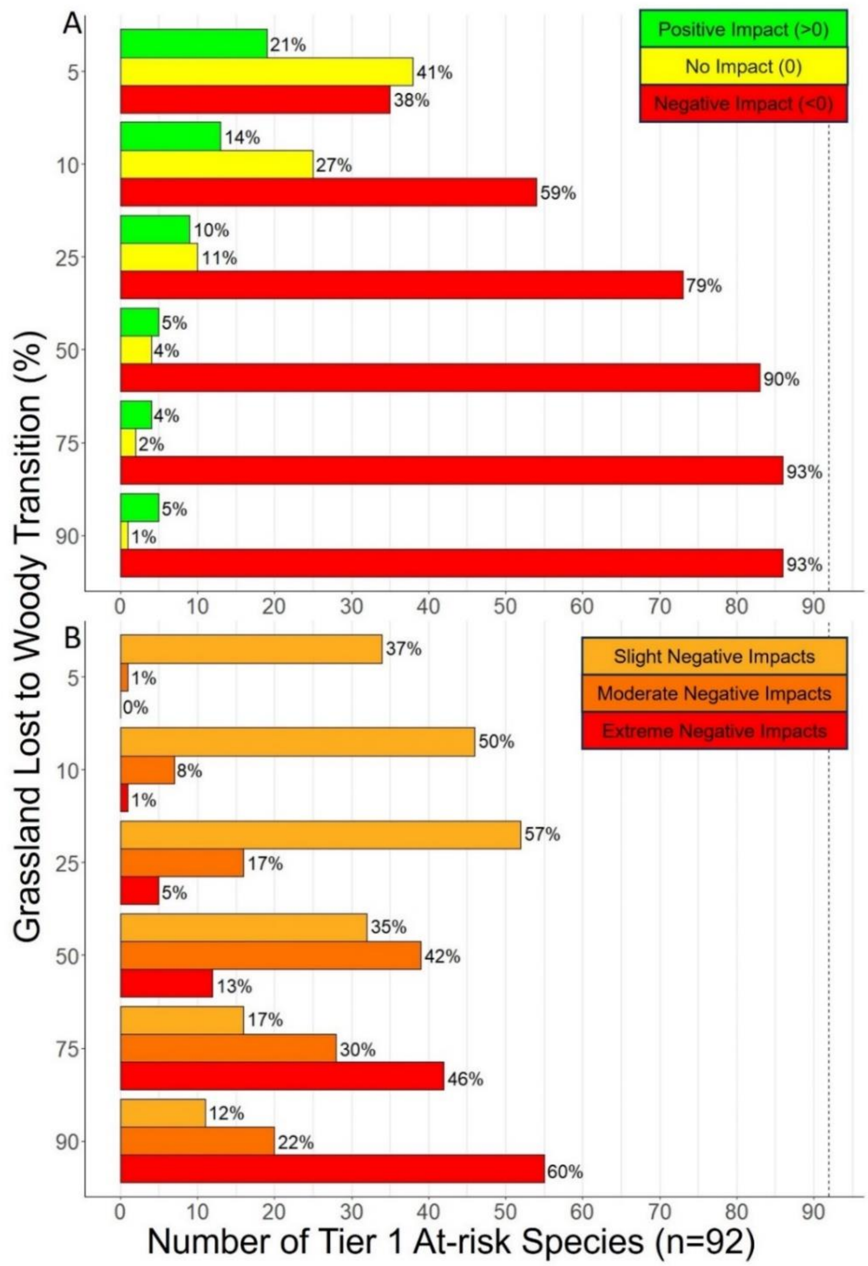


Figure 2.2 **A.** Summary of the estimated positive impact, negative impact, and no impact to Tier 1 at-risk species across each scenario of grassland lost to woody transition. **B.** Summary of the degree of negative impacts (slight, moderate, extreme) to Tier 1 at-risk species across each scenario of grassland lost to woody transition. See table 2.2 for a description of the scenarios. See table 2.3 for a description of impact.

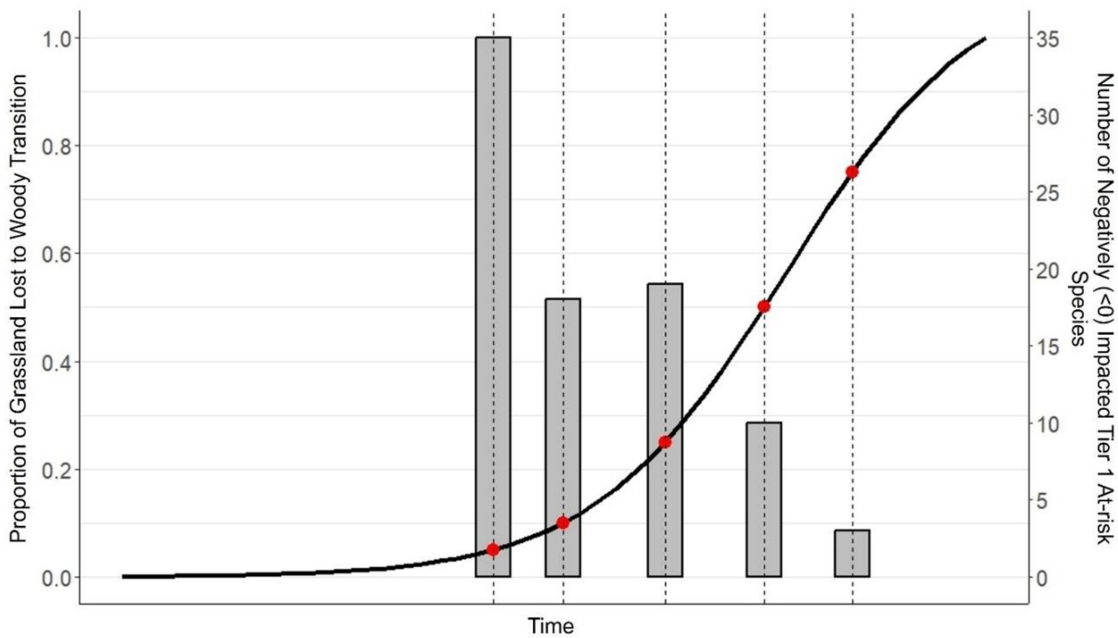


Figure 2.3 Conceptually shows when Tier 1 at-risk species become negatively impacted and how many become negatively impacted at each point of grassland lost to woody transition. The left Y-axis shows the values for the curve which signifies the rate of woody invasion into grasslands (Robert et al., 2018). The red dot along the curve shows the point at which Tier 1 at-risk species were expected to become negatively impacted. The right Y-axis shows the values for the bar graph which signifies the number of Tier 1 at-risk species that were expected to become negatively impacted at each point.

Figure 2.4 Summary of the estimated positive impacts, negative impact, and no impact to Tier 1 at-risk species taxonomic groups across each scenario of grassland lost to woody transition. Shows differing sensitivities between Tier 1 at-risk taxa. See tables 2.5 – 2.10 to see which Tier 1 species were included in each taxonomic group. See table 2.2 for a description of scenarios. See table 2.3 for a description of impacts.

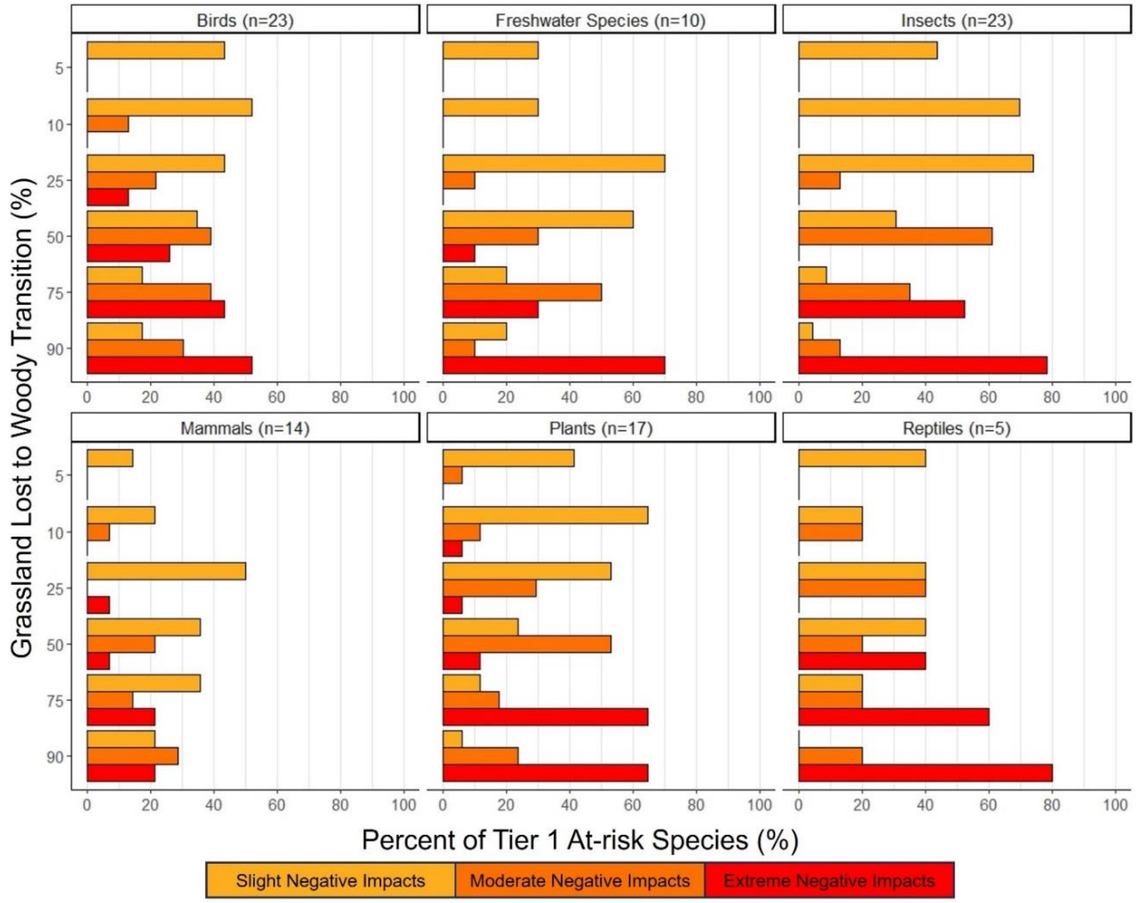


Figure 2.5 Summary of the estimated degree of negative impact (slight, moderate, extreme) on Tier 1 at-risk species taxonomic groups across each scenario of grassland lost to woody transition. Shows differing sensitivities between Tier 1 at-risk taxa. See tables 2.5 – 2.10 to see which species were included in each taxonomic group. See table 2.2 for a description of scenarios. See table 2.3 for a description of impacts.

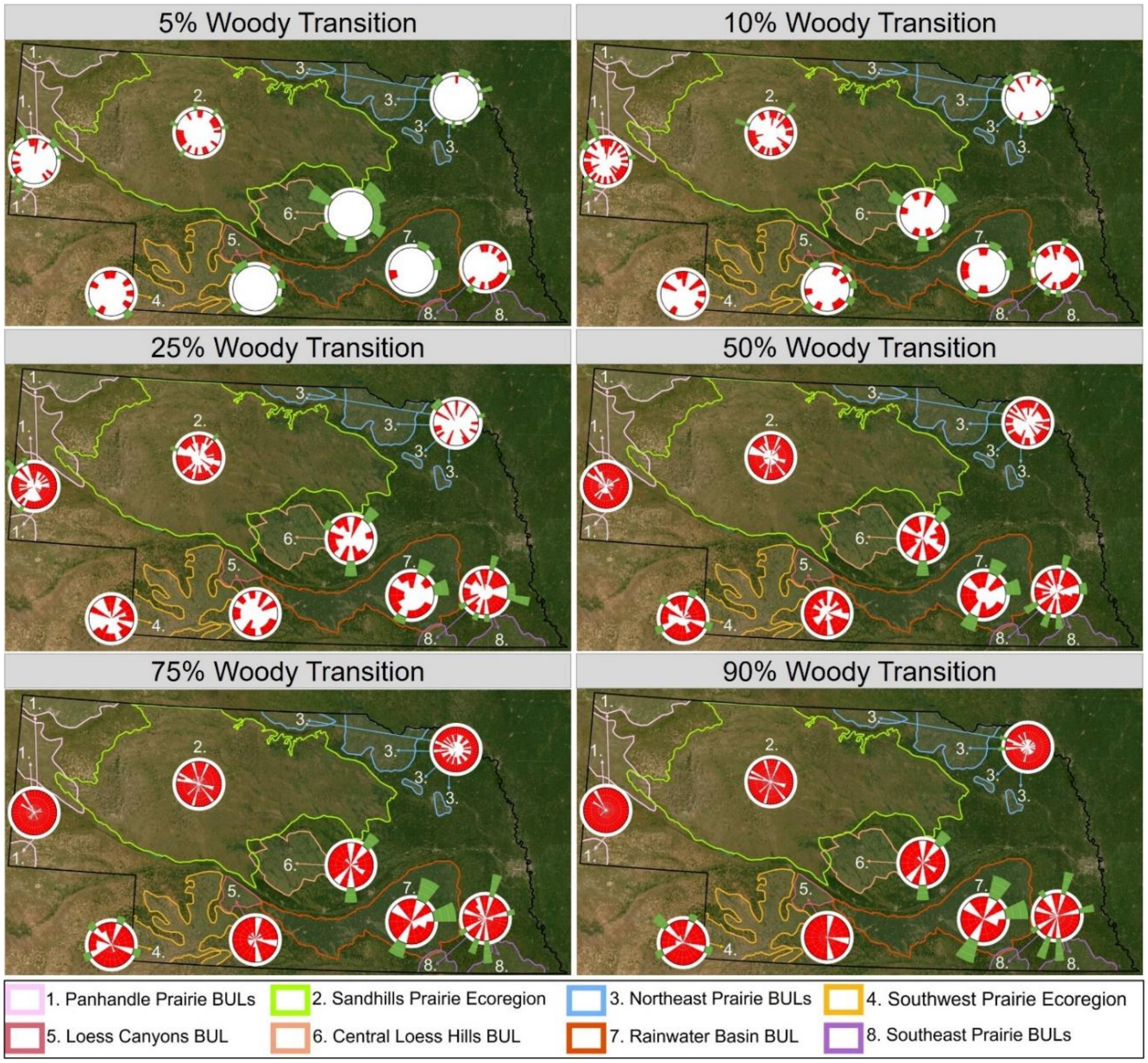


Figure 2.6 Data visualization showing regional estimated impact on Tier 1 at-risk species for six scenarios of grassland lost to woody transition. Each panel represents a scenario of grassland lost to woody transition, and each flower diagram shows the estimated impact to each Tier 1 at-risk species associated with each ecoregion. Green petals projected outward reflect positive impacts, while red petals projected inward reflect negative impacts. The length of each petal reflects the degree of the impact, where longer petals represent more extreme impacts. See table 2.3 for a description of impacts.

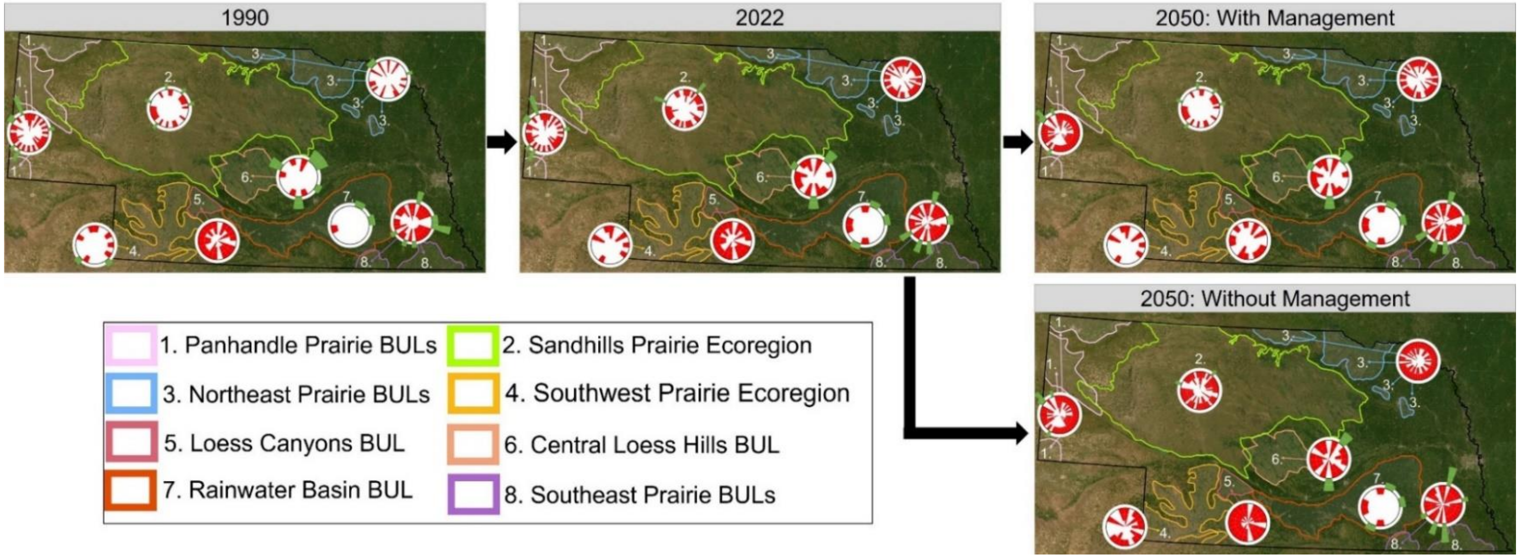


Figure 2.7 Data visualization showing the estimated impact to Tier 1 at-risk species for each ecoregion within each timeframe. The panels represent past (1990), present (2022), and future (2050) timeframes. The 2050 timeframe has two alternative conditions: (1) with continued woody encroachment management, and (2) without continued woody encroachment management. The flower diagrams represent the regional Tier 1 species impact estimation for the nearest scenario to the timeframe prediction of grassland lost to woody transition. Green petals projected outward reflect positive impacts, while red petals projected inward reflect negative impacts. The length of each petal reflects the degree of the impact, where longer petals represent more extreme impacts. See table 2.3 for a description of impacts.

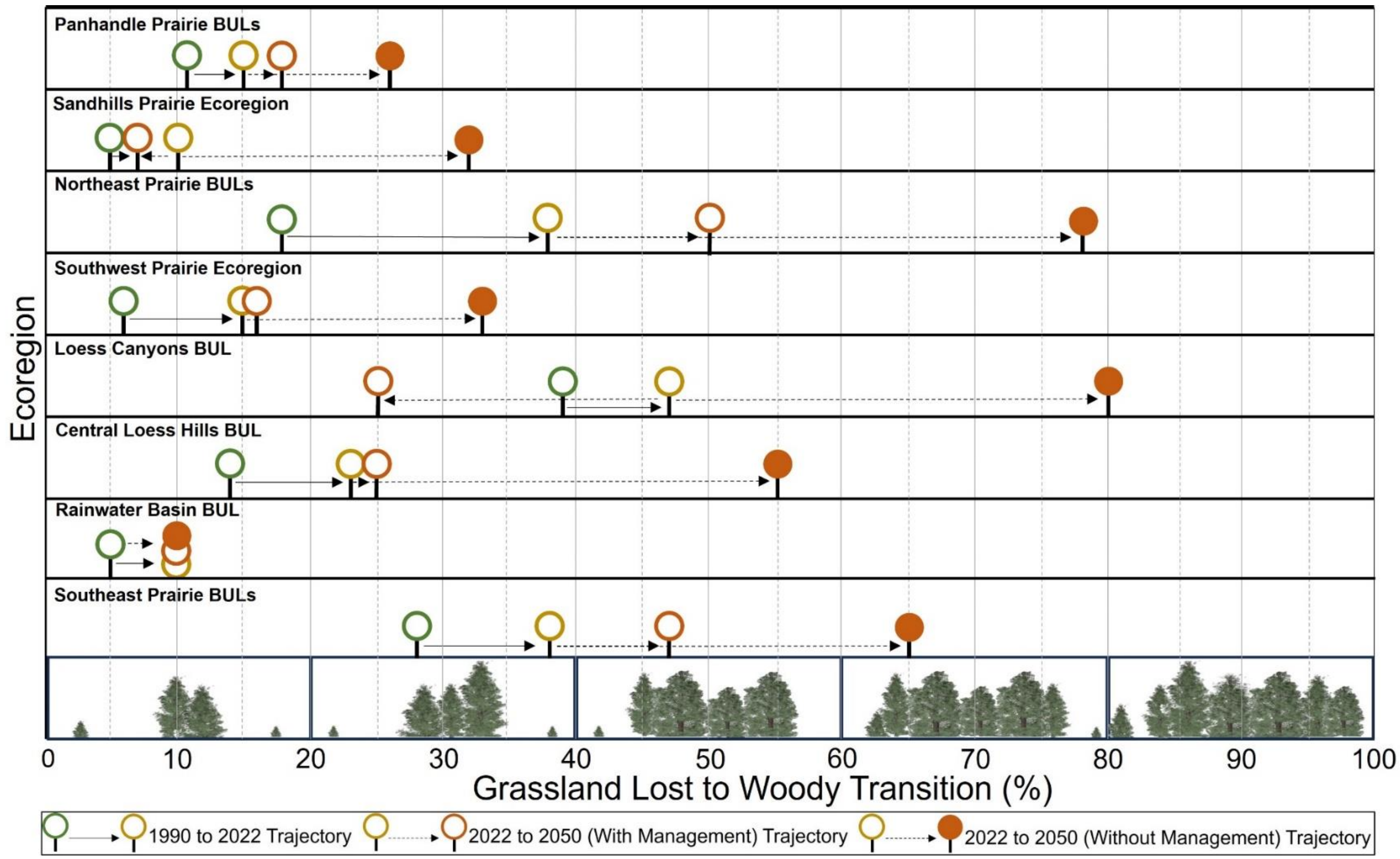


Figure 2.8 The estimated percent of grassland lost to woody transition within each ecoregion for 1990, 2022, 2050 with continued management, and 2050 without continued management. The solid arrow represents trajectory from 1990 to 2022, while the dashed arrow represents the trajectory between 2022 and the two alternative futures.

Ecoregion	BUL	GPGI Region	Ecoregion(s) Orgin Name
1. Panhandle Pairie BULs	X		Ogallala Grasslands, Panhandle Grasslands, and Kimball Grasslands
2. Sandhills Prairie Ecoregion		X	Sandhills
3. Northeast Prairie BULs	X	X	BULs: Verdigris Bazile, Keya Paha, Elkhorn Confluence, and Willow Creek Prairies; GPGI: Verdigris-Bazile Mod
4. Southwest Prairie Ecoregion		X	Southwestern Mixed Grass Prairies
5. Loess Canyons BUL	X	X	Loess Canyons
6. Central Loess Hills BUL	X		Central Loess Hills
7. Rainwater Basin BUL	X		Rainwater Basin
8. Southeast Prairie BULs	X		Sandstone Prairies, and Southeast Prairies

TABLES

Table 2.1 Description of the six study ecoregions used in this study. Shows weather it was created using BULs from Nebraska's Natural Legacy Project (Schneider et al., 2011), regions from Nebraska's Great Plains Grassland Initiative (USDA-NRCS, n.d.), or a hybrid of the two (Northeast Prairie BULs). Shows which ecoregions from the two different sources were used.

Scenarios: Grassland Lost to Woody Transition						
Scenario	WT: 5%	WT: 10%	WT: 25%	WT: 50%	WT: 75%	WT: 90%
Woodland (%)	5	10	25	50	75	90
Grassland (%)	95	90	75	50	25	10

Table 2.2 Description of difference between each scenario of grassland lost to woody transition, outlining the percent of each ecoregion's rangeland that is woodland and grassland. Each scenario is relative to the assumption that 100% of the ecoregion's rangeland was originally grassland.

7-Point Global Rating of Change: Impact Scale			
Rating Number	**Rating Range**	**Impact**	**Description**
3	> 2.5	Extremely Positive	An extreme increase in the populations of Tier 1 at-risk species, reaching or surpassing historical estimates, resulting in their removal from the at-risk listing.
2	≤ 2.5 to >1.5	Moderately Positive	A moderate increase in the populations of Tier 1 at-risk species, nearing historical estimates, resulting in their removal from the at-risk listing.
1	≤ 1.5 to >0.5	Slightly Positive	A slight positive increase in the populations of Tier 1 at-risk species, which leads to lowering the concern for the species, moving them to the tier 2 at-risk species list.
0	≤0.5 to >-0.5	No Impact	Tier 1 at-risk species stay at their current predicted status.
-1	≤-0.5 to >-1.5	Slightly Negative	A slight negative impact in the tier 1 species populations, creating elevated concern for already at-risk species.
-2	≤-1.5 to >-2.5	Moderately Negative	A moderate negative impact in tier 1 species populations, creating high concern for already at-risk species.
-3	<-2.5	Extremely Negative	An extreme negative impact in tier 1 species populations, nearing or reaching local extirpation.

Table 2.3 Description of each point in the 7-point Global Rating of Change impact scale. Shows the rating number and the rating range used for analysis summarizing Tier 1 at risk species impact means (figures 2.2 – 2.6).

Nebraska Tier 1 At-risk Species				Grassland Lost to Woody Transition					
Common Name	**Scientific Name**	**2011**	**2018**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**
C. Butterfly Plant	*Gaura neomexicana coloradensis*	X	X	-2.0	-3.0	-3.0	-3.0	-3.0	-3.0
C-collared Longspur	*Calcarius ornatus*	X	X	-1.0	-2.0	-3.0	-3.0	-3.0	-3.0
McCown's Longspur	*Rhynchophanes mccownii*	X	X	-1.0	-2.0	-3.0	-3.0	-3.0	-3.0
Mountain Plover	*Charadrius montanus*	X	X	-1.0	-2.0	-3.0	-3.0	-3.0	-3.0
Swift Fox	*Vulpes velox*	X	X	-1.0	-2.0	-3.0	-3.0	-3.0	-3.0
Dog-parsley	*Lomatium nuttallii*	X	X	-1.0	-2.0	-2.0	-3.0	-3.0	-3.0
Timber Rattlesnake	*Crotalus horridus*	X	X	-1.0	-2.0	-2.0	-3.0	-3.0	-3.0
Barr's Milkvetch	*Astragalus barrii*	X	X	-1.0	-2.0	-2.0	-2.0	-3.0	-3.0
Ghost Tiger Beetle	*Cicindela lepida*	X	X	-1.0	-1.5	-2.5	-2.5	-3.0	-3.0
Massasauga	*Sistrurus tergeminus*	X	X	-1.0	-1.0	-2.0	-3.0	-3.0	-3.0
Pistolgrip	*Tritogonia verrucosa*	X	X	-1.0	-1.0	-2.0	-3.0	-3.0	-3.0
Mottled Duskywing	*Erynnis martialis*	X	X	-1.0	-1.0	-2.0	-2.0	-3.0	-3.0
S. Plains Bumble Bee	*Bombus fraternus*		X	-1.0	-1.0	-2.0	-2.0	-3.0	-3.0
Sandhill Goosefoot	*Chenopodium cycloides*	X	X	-1.0	-1.0	-2.0	-2.0	-3.0	-3.0
Whooping Crane	*Grus americana*	X	X	-0.6	-0.8	-1.6	-2.2	-2.6	-2.8
GRPC	*Tympanuchus cupido*	X		-0.5	-1.5	-2.5	-2.8	-2.8	-3.0
Long-billed Curlew	*Numenius americanus*	X	X	-0.5	-1.5	-2.0	-3.0	-3.0	-3.0
L-S Prairie-clover	*Dalea cylindriceps*	X	X	-0.5	-1.0	-1.5	-2.0	-3.0	-3.0
Piping Plover	*Charadrius melodus*	X	X	-0.5	-1.0	-1.5	-2.0	-2.0	-2.5
Nebraska Fritillary	*Boloria selene nebraskensis*		X	-0.5	-0.5	-1.5	-2.0	-2.5	-3.0
W. P. Fringed Orchid	*Platanthera praeclara*	X	X	-0.5	-0.5	-1.5	-1.5	-2.5	-2.5
Wolf Spikerush	*Eleocharis wolfii*	X	X	-0.5	-0.5	-1.5	-1.5	-2.5	-2.5
Iowa Skipper	*Atrytone arogos iowa*	X	X	-0.5	-0.5	-1.0	-1.5	-2.5	-3.0
Ottoe Skipper	*Hesperia ottoe*	X	X	-0.5	-0.5	-1.0	-1.5	-2.5	-3.0
Two-spotted Skipper	*Euphyes bimacula illinois*		X	-0.5	-0.5	-1.0	-1.5	-2.5	-3.0

Bucholz Black Dash	*Euphyes conspicua bucholzi*	X	X	-0.5	-0.5	-1.0	-1.5	-2.5	-2.5
Burrowing Owl	*Athene cunicularia*	X	X	-0.4	-1.1	-2.0	-2.1	-2.9	-2.9
Plains Harvest Mouse	*Reithrodontomys montanus griseus*	X		-0.3	-0.7	-1.3	-1.7	-2.3	-2.3
Plain Pocketbook	*Lampsilis cardium*	X	X	-0.3	-0.7	-1.0	-2.0	-2.3	-2.7
Pimpleback	*Quadrula pustulosa*	X	X	-0.3	-0.3	-1.3	-2.0	-2.7	-3.0
ABB	*Nicrophorus americanus*	X	X	-0.3	-0.3	-1.0	-1.7	-2.7	-3.0
Henslow's Sparrow	*Ammodramus henslowii*	X	X	-0.3	-0.3	-1.0	-1.7	-2.7	-3.0
Regal Fritillary	*Speyeria idalia*	X	X	-0.3	-0.4	-1.1	-1.9	-2.8	-3.0
Married Underwing	*Catocala nuptialis*	X	X	-0.2	-0.6	-1.2	-1.6	-2.6	-2.8
Sprague's Pipit	*Anthus spragueii*	X	X	-0.1	-0.5	-1.3	-2.0	-2.5	-2.9
G. Wild Buckwheat	*Eriogonum gordonii*	X	X	0.0	-1.0	-2.0	-2.0	-3.0	-3.0
Matted Prickly-phlox	*Linanthus caespitosus*	X	X	0.0	-1.0	-2.0	-2.0	-3.0	-3.0
C. N. Pocket Gopher	*Thomomys talpoides cheyennensis*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
Hall's Bulrush	*Schoenoplectus hallii*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
Kohler's Fritillary	*Boloria selene sabulocollis*		X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
P. N. Pocket Gopher	*Thomomys talpoides pierreicolus*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
R.M. Bulrush	*Schoenoplectus saximontanus*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
S. Cuckoo Bumble Bee	*Bombus suckleyi*		X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
S. W. Lady's-slipper	*Cypripedium candidum*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
Short's Milkvetch	*Astragalus shortianus*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
Western Bumblebee	*Bombus occidentalis ccidentalis*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
Short-eared Owl	*Asio flammeus*	X	X	0.0	-0.8	-1.8	-2.8	-3.0	-3.0
B-b Sandpiper	*Tryngites subruficollis*	X	X	0.0	-0.5	-1.0	-1.5	-2.0	-2.0
Smoky-eyed Brown	*Lethe 75imbate75 fumosa*		X	0.0	-0.5	-0.5	-1.0	-2.0	-2.0
Black Tern	*Chlidonias niger*		X	0.0	-0.4	-1.0	-1.6	-1.7	-1.9
Whitney Underwing	*Catocala whitneyi*	X	X	0.0	-0.4	-1.2	-1.6	-2.4	-2.8
Monarch	*Danaus plexippus*		X	0.0	-0.4	-0.8	-1.4	-2.4	-3.0

Baird's Sparrow	*Ammodramus bairdii*	X	X	0.0	-0.3	-0.9	-1.6	-1.9	-2.1
9-s Ladybird Beetle	*Cuccinelli novemnotata*	X	X	0.0	0.0	-1.0	-2.0	-3.0	-3.0
C. Rita Dotted-blue	*Euphilotes rita coloradensis*	X	X	0.0	0.0	-1.0	-2.0	-3.0	-3.0
Glossy Snake	*Arizona elegans*		X	0.0	0.0	-1.0	-2.0	-3.0	-3.0
Plains Pocket Mouse	*Perognathus flavescens perniger*	X	X	0.0	0.0	-1.0	-1.0	-2.0	-2.0
Sandy Tiger Beetle	*Cicindela 76imbate limbata*		X	0.0	0.0	-1.0	-1.0	-2.0	-2.0
Blacknose Shiner	*Notropis heterolepis*	X	X	0.0	0.0	-0.5	-1.5	-2.5	-2.5
Blanding's Turtle	*Emydoidea blandingii*	X	X	0.0	0.0	-0.5	-1.0	-1.5	-2.0
Blowout Penstemon	*Penstemon haydenii*	X	X	0.0	0.0	-0.5	-0.5	-1.5	-1.5
Wood Thrush	*Hylocichla mustelina*	X	X	0.0	0.0	-0.3	-0.3	-0.7	-0.3
Two-lined Stonefly	*Perlesta golconda*		X	0.0	0.0	0.0	-1.0	-1.0	-2.0
Ornate Fairy Shrimp	*Eubranchipus ornatus*		X	0.0	0.0	0.0	-1.0	-1.0	-1.0
P-l Fairy Shrimp	*Branchinecta potassa*		X	0.0	0.0	0.0	-1.0	-1.0	-1.0
Interior Least Tern	*Sternula antillarum athalassos*	X	X	0.0	0.0	0.0	-0.5	-0.5	-1.0
Prairie Moonwort	*Botrychium campestre*	X	X	0.0	0.0	0.0	0.0	-1.0	-2.0
Lakota Mayfly	*Apobaetis lakota*		X	0.0	0.0	0.0	0.0	-1.0	-1.0
Fox Mayfly	*Cercobrachys fox*		X	0.0	0.0	0.0	0.0	0.0	0.0
B. Eastern Woodrat	*Neotoma floridana baileyi*	X	X	0.0	0.0	0.0	0.0	0.0	1.0
Missouri Sedge	*Carex missouriensis*	X	X	0.0	0.0	0.5	0.5	0.5	1.0
Plains Spotted Skunk	*Spilogale putorius interrupta*		X	0.0	0.5	0.5	1.0	1.5	1.5
Byssus Skipper	*Problema byssus kumskaka*		X	0.0	1.0	-1.0	-2.0	-3.0	-3.0
Plains Topminnow	*Fundulus sciadicus*	X	X	0.3	0.0	-0.8	-1.5	-2.5	-2.8
Black-billed Magpie	*Pica hudsonia*		X	0.3	0.5	0.5	-0.5	-1.3	-1.3
Ferruginous Hawk	*Buteo regalis*	X	X	0.5	-0.5	-1.5	-2.5	-3.0	-3.0
E. Little Brown Bat	*Myotis lucifugus lucifugus*		X	0.5	0.0	-0.5	-1.0	-1.5	-2.0
Trumpeter Swan	*Cygnus buccinator*	X		0.5	0.0	0.0	-0.5	-0.5	-0.5
Eastern Red Bat	*Lasiurus borealis*		X	0.5	0.3	-0.1	-0.4	-0.4	-0.4

Brewer's Sparrow	*Spizella breweri*	X	X	0.5	1.0	-0.5	-1.5	-2.5	-3.0
Tricolored Bat	*Perimyotis subflavus*		X	0.5	1.0	0.5	0.5	-0.5	-0.5
Silver-haired Bat	*Lasionycteris noctivagans*		X	0.6	0.9	0.5	0.5	0.1	0.3
N. Redbelly Dace	*Chrosomus eos*	X	X	0.7	0.0	-0.7	-1.0	-2.0	-2.7
Finescale Dace	*Chrosomus neogaeus*	X	X	0.7	0.0	-0.7	-1.0	-1.7	-2.7
Northern River Otter	*Lontra canadensis*	X		0.7	0.0	-0.3	-0.7	-1.3	-1.3
Hoary Bat	*Lasiurus cinereus*		X	0.8	0.9	0.6	0.4	0.5	0.1
Loggerhead Shrike	*Lanius ludovicianus*	X	X	0.9	0.8	-0.5	-1.6	-2.3	-2.4
Topeka Shiner	*Notropis topeka*	X	X	1.0	0.0	-1.0	-2.0	-3.0	-3.0
Bell's Vireo	*Vireo bellii*	X		1.0	0.7	0.0	-0.8	-2.0	-2.3
Black-billed Cuckoo	*Coccyzus erythropthalmus*		X	1.0	1.0	0.5	-1.0	-2.0	-2.5
N. Long-eared Bat	*Myotis septentrionalis*		X	1.0	1.5	1.5	-1.0	-1.5	-2.5
Sagebrush Lizard	*Sceloporus graciosus*	X	X	2.0	2.0	1.0	-1.0	-2.0	-3.0

Table 2.4 Mean estimated impact on Tier 1 at-risk species across each scenario of grassland lost to woody transition. Green font indicates positive impact, red font indicates negative impact.

Nebraska Tier 1 At-risk Birds				Grassland Lost to Woody Transition					
Common Name	**Scientific Name**	**2011**	**2018**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**
C-collared Longspur	*Calcarius ornatus*	X	X	-1.0	-2.0	-3.0	-3.0	-3.0	-3.0
McCown's Longspur	*Rhynchophanes mccownii*	X	X	-1.0	-2.0	-3.0	-3.0	-3.0	-3.0
Mountain Plover	*Charadrius montanus*	X	X	-1.0	-2.0	-3.0	-3.0	-3.0	-3.0
Whooping Crane	*Grus americana*	X	X	-0.6	-0.8	-1.6	-2.2	-2.6	-2.8
GRPC	*Tympanuchus cupido*	X		-0.5	-1.5	-2.5	-2.8	-2.8	-3.0
Long-billed Curlew	*Numenius americanus*	X	X	-0.5	-1.5	-2.0	-3.0	-3.0	-3.0
Piping Plover	*Charadrius melodus*	X	X	-0.5	-1.0	-1.5	-2.0	-2.0	-2.5
Burrowing Owl	*Athene cunicularia*	X	X	-0.4	-1.1	-2.0	-2.1	-2.9	-2.9
Henslow's Sparrow	*Ammodramus henslowii*	X	X	-0.3	-0.3	-1.0	-1.7	-2.7	-3.0
Sprague's Pipit	*Anthus spragueii*	X	X	-0.1	-0.5	-1.3	-2.0	-2.5	-2.9
Short-eared Owl	*Asio flammeus*	X	X	0.0	-0.8	-1.8	-2.8	-3.0	-3.0
B-b Sandpiper	*Tryngites subruficollis*	X	X	0.0	-0.5	-1.0	-1.5	-2.0	-2.0
Black Tern	*Chlidonias niger*		X	0.0	-0.4	-1.0	-1.6	-1.7	-1.9
Baird's Sparrow	*Ammodramus bairdii*	X	X	0.0	-0.3	-0.9	-1.6	-1.9	-2.1
Wood Thrush	*Hylocichla mustelina*	X	X	0.0	0.0	-0.3	-0.3	-0.7	-0.3
Interior Least Tern	*Sternula antillarum athalassos*	X	X	0.0	0.0	0.0	-0.5	-0.5	-1.0
Black-billed Magpie	*Pica hudsonia*		X	0.3	0.5	0.5	-0.5	-1.3	-1.3
Ferruginous Hawk	*Buteo regalis*	X	X	0.5	-0.5	-1.5	-2.5	-3.0	-3.0
Trumpeter Swan	*Cygnus buccinator*	X		0.5	0.0	0.0	-0.5	-0.5	-0.5
Brewer's Sparrow	*Spizella breweri*	X	X	0.5	1.0	-0.5	-1.5	-2.5	-3.0
Loggerhead Shrike	*Lanius ludovicianus*	X	X	0.9	0.8	-0.5	-1.6	-2.3	-2.4
Bell's Vireo	*Vireo bellii*	X		1.0	0.7	0.0	-0.8	-2.0	-2.3
Black-billed Cuckoo	*Coccyzus erythropthalmus*		X	1.0	1.0	0.5	-1.0	-2.0	-2.5

Table 2.5 Mean estimated impact on Tier 1 at-risk birds across each scenario of grassland lost to woody transition.

Nebraska Tier 1 At-risk Freshwater Species					Grassland Lost to Woody Transition					
Common Name	**Scientific Name**	**Taxa Group**	**2011**	**2018**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**
Pistolgrip	*Tritogonia verrucosa*	*Mollusks*	X	X	-1.0	-1.0	-2.0	-3.0	-3.0	-3.0
Plain Pocketbook	*Lampsilis cardium*	*Mollusks*	X	X	-0.3	-0.7	-1.0	-2.0	-2.3	-2.7
Pimpleback	*Quadrula pustulosa*	*Mollusks*	X	X	-0.3	-0.3	-1.3	-2.0	-2.7	-3.0
Blacknose Shiner	*Notropis heterolepis*	*Fish*	X	X	0.0	0.0	-0.5	-1.5	-2.5	-2.5
Ornate Fairy Shrimp	*Eubranchipus ornatus*	*Crustaceans*		X	0.0	0.0	0.0	-1.0	-1.0	-1.0
P-l Fairy Shrimp	*Branchinecta potassa*	*Crustaceans*		X	0.0	0.0	0.0	-1.0	-1.0	-1.0
Plains Topminnow	*Fundulus sciadicus*	*Fish*	X	X	0.3	0.0	-0.8	-1.5	-2.5	-2.8
N. Redbelly Dace	*Chrosomus eos*	*Fish*	X	X	0.7	0.0	-0.7	-1.0	-2.0	-2.7
Finescale Dace	*Chrosomus neogaeus*	*Fish*	X	X	0.7	0.0	-0.7	-1.0	-1.7	-2.7
Topeka Shiner	*Notropis topeka*	*Fish*	X	X	1.0	0.0	-1.0	-2.0	-3.0	-3.0

Table 2.6 Mean estimated impact on Tier 1 at-risk freshwater species across each scenario of grassland lost to woody transition.

Nebraska Tier 1 At-risk Insects				Grassland Lost to Woody Transition					
Common Name	**Scientific Name**	**2011**	**2018**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**
Ghost Tiger Beetle	*Cicindela lepida*	X	X	-1.0	-1.5	-2.5	-2.5	-3.0	-3.0
Mottled Duskywing	*Erynnis martialis*	X	X	-1.0	-1.0	-2.0	-2.0	-3.0	-3.0
S. Plains Bumble Bee	*Bombus fraternus*		X	-1.0	-1.0	-2.0	-2.0	-3.0	-3.0
Nebraska Fritillary	*Boloria selene nebraskensis*		X	-0.5	-0.5	-1.5	-2.0	-2.5	-3.0
Iowa Skipper	*Atrytone arogos iowa*	X	X	-0.5	-0.5	-1.0	-1.5	-2.5	-3.0
Ottoe Skipper	*Hesperia ottoe*	X	X	-0.5	-0.5	-1.0	-1.5	-2.5	-3.0
Two-spotted Skipper	*Euphyes bimacula illinois*		X	-0.5	-0.5	-1.0	-1.5	-2.5	-3.0
ABB	*Nicrophorus americanus*	X	X	-0.3	-0.3	-1.0	-1.7	-2.7	-3.0
Regal Fritillary	*Speyeria idalia*	X	X	-0.3	-0.4	-1.1	-1.9	-2.8	-3.0
Married Underwing	*Catocala nuptialis*	X	X	-0.2	-0.6	-1.2	-1.6	-2.6	-2.8
Kohler's Fritillary	*Boloria selene sabulocollis*		X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
S. Cuckoo Bumble Bee	*Bombus suckleyi*		X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
Western Bumblebee	*Bombus occidentalis ccidentalis*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
Smoky-eyed Brown	*Lethe 80imbate80 fumosa*		X	0.0	-0.5	-0.5	-1.0	-2.0	-2.0
Whitney Underwing	*Catocala whitneyi*	X	X	0.0	-0.4	-1.2	-1.6	-2.4	-2.8
Monarch	*Danaus plexippus*		X	0.0	-0.4	-0.8	-1.4	-2.4	-3.0
9-s Ladybird Beetle	*Coccinella novemnotata*	X	X	0.0	0.0	-1.0	-2.0	-3.0	-3.0
C. Rita Dotted-blue	*Euphilotes rita coloradensis*	X	X	0.0	0.0	-1.0	-2.0	-3.0	-3.0
Sandy Tiger Beetle	*Cicindela 80imbate limbata*		X	0.0	0.0	-1.0	-1.0	-2.0	-2.0
Two-lined Stonefly	*Perlesta golconda*		X	0.0	0.0	0.0	-1.0	-1.0	-2.0
Lakota Mayfly	*Apobaetis lakota*		X	0.0	0.0	0.0	0.0	-1.0	-1.0
Fox Mayfly	*Cercobrachys fox*		X	0.0	0.0	0.0	0.0	0.0	0.0
Byssus Skipper	*Problema byssus kumskaka*		X	0.0	1.0	-1.0	-2.0	-3.0	-3.0

Table 2.7 Mean estimated impact on Tier 1 at-risk insects across each scenario of grassland lost to woody transition.

Nebraska Tier 1 At-risk Mammals				Grassland Lost to Woody Transition					
Common Name	**Scientific Name**	**2011**	**2018**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**
Swift Fox	*Vulpes velox*	X	X	-1.0	-2.0	-3.0	-3.0	-3.0	-3.0
Plains Harvest Mouse	*Reithrodontomys montanus griseus*	X		-0.3	-0.7	-1.3	-1.7	-2.3	-2.3
C. N. Pocket Gopher	*Thomomys talpoides cheyennensis*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
P. N. Pocket Gopher	*Thomomys talpoides pierreicolus*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
Plains Pocket Mouse	*Perognathus flavescens perniger*	X	X	0.0	0.0	-1.0	-1.0	-2.0	-2.0
B. Eastern Woodrat	*Neotoma floridana baileyi*	X	X	0.0	0.0	0.0	0.0	0.0	1.0
Plains Spotted Skunk	*Spilogale putorius interrupta*		X	0.0	0.5	0.5	1.0	1.5	1.5
E. Little Brown Bat	*Myotis lucifugus lucifugus*		X	0.5	0.0	-0.5	-1.0	-1.5	-2.0
Eastern Red Bat	*Lasiurus borealis*		X	0.5	0.3	-0.1	-0.4	-0.4	-0.4
Tricolored Bat	*Perimyotis subflavus*		X	0.5	1.0	0.5	0.5	-0.5	-0.5
Silver-haired Bat	*Lasionycteris noctivagans*		X	0.6	0.9	0.5	0.5	0.1	0.3
Northern River Otter	*Lontra canadensis*	X		0.7	0.0	-0.3	-0.7	-1.3	-1.3
Hoary Bat	*Lasiurus cinereus*		X	0.8	0.9	0.6	0.4	0.5	0.1
N. Long-eared Bat	*Myotis septentrionalis*		X	1.0	1.5	1.5	-1.0	-1.5	-2.5

Table 2.8 Mean estimated impact on Tier 1 at-risk mammals across each scenario of grassland lost to woody transition.

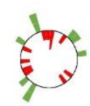
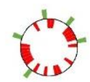
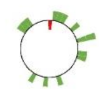
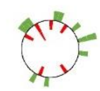
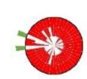
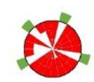
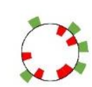
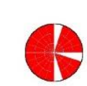
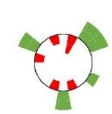
Nebraska Tier 1 At-risk Plants		Grassland Lost to Woody Transition							
Common Name	**Scientific Name**	**2011**	**2018**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**
C. Butterfly Plant	*Gaura neomexicana coloradensis*	X	X	-2.0	-3.0	-3.0	-3.0	-3.0	-3.0
Dog-parsley	*Lomatium nuttallii*	X	X	-1.0	-2.0	-2.0	-3.0	-3.0	-3.0
Barr's Milkvetch	*Astragalus barrii*	X	X	-1.0	-2.0	-2.0	-2.0	-3.0	-3.0
Sandhill Goosefoot	*Chenopodium cycloides*	X	X	-1.0	-1.0	-2.0	-2.0	-3.0	-3.0
L-S Prairie-clover	*Dalea cylindriceps*	X	X	-0.5	-1.0	-1.5	-2.0	-3.0	-3.0
W. P. Fringed Orchid	*Platanthera praeclara*	X	X	-0.5	-0.5	-1.5	-1.5	-2.5	-2.5
Wolf Spikerush	*Eleocharis wolfii*	X	X	-0.5	-0.5	-1.5	-1.5	-2.5	-2.5
Bucholz Black Dash	*Euphyes conspicua bucholzi*	X	X	-0.5	-0.5	-1.0	-1.5	-2.5	-2.5
G. Wild Buckwheat	*Eriogonum gordonii*	X	X	0.0	-1.0	-2.0	-2.0	-3.0	-3.0
Matted Prickly-phlox	*Linanthus caespitosus*	X	X	0.0	-1.0	-2.0	-2.0	-3.0	-3.0
Hall's Bulrush	*Schoenoplectus hallii*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
R.M. Bulrush	*Schoenoplectus saximontanus*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
S. W. Lady's-slipper	*Cypripedium candidum*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
Short's Milkvetch	*Astragalus shortianus*	X	X	0.0	-1.0	-1.0	-2.0	-3.0	-3.0
Blowout Penstemon	*Penstemon haydenii*	X	X	0.0	0.0	-0.5	-0.5	-1.5	-1.5
Prairie Moonwort	*Botrychium campestre*	X	X	0.0	0.0	0.0	0.0	-1.0	-2.0
Missouri Sedge	*Carex missouriensis*	X	X	0.0	0.0	0.5	0.5	0.5	1.0

Table 2.9 Mean estimated impact on Tier 1 at-risk plants across each scenario of grassland lost to woody transition.

Nebraska Tier 1 At-risk Reptiles		Grassland Lost to Woody Transition							
Common Name	**Scientific Name**	**2011**	**2018**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**
Timber Rattlesnake	*Crotalus horridus*	X	X	-1.0	-2.0	-2.0	-3.0	-3.0	-3.0
Massasauga	*Sistrurus tergeminus*	X	X	-1.0	-1.0	-2.0	-3.0	-3.0	-3.0
Glossy Snake	*Arizona elegans*		X	0.0	0.0	-1.0	-2.0	-3.0	-3.0
Blanding's Turtle	*Emydoidea blandingii*	X	X	0.0	0.0	-0.5	-1.0	-1.5	-2.0
Sagebrush Lizard	*Sceloporus graciosus*	X	X	2.0	2.0	1.0	-1.0	-2.0	-3.0

Table 2.10 Mean estimated impact on Tier 1 at-risk reptiles across each scenario of grassland lost to woody transition.

Grassland Lost to Woody Transition

Ecoregion		5%	10%	25%	50%	75%	90%
1. Panhandle Prairie BULs							
Proportion of Species with Negative Impacts	≤ -1	0.26	0.62	0.85	0.95	0.97	0.97
	≤ -2	0.03	0.18	0.46	0.79	0.95	0.95
	-3	0.00	0.03	0.13	0.38	0.77	0.92
2. Sandhills Prairie Ecoregion							
Proportion of Species with Negative Impacts	≤ -1	0.41	0.57	0.76	0.85	0.87	0.87
	≤ -2	0.00	0.09	0.41	0.68	0.78	0.80
	-3	0.00	0.00	0.04	0.11	0.70	0.76
3. Northeast Prairie BULs							
Proportion of Species with Negative Impacts	≤ -1	0.02	0.13	0.28	0.76	0.96	0.96
	≤ -2	0.00	0.02	0.11	0.17	0.51	0.87
	-3	0.00	0.00	0.02	0.04	0.07	0.26
4. Southwest Prairie Ecoregion							
Proportion of Species with Negative Impacts	≤ -1	0.33	0.33	0.62	0.81	0.81	0.81
	≤ -2	0.00	0.14	0.33	0.62	0.67	0.81
	-3	0.00	0.00	0.14	0.19	0.62	0.67
5. Loess Canyons BUL							
Proportion of Species with Negative Impacts	≤ -1	0.00	0.30	0.55	0.85	0.85	0.85
	≤ -2	0.00	0.00	0.15	0.55	0.85	0.85
	-3	0.00	0.00	0.00	0.15	0.45	0.85
6. Central Loess Hills BUL							
Proportion of Species with Negative Impacts	≤ -1	0.00	0.28	0.56	0.67	0.78	0.78
	≤ -2	0.00	0.06	0.28	0.56	0.72	0.72
	-3	0.00	0.00	0.06	0.22	0.56	0.61

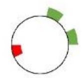
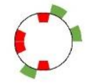
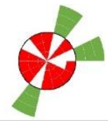
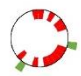
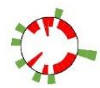
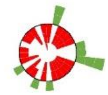
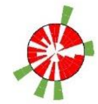
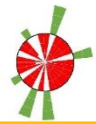
7. RAINWATER BASIN BUL							
Proportion of Species with Negative Impacts	≤ -1	0.07	0.29	0.64	0.64	0.71	0.71
	≤ -2	0.00	0.00	0.21	0.50	0.64	0.64
	-3	0.00	0.00	0.00	0.00	0.50	0.64
8. Southeast Prairie BULs							
Proportion of Species with Negative Impacts	≤ -1	0.38	0.47	0.63	0.66	0.69	0.67
	≤ -2	0.00	0.06	0.47	0.56	0.66	0.66
	-3	0.00	0.00	0.03	0.19	0.50	0.59

Table 2.11 Shows the estimated impact on Tier 1 at-risk species across each scenario of grassland lost to woody transition. Green petals projected outward reflect positive impacts, while red petals projected inward reflect negative impacts. The length of each petal reflects the degree of the impact, where longer petals represent more extreme impacts. The proportion of Tier 1 at-risk species reaching each degree of negative impact are quantified for each scenario of grassland lost to a woody transition across each ecoregion. The shaded cells depict tipping points, where Tier 1 at-risk species meet a specific proportional threshold for each degree of negative impact. Light tan cells represent 25%, gold cells represent 50%, and brown cells represent 75% of Tier 1 at-risk species reaching each degree of negative impact. See table 2.3 for a description of impacts.

APPENDIX A: CHAPTER 2 – EXAMPLE OF TIER 1 AT-RISK SPECIES QUESTIONAIRRE

Northern River Otter

Estimate the impact on **Northern river otter** abundance as the focal area's rangeland transitions from 100% grassland to the following woodland transition scenarios.

(WT = woodland transition)

	Estimated Impact	Confidence
a. WT: 5%		
b. WT: 10%		
c. WT: 25%		
d. WT: 50%		
e. WT: 75%		
f. WT: 90%		

Bell's Vireo

Estimate the impact on **Bell's vireo** abundance as the focal area's rangeland transitions from 100% grassland to the following woodland transition scenarios.

(WT = woodland transition)

	Estimated Impact	Confidence
a. WT: 5%		
b. WT: 10%		

	Estimated Impact	Confidence
c. WT: 25%		
d. WT: 50%		
e. WT: 75%		
f. WT: 90%		

Burrowing Owl

Estimate the impact on **burrowing owl** abundance as the focal area's rangeland transitions from 100% grassland to the following woodland transition scenarios.

(WT = woodland transition)

	Estimated Impact	Confidence
a. WT: 5%		
b. WT: 10%		
c. WT: 25%		
d. WT: 50%		
e. WT: 75%		
f. WT: 90%		

GRPC

Estimate the impact on **greater prairie-chicken** abundance as the focal area's rangeland transitions from 100% grassland to the following woodland transition scenarios.

(WT = woodland transition)

	Estimated Impact	Confidence
a. WT: 5%		
b. WT: 10%		
c. WT: 25%		
d. WT: 50%		
e. WT: 75%		
f. WT: 90%		

Loggerhead Shrike

Estimate the impact on **loggerhead shrike** abundance as the focal area's rangeland transitions from 100% grassland to the following woodland transition scenarios.

(WT = woodland transition)

	Estimated Impact	Confidence
a. WT: 5%		
b. WT: 10%		
c. WT: 25%		

	Estimated Impact	Confidence
d. WT: 50%		
e. WT: 75%		
f. WT: 90%		

Trumpeter Swan

Estimate the impact on **trumpeter swan** abundance as the focal area's rangeland transitions from 100% grassland to the following woodland transition scenarios.

(WT = woodland transition)

	Estimated Impact	Confidence
a. WT: 5%		
b. WT: 10%		
c. WT: 25%		
d. WT: 50%		
e. WT: 75%		
f. WT: 90%		

Whooping Crane

Estimate the impact on **whooping crane** abundance as the focal area's rangeland transitions from 100% grassland to the following woodland transition scenarios.

(WT = woodland transition)

	Estimated Impact	Confidence
a. WT: 5%		
b. WT: 10%		
c. WT: 25%		
d. WT: 50%		
e. WT: 75%		
f. WT: 90%		

Regal Fritillary

Estimate the impact on **regal fritillary** abundance as the focal area's rangeland transitions from 100% grassland to the following woodland transition scenarios.

(WT = woodland transition)

	Estimated Impact	Confidence
a. WT: 5%		
b. WT: 10%		
c. WT: 25%		
d. WT: 50%		

	Estimated Impact	Confidence
e. WT: 75%		
f. WT: 90%		

Married Underwing

Estimate the impact on **married underwing** abundance as the focal area's rangeland transitions from 100% grassland to the following woodland transition scenarios.

(WT = woodland transition)

	Estimated Impact	Confidence
a. WT: 5%		
b. WT: 10%		
c. WT: 25%		
d. WT: 50%		
e. WT: 75%		
f. WT: 90%		

Whitney Underwing

Estimate the impact on **whitney underwing** abundance as the focal area's rangeland transitions from 100% grassland to the following woodland transition scenarios.

(WT = woodland transition)

	Estimated Impact	Confidence
a. WT: 5%		
b. WT: 10%		
c. WT: 25%		
d. WT: 50%		
e. WT: 75%		
f. WT: 90%		

Powered by Qualtrics

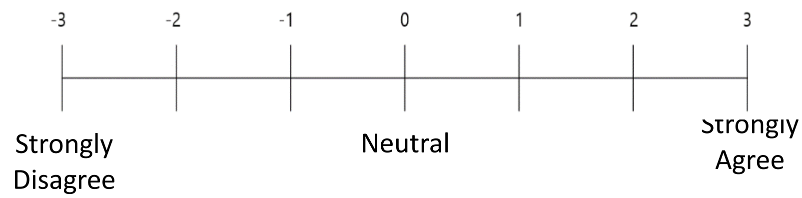
APPENDIX B: CHAPTER 2 – FOLLOW UP QUESTIONAIRRE

Please indicate what focal area you are representing (i.e.. Statewide, Central Loess Hills, etc.): _________________

1. What proportion of each focal area's rangeland do you anticipate was/will be transitioned to woodland dominance during the listed time frame scenarios? Write a number between 0-100% for each focal area.
   How confident are you in your answer? None (0), Low (1), Moderate (2), High (3), Very High (4).
   CF = Confidence

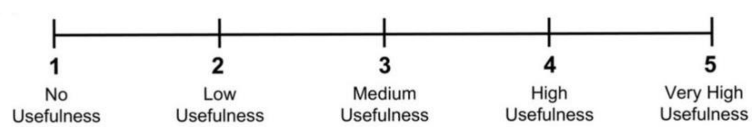
	Pre-settlement % woodland	CF	30 years: Past (1990) % woodland	CF	Today % woodland	CF	30 years: Future (2050) without management. % woodland	CF	30 years: Future (2050) with management. % woodland	CF
Central Loess Hill										
Loess Canyons										
Northeast Region										
Panhandle Region										
Rainwater Basin										
Sandhills										
Southeast										
Southwest										

2. How much do you agree/disagree with the assessment output for each focal area?



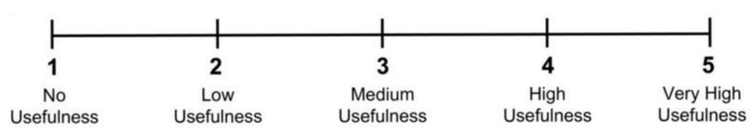
	Ecosystem Services	Grassland Taxa	Tier-one species
Central Loess Hill			
Loess Canyons			
Northeast Region			
Panhandle Region			
Rainwater Basin			
Sandhills			
Southeast Region			
Southwest Region			

3. How useful was this workshop for understanding the threat of woody encroachment to ecosystem services, grassland taxa, and at-risk tier-one species?



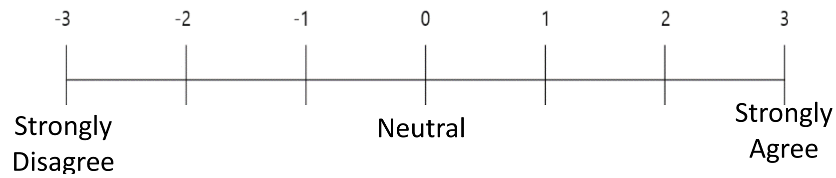
Answer: ______

4. How useful was this assessment in capturing local ecological knowledge that is absent from the scope of scientific literature?



Answer: ______

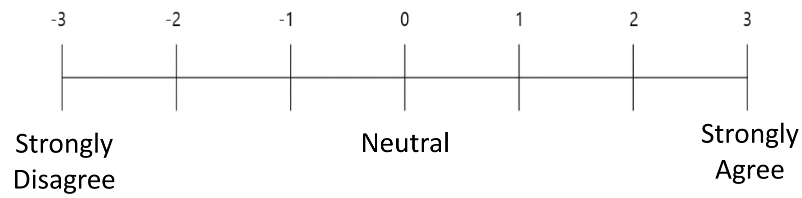
5. I learned from other participants while participating in this workshop.



Answer:_____

APPENDIX C: CHAPTER 2 – COMPILED FOLLOW UP QUESTIONAIRRE ANSWERS

2. How much do you agree/disagree with the assessment output for each focal area?

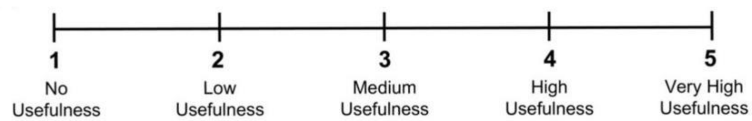


Ecoregion	Answer Mean
Loess Canyons BUL	1.86
Central Loess Hills BUL	1.52
Northeast BULs	1.52
Panhandle BULs	1.50
Rainwater Basin BULs	1.76
Southeast BULs	1.50
Sandhills	1.40
Southwest	1.67

Comments:

"Overall lack of understanding of aquatic species impacts."

3. How useful was this workshop for understanding the threat of woody encroachment to ecosystem services, grassland taxa, and at-risk tier-one species?

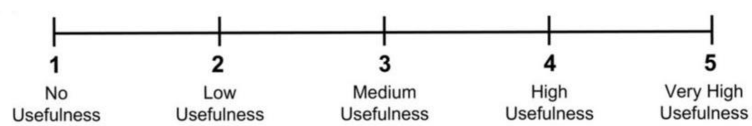


Answer Mean: 3.18

Comments:

"Interesting to see the differences between regions teared out. It might help us better place each other's advice into context."

4. How useful was this assessment in capturing local ecological knowledge that is absent from the scope of scientific literature?

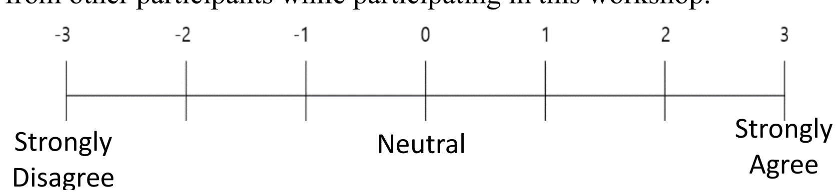


Answer Mean: 3.61

Comments:

"This is a boots on the ground assessment. So, it's more useful in identifying where literature is reaching the field. It doesn't tell us if the gap is/isn't there."

5. I learned from other participants while participating in this workshop.



Answer Mean: 2.50

APPENDIX C: CHAPTER 2 – CONFIDENCE IN TIER 1 AT-RISK SPECIES IMPACT RESPONSES

Nebraska Tier 1 At-risk Species				Grassland Lost to Woody Transition					
Common Name	**Scientific Name**	**2011**	**2018**	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**
C. Butterfly Plant	*Gaura neomexicana coloradensis*	X	X	Moderate	Moderate	Moderate	High	High	High
C-collared Longspur	*Calcarius ornatus*	X	X	High	Moderate	High	High	High	High
McCown's Longspur	*Rhynchophanes mccownii*	X	X	High	High	Extreme	Extreme	Extreme	Extreme
Mountain Plover	*Charadrius montanus*	X	X	High	High	Extreme	Extreme	Extreme	Extreme
Swift Fox	*Vulpes velox*	X	X	Moderate	High	High	Extreme	Extreme	Extreme
Dog-parsley	*Lomatium nuttallii*	X	X	Low	Moderate	Moderate	High	High	High
Timber Rattlesnake	*Crotalus horridus*	X	X	Moderate	Moderate	Moderate	High	High	High
Barr's Milkvetch	*Astragalus barrii*	X	X	Low	Low	Moderate	Moderate	High	High
Ghost Tiger Beetle	*Cicindela lepida*	X	X	Low	Low	Moderate	Moderate	High	High
Massasauga	*Sistrurus tergeminus*	X	X	Moderate	Moderate	Moderate	High	High	High
Pistolgrip	*Tritogonia verrucosa*	X	X	Moderate	Moderate	Moderate	High	High	High
Mottled Duskywing	*Erynnis martialis*	X	X	Low	Low	Low	Low	Low	Low
S. Plains Bumble Bee	*Bombus fraternus*		X	Low	None	Low	Low	Low	Low
Sandhill Goosefoot	*Chenopodium cycloides*	X	X	High	High	Moderate	Low	High	Extreme
Whooping Crane	*Grus americana*	X	X	Moderate	Moderate	Moderate	High	High	High
GRPC	*Tympanuchus cupido*	X		High	High	High	High	Extreme	Extreme
Long-billed Curlew	*Numenius americanus*	X	X	High	High	Extreme	Extreme	Extreme	Extreme
L-S Prairie-clover	*Dalea cylindriceps*	X	X	Low	Low	Low	Moderate	High	Extreme
Piping Plover	*Charadrius melodus*	X	X	Extreme	High	High	High	High	High

Nebraska Fritillary	*Boloria selene nebraskensis*		**X**	**High**	**High**	**High**	**High**	**High**	**Moderate**
W. P. Fringed Orchid	*Platanthera praeclara*	X	X	High	High	Moderate	High	High	High
Wolf Spikerush	*Eleocharis wolfii*	X	X	High	High	Moderate	Moderate	Moderate	High
Iowa Skipper	*Atrytone arogos iowa*	X	X	Low	Low	Low	Low	Low	Low
Ottoe Skipper	*Hesperia ottoe*	X	X	Low	Low	Low	Low	Low	Low
Two-spotted Skipper	*Euphyes bimacula illinois*		X	Moderate	Moderate	Low	Low	Low	Moderate
Bucholz Black Dash	*Euphyes conspicua bucholzi*	X	X	Moderate	Moderate	Low	Low	Low	Low
Burrowing Owl	*Athene cunicularia*	X	X	High	High	High	High	Extreme	Extreme
Plains Harvest Mouse	*Reithrodontomys montanus griseus*	X		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Plain Pocketbook	*Lampsilis cardium*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Pimpleback	*Quadrula pustulosa*	X	X	Low	Low	Low	Moderate	Moderate	Moderate
ABB	*Nicrophorus americanus*	X	X	Moderate	Moderate	Moderate	High	High	High
Henslow's Sparrow	*Ammodramus henslowii*	X	X	High	High	Moderate	Moderate	High	High
Regal Fritillary	*Speyeria idalia*	X	X	Moderate	Moderate	Moderate	Moderate	High	High
Married Underwing	*Catocala nuptialis*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Sprague's Pipit	*Anthus spragueii*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
G. Wild Buckwheat	*Eriogonum gordonii*	X	X	Low	Low	Low	Low	Low	Low
Matted Prickly-phlox	*Linanthus caespitosus*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
C. N. Pocket Gopher	*Thomomys talpoides cheyennensis*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Hall's Bulrush	*Schoenoplectus hallii*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Kohler's Fritillary	*Boloria selene sabulocollis*		X	Low	Low	Low	Low	Low	Low

P. N. Pocket Gopher	*Thomomys talpoides pierreicolus*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
R.M. Bulrush	*Schoenoplectus saximontanus*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
S. Cuckoo Bumble Bee	*Bombus suckleyi*		X	Low	Low	Moderate	Moderate	Moderate	High
S. W. Lady's-slipper	*Cypripedium candidum*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Short's Milkvetch	*Astragalus shortianus*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Western Bumblebee	*Bombus occidentalis ccidentalis*	X	X	Low	Low	Moderate	Moderate	Moderate	High
Short-eared Owl	*Asio flammeus*	X	X	Moderate	Moderate	Moderate	High	High	High
B-b Sandpiper	*Tryngites subruficollis*	X	X	High	High	High	High	High	Extreme
Smoky-eyed Brown	*Lethe eurydice fumosa*		X	Low	Low	Low	Low	Low	Low
Black Tern	*Chlidonias niger*		X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Whitney Underwing	*Catocala whitneyi*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Monarch	*Danaus plexippus*		X	High	High	Moderate	High	High	Moderate
Baird's Sparrow	*Ammodramus bairdii*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
9-s Ladybird Beetle	*Coccinella novemnotata*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
C. Rita Dotted-blue	*Euphilotes rita coloradensis*	X	X	Moderate	Low	Moderate	Moderate	High	High
Glossy Snake	*Arizona elegans*		X	Extreme	High	Moderate	Moderate	High	High
Plains Pocket Mouse	*Perognathus flavescens perniger*	X	X	Moderate	Moderate	Moderate	Low	Low	Low
Sandy Tiger Beetle	*Cicindela imbate limbata*		X	Low	Low	Low	Low	Low	Low
Blacknose Shiner	*Notropis heterolepis*	X	X	High	High	Low	Low	High	High
Blanding's Turtle	*Emydoidea blandingii*	X	X	High	High	Moderate	Moderate	Moderate	Low
Blowout Penstemon	*Penstemon haydenii*	X	X	High	High	High	High	High	High
Wood Thrush	*Hylocichla mustelina*	X	X	Moderate	Moderate	Moderate	Moderate	Low	Low

Two-lined Stonefly	*Perlesta golconda*		X	Low	Moderate	Moderate	Moderate	High	High
Ornate Fairy Shrimp	*Eubranchipus ornatus*		X	Moderate	Moderate	Moderate	Low	Low	Low
P-l Fairy Shrimp	*Branchinecta potassa*		X	Low	Low	Low	Low	Low	Low
Interior Least Tern	*Sternula antillarum athalassos*	X	X	High	Moderate	Moderate	Moderate	Low	Low
Prairie Moonwort	*Botrychium campestre*	X	X	Low	Low	None	None	Low	None
Lakota Mayfly	*Apobaetis lakota*		X	Low	Low	Low	Low	Low	Low
Fox Mayfly	*Cercobrachys fox*		X	Low	Low	Low	Low	Low	Low
B. Eastern Woodrat	*Neotoma floridana baileyi*	X	X	High	High	High	Moderate	Moderate	Low
Missouri Sedge	*Carex missouriensis*	X	X	None	None	None	None	None	None
Plains Spotted Skunk	*Spilogale putorius interrupta*		X	Low	Low	Low	Low	Low	Low
Byssus Skipper	*Problema byssus kumskaka*		X	Low	Low	Low	Low	Low	Low
Plains Topminnow	*Fundulus sciadicus*	X	X	High	High	Moderate	Moderate	High	High
Black-billed Magpie	*Pica hudsonia*		X	High	High	High	Moderate	High	High
Ferruginous Hawk	*Buteo regalis*	X	X	High	Moderate	Low	Moderate	High	High
E. Little Brown Bat	*Myotis lucifugus lucifugus*		X	Low	Low	Low	Low	Low	Moderate
Trumpeter Swan	*Cygnus buccinator*	X		High	Moderate	Moderate	Moderate	Moderate	Moderate
Eastern Red Bat	*Lasiurus borealis*		X	Low	Low	Low	Low	Low	Low
Brewer's Sparrow	*Spizella breweri*	X	X	Moderate	Moderate	High	High	High	Extreme
Tricolored Bat	*Perimyotis subflavus*		X	Low	Low	Low	Low	Low	Moderate
Silver-haired Bat	*Lasionycteris noctivagans*		X	Moderate	Moderate	Moderate	Low	Low	Moderate
N. Redbelly Dace	*Chrosomus eos*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	High
Finescale Dace	*Chrosomus neogaeus*	X	X	Moderate	Moderate	High	Moderate	Moderate	High
Northern River Otter	*Lontra canadensis*	X		High	Moderate	Moderate	Moderate	Moderate	Moderate

Hoary Bat	*Lasiurus cinereus*		X	Moderate	Moderate	Low	Low	Low	Low
Loggerhead Shrike	*Lanius ludovicianus*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	High
Topeka Shiner	*Notropis topeka*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Bell's Vireo	*Vireo bellii*	X		High	High	High	Moderate	High	High
Black-billed Cuckoo	*Coccyzus erythropthalmus*		X	High	High	High	Low	Moderate	High
N. Long-eared Bat	*Myotis septentrionalis*		X	Moderate	Moderate	Moderate	Moderate	Moderate	High
Sagebrush Lizard	*Sceloporus graciosus*	X	X	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate