

Status of native bumble bees (*Bombus* spp.) at Fort Riley Military Reservation, Kansas

by

Cassidy Lathrom

B.S., Kansas State University, 2023

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Division of Biology
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2025

Approved by:

Major Professor
Dr. David A. Haukos

Copyright

© Cassidy Lathrom 2025.

Abstract

Bumble bees (*Bombus* spp.) serve as essential pollinators of native grassland forbs and agricultural crops, supporting plant reproductive success, maintaining floral diversity, and enhancing ecosystem resilience. Despite their ecological importance, *Bombus* spp. have experienced substantial declines in abundance and distribution, prompting concerns for pollinator conservation across Great Plains ecosystems, including the tallgrass prairie ecoregion. The ecoregion is home to a suite of six native bumble bee species: American bumble bee (*B. pensylvanicus*), Southern Plains bumble bee (*B. fraternus*), Black and Gold bumble bee (*B. auricomus*), Common Eastern bumble bee (*B. impatiens*), Brown-Belted bumble bee (*B. griseocollis*), and Two-spotted bumble bee (*B. bimaculatus*). Of conservation concern are the Southern Plains bumble bee and American bumble bee, with an estimated 89% population decline over the past 20 years. I assessed *Bombus* spp. community composition, occurrence, land cover associations, and population density within Fort Riley Military Reservation, Kansas, a key large remnant of the tallgrass prairie ecoregion. My research integrated three objectives to evaluate *Bombus* spp. populations over time and space by assessing: (1) variation in *Bombus* spp. diversity and abundance relative to land cover, floral type, and prairie management practices, focusing on Southern Plains bumble bee and American bumble bee; (2) the potential for use of distance sampling to estimate bumble bee density; and (3) local-scale relationships between floral resource availability and *Bombus* spp. density through capture-mark-recapture methods. Land cover associations were analyzed by performing canonical correspondence analysis (i.e., visualizing relationships among land cover types, management intensity, and bumble bee species abundances). There was separation among species relative to use of land cover types, indicating that *Bombus* spp. segregate among land cover types on the landscape. I used package *Distance*

in Program R to evaluate the potential to estimate density of *Bombus* spp. across Fort Riley using distance sampling. Data were comprised of six species, including American bumble bee, Southern Plains bumble bee, Black and Gold bumble bee, Common Eastern bumble bee, Brown-Belted bumble bee, and Two-Spotted bumble bee. I estimated 1.30 *Bombus* spp./ha (CV = 0.184), 1.40 *Bombus* spp./ha (CV = 0.122), and 1.80 *Bombus* spp./ha (CV = 0.108) during 2022, 2023, and 2024, respectively. These results indicate that distance sampling can be used to estimate *Bombus* spp. density in the tallgrass prairie and serve as a baseline for future assessments. Over three field seasons (2022–2024), a total of 15,596 individual bumble bees were captured and marked across 44 unique sampling sites representing all six native *Bombus* species. Across these sites, 37 unique floral colonies (i.e., dense patches of nectaring flowers for bumble bee foraging habitat) were identified: 10 in 2022, 18 in 2023, and 9 in 2024. Among these, five dominant floral types were most frequently observed across years and sample bouts: tall thistle (*Cirsium altissimum*), roundhead prairie clover (*Dalea multiflora*), wild bergamot (*Monarda fistulosa*), partridge pea (*Chamaecrista fasciculata*), and milkweed (*Asclepias* spp.). Three bumble bee species accounted for >80% of all captures: Brown-belted bumble bee (5,618 individuals; 36%), Black and Gold bumble bee (3,826; 25%), and American bumble bee (3,412; 22%). Southern Plains bumble bee comprised 13% of total abundance, while Two-spotted and Common Eastern bumble bees each represented just 2% of individuals captured. Site-level species richness remained consistently high across years and bouts, ranging from 4 to 6 species per site (mean $\pm$ SD = 5.0 ± 0.4), indicating strong community diversity and persistence of all six species on Fort Riley across years. Results provide baseline data for future monitoring efforts and support compliance with federal conservation mandates under the Sikes Act of 1960 and the 1973 Endangered Species Act, should species of concern be listed.

Table of Contents

List of Figures	vii
List of Tables	ix
Acknowledgements	xi
Dedication	xiii
Chapter 1 - Ecology of Native Bumble bees (<i>Bombus</i> spp.) in Tallgrass Prairie: An Introduction	1
Background	3
Value of Local Conservation Efforts in the Great Plains.....	6
Tallgrass Prairie Ecology	9
Military Lands: Provisions for Conservation Management.....	12
Challenges and Limitations Related to Understanding <i>Bombus</i> Ecology.....	15
Literature Cited	21
Chapter 2 – Community Composition and Landcover Associations of Native Bumble bees	
(<i>Bombus</i> spp.) on Fort Riley Military Reservation.....	32
Introduction.....	32
Methods	35
Study Area	35
<i>Bombus</i> spp. Capture Surveys.....	37
<i>Bombus</i> spp. Landcover Association	38
Results.....	40
Discussion.....	42
Community Composition and Temporal Stability	42
Seasonal Turnover and Floral Phenology	43
Landcover Associations and Habitat Preferences	43
Management Implications.....	44
Conservation Significance	45
Conclusion	45
Literature Cited	47
Chapter 3 – Evaluation of Distance Sampling to Estimate Density of Native Bumble bees	
(<i>Bombus</i> spp.) on Fort Riley Military Reservation.....	57
Introduction.....	57

Methods	61
Study Area	61
Estimating <i>Bombus</i> spp. Distribution and Density: Distance Surveys	63
Data Analysis	64
Results.....	66
Distance Sampling Detection Models.....	66
Interannual Trends in <i>Bombus</i> spp. Density and Abundance	66
Seasonal Dynamics of Density, Abundance, and Detection.....	67
Discussion.....	67
Management Implications.....	70
Conclusion	71
Literature Cited	73
Chapter 4 - Local-Scale Assessments of <i>Bombus</i> spp. Abundance on Fort Riley Using Mark-	
Recapture Techniques.....	82
Introduction.....	82
Methods	84
Study Area	84
Capture-Mark-Recapture (CMR) Surveys of <i>Bombus</i> spp.	85
Abundance and Density Calculations	86
Results.....	87
Species Abundance and Temporal Trends (2022–2024)	87
Seasonal Patterns by Sampling Bout	88
Program MARK Analysis.....	89
Discussion.....	90
Phenological Timing and Bout-Specific Dynamics.....	92
Interannual Fluctuations and Environmental Sensitivity	93
Species-Specific Habitat and Management Considerations	94
Ecological Implications and Monitoring Recommendations.....	94
Conclusion	95
Literature Cited	97

List of Figures

Figure 1. 1. Representative images of the six native bumble bee species documented within the tallgrass prairie ecoregion at Fort Riley Military Reservation, Kansas. Species depicted include: American bumble bee (<i>B. pensylvanicus</i>), Southern Plains bumble bee (<i>B. fraternas</i>), Black and Gold bumble bee (<i>B. auricomus</i>), Common Eastern bumble bee (<i>B. impatiens</i>), Brown-belted bumble bee (<i>B. griseocollis</i>), and Two-spotted bumble bee (<i>B. bimaculatus</i>).....	29
Figure 1. 2. Conceptual diagram illustrates the integration of spatial and temporal scales concerning native bumble bee (<i>Bombus</i> spp.) populations in prairie ecosystems. Local, unit, and landscape scales capture scale-specific responses to floral resources, habitat structure, and land cover configuration. This hierarchical approach supports spatially informed pollinator conservation (Hines & Hendrix, 2005; Buckles & Harmon-Threatt, 2019).	30
Figure 2. 1. Location of Fort Riley in the northern Flint Hills (green) of Kansas (upper panel) and broad land use and land cover characteristics of the >40,000 ha installation (lower panel). Individual polygons represent designated training units (n = 104).....	50
Figure 2. 2. Spatial distribution of <i>Bombus</i> spp. capture sites (n = 44) surveyed across Fort Riley Military Reservation, Kansas, from 2022 to 2024. Colored circles represent sampling years: yellow (2022, n = 12 sites), red (2023, n = 21), and blue (2024, n = 11).	51
Figure 2. 3. Dominant vegetation cover types across 104 management units at Fort Riley Military Reservation, Kansas. Each unit (polygon) is classified by associated dominant land cover type based on percentage cover: Natural Prairie (orange; 52 units, 39%), Go-Back Prairie (tan; 30 units, 38%), and Woodland (green; 13 units, 19%).....	52
Figure 2. 4. Proportional captures of <i>Bombus</i> spp. across all sampling efforts from 2022 to 2024 at Fort Riley Military Reservation, Kansas. Brown-belted bumblebee (BRBE) represented the largest proportion of captures (36%), followed by Black and Gold bumblebee (BG; 25%), American bumblebee (AMER; 22%), and Southern Plains bumblebee (SOPL; 13%). Two-Spotted bumblebee (TWSP) and Common Eastern bumblebee (COEA) were least abundant, each accounting for 2% of total captures. Capture data reflect pooled counts across 44 unique capture sites sampled over three field seasons.	53
Figure 2. 5. Canonical Correspondence Analysis (CCA) plot visualizes relationships among seven land cover types and management regime intensities relative to <i>Bombus</i> spp. occurrence based on capture data across Fort Riley (2022-2024). Illustrated are all six	

bumble bee species: American bumble bee (AMER), Southern Plains bumble bee (SOPL), Brown Belted bumble bee (BRBE), Black and Gold bumble bee (BG), Two Spotted bumble bee (TWSP), and Common Eastern bumble bee (COEA).	54
Figure 3. 1. 151 randomized distance transects across Fort Riley, Kansas. Points reference individual walking transects for 500-m distance surveys for bumblebee detection surveys. All transects were sampled twice per field season; once for bout 1 (01 May- 30 July) and once for bout two (01 July – 30 August) across 2022- 2024.	76
Figure 3. 2. Cumulative annual detection function fitted to <i>Bombus</i> spp. distance sampling data in 2022 (01 May – 30 August) using a half-normal key function with cosine adjustments. Vertical bars represent a histogram of detection distances; the fitted line represents the modeled detection probability across increasing distance from the observer. Fitted detection function followed a steep decline, with majority of detections occurring within 20 m of the transect.	77
Figure 3. 3. Cumulative annual detection function fitted to <i>Bombus</i> spp. distance sampling data in 2023 (01 May – 30 August) using a half-normal key function with cosine adjustments. Vertical bars represent a histogram of detection distances; the fitted line represents the modeled detection probability across increasing distance from the observer. Model shows a broader detection shoulder, suggesting higher detectability at intermediate distances compared to other years.	78
Figure 3. 4. Cumulative annual detection function fitted to <i>Bombus</i> spp. distance sampling data in 2024 (01 May – 30 August) using a half-normal key function with cosine adjustments. Vertical bars represent a histogram of detection distances; the fitted line represents the modeled detection probability across increasing distance from the observer. A steeper detection curve and reduced shoulder indicate lower overall detectability.	79
Figure 4. 1. Spatial distribution of <i>Bombus</i> spp. capture sites (n = 44) surveyed across Fort Riley Military Reservation, Kansas, from 2022 to 2024. Colored circles represent sampling years: yellow (2022, n = 12 sites), red (2023, n = 21), and blue (2024, n = 11). Sampling sites were distributed across 41 unique training units within the installation, with 2022 surveys conducted in 10 units, 2023 in 21 units, and 2024 in 10 units.	100

List of Tables

Table 1. 1. Framework outlining the hierarchical assessment of <i>Bombus</i> spp. ecology across three spatial scales: local (site-level), unit, and landscape. Highlighted are scale-specific management relevance, linking observational metrics to conservation applications such as floral enhancement (local), treatment timing (unit), and regional habitat prioritization (landscape).	31
Table 2. 1. Land Cover Types and Land Management Practices on Fort Riley	55
Table 2. 2. Total number of <i>Bombus</i> spp. captured across three field seasons (2022–2024) at Fort Riley Military Reservation, Kansas. Species include American bumble bee (AMER), Brown-belted bumble bee (BRBE), Black and Gold bumble bee (BG), Southern Plains bumble bee (SOPL), Two-spotted bumble bee (TWSP), and Common Eastern bumble bee (COEA). Annual totals and cumulative counts are reported across all sampling sites (n = 44 sites).	56
Table 3. 1. Estimates ($\pm$ SE) and 95% confidence intervals of density (bees/ha) and detection probability (ρ) for native bumble bee (<i>Bombus</i> spp.) using distance sampling for 151 transects for two survey bouts (bout 1 = May 1 – June 30, bout 2 = July 1 – August 30) sampled during 2022–2024 at the Fort Riley Military Reservation, Kansas.	80
Table 3. 2. Estimated abundance and 95% confidence intervals of native bumble bees (<i>Bombus</i> spp.) using distance sampling for 151 transects for two survey bouts (bout 1 = May 1 – June 30, bout 2 = July 1 – August 30) sampled during 2022–2024 at the Fort Riley Military Reservation, Kansas.	81
Table 4. 1. Total <i>Bombus</i> spp.1 captures, including recaptures at Fort Riley, Kansas, during 2022- 2024, by species and year.	101
Table 4. 2. Total abundance of <i>Bombus</i> spp.1 individuals captured (excluding recaptures) at Fort Riley, Kansas, during 2022-2024, by species and year.	102
Table 4. 3. Total <i>Bombus</i> spp. captured on Fort Riley, Kansas, during 2022-2024, separated by bout 1 (left; May-June) and bout 2 (right: July-August).....	103
Table 4. 4. Total capture of <i>Bombus</i> spp.1 on Fort Riley, Kansas, during 2023-2024 for Bout 2 (July-August).	104

Table 4. 5. Dominant plant type and area of 31 floral colonies where capture-mark-recapture occasion data sampled over 3-4 capture events were used estimate native bumble bee abundance on Fort Riley, Kansas, during 2022–2024.	105
--	-----

Acknowledgements

This thesis marks the culmination of not only years of academic work but also personal growth, resilience, and transformation, which would have been possible without the incredible people who have supported me along the way.

First and foremost, I want to express my deepest gratitude to my advisor and mentor, Dr. David Haukos. Thank you for believing in me, recognizing my passion for conservation as both potential and promise, and choosing to invest in me as a scholar and as a person. Your guidance has shaped much more than my academic journey; it has helped define who I am today. What began as a vision for research became a calling, and your mentorship has made all the difference. I entered this program thinking I knew what I wanted, but you gave me the opportunity I truly needed. I am equally grateful to Caroline Skidmore, who laid the groundwork for this research and has served as both a mentor and a friend. Your tireless dedication, generous mentorship, and unwavering support brought this project to life in ways I could not have achieved alone. Your contributions of time, expertise, and friendship have been invaluable. Thank you.

To my committee members and lab mates, thank you for challenging me to think critically, conduct meaningful science, and hold myself to the highest standards. I am proud to have worked alongside such an inspiring and dedicated team of scholars. You have helped me become not only a better scientist but a more grounded and reflective researcher.

This work was made possible through the generous support and funding from the Department of Defense, specifically the Environmental Division at Fort Riley Military Reservation, Kansas State University, Kansas Cooperative Fish and Wildlife Research Unit, Kansas State Division of Biology, United States Fish and Wildlife Service, and United States Geological Survey. I am especially grateful to the Fort Riley Environmental Division for their partnership and field support. A special thank you to Mike Houck, Derek Moon, and Brian

Monser, your steadfast support and commitment to this project never went unnoticed, and I am so fortunate to have had the opportunity to work alongside each and every one of you. I would also like to recognize the extraordinary effort of my field technicians: Hannah Huyett, Taylor Rodriguez-Blash, Caroline Hoggatt, and Fabel Yanez. Your perseverance, sharp eyes, and good humor during long days in the field were invaluable to the project's success. Thank you for your enthusiasm, your flexibility, and your dedication to the bees.

To my family, thank you for providing me with the tools to pursue a life driven by curiosity, service, and love for the natural world. Your encouragement and belief in me carried me through my most challenging moments. To my parents, thank you for raising me to follow my passions, even when they led me through muddy fields chasing insects. To my fiancé, Ethan, and the entire Schraad family, your patience, encouragement, and unwavering support helped me get through the long days and late nights. Thank you for sharing my passion and believing in my work.

Lastly, I must thank the bumble bees themselves. They have taught me a great deal throughout my research journey. I would not be where I am today without their necessity, and I am honored to have had the opportunity to answer their call in their time of need. I owe it to them to ensure they are advocated for and have healthy environments in which to thrive for generations to come. I am motivated every day to work for the bees and do right by them. Because without them, I would have nothing to work for at all; none of us would.

Dedication

To my grandfather, Everett Lathrom—a devoted steward of the land, a quiet teacher of ethics, and the unwavering cornerstone of our family. You raised me in the outdoors, where you taught me to listen, to wonder, and to care. It was under your guidance that my passion for the natural world took root and began to grow. Though you are no longer with us, your spirit is ever-present. I see you in the wildflowers that mirror your vibrant charisma, in the stillness beneath the oak trees that served as your chapel, and in every walk across the prairie or quiet moment in a deer stand. This work, and all that I aspire to in conservation, is rooted in the love and reverence you instilled in me. I carry you with me always

Chapter 1 - Ecology of Native Bumble bees (*Bombus* spp.) in Tallgrass Prairie: An Introduction

Pollination is a critical element of natural ecosystem goods and services. Essential for food production and persistence of native plant communities, pollination is the transfer of pollen from the male organ of a plant to the female organ of a flowering plant, often facilitated by invertebrates that feed on nectar and collect pollen on their bodies. Diverse communities of wild invertebrate pollinators enhance ecological resilience, biodiversity, and productivity of both agricultural and natural ecosystems; thereby increasing ecosystem stability and crop yields (Kremen et al., 2002; Carvalheiro et al., 2011; Garibaldi et al., 2011). Ecosystem service values derived from pollinators depend on the condition and extent of pollinator stocks that form a portion of the natural capital of an area. In particular, native bumble bees (*Bombus* spp.) are essential pollinators for numerous native grassland forbs and agricultural crops worldwide, but have declined in abundance, diversity, and occurrence over the past several decades (Thomann et al., 2013).

The steady decline of bumble bee populations has raised growing concerns for sustainable management practices across the Great Plains. Of conservation concern are the Southern Plains bumble bee (*B. fraternus*) and American bumble bee (*B. pensylvanicus*), with an estimated 89% population decline over the past 20 years (Larson et al., 2018). These *Bombus* species are key pollinators for wildflowers and other forbs in the Great Plains, playing a vital role in maintaining species richness and diversity; however, they demonstrate notable sensitivity to habitat disturbances and environmental variability in the biome (Glenn & Collins, 1990; Howe, 1994; Steuter et al., 1995; Larson et al., 2018). Addressing current knowledge gaps regarding population dynamics of native bumble bees within grassland ecosystems is essential,

especially in the tallgrass prairie ecoregion of the eastern Great Plains, where such data remain limited.

Bombus spp. populations are declining due to several factors, including pesticide exposure, pathogens, invasive species, habitat loss, and climate change (Goulson et al., 2015; Kerr et al., 2015; Vanbergen et al., 2013). Habitat loss due to agricultural intensification, urbanization, and invasive species has led to local extinctions and decreased abundance (Bommarco et al., 2011; Winfree et al., 2009). Assessing the current status of *Bombus* spp. across landscapes and identifying critical factors affecting species occurrence and population trends are essential for informing targeted management plans for native bumble bees, particularly informing knowledge of the scope of species-specific habitat use areas and associated environmental conditions and management regimes.

Relative to growing concern for pollinator declines, native bumble bee populations in grassland ecosystems require an integrative management approach because *Bombus* spp. Respond to factors at multiple spatial scales. addressing this research gap requires integrative approaches that examine how local and landscape-level factors interact to shape *Bombus* spp. communities. For example, combining floral patch attributes (e.g., bloom density, area, and phenology) with spatial land cover data enables identification of key habitat features that support native bumble bee populations adds specificity to understanding habitat use and response to conservation efforts. Evaluating the influence of floral resource availability, land use, and management regimes (e.g., prescribed fire, haying) provides insight into ecological drivers of *Bombus* spp. abundance and diversity. My overall objective was to provide a comprehensive overview of the status of native bumble bee populations in the tallgrass prairie ecoregion within the eastern Great Plains, with particular emphasis on species of conservation concern (e.g.,

American bumble bee and Southern Plains bumble bee). My research supports the development of local management recommendations for the conservation of *Bombus* spp. relative to population status, distribution, and habitat use across space and time.

Background

The tallgrass prairie once spanned much of the central United States, providing essential habitat for a wide range of native species, including native bumble bees (Bendel et al., 2019). Native prairies support a diverse assemblage of plant species, providing abundant floral resources for *Bombus* spp. Tallgrass prairies are dominated by grasses such as big bluestem (*Andropogon gerardii*) and switchgrass (*Panicum virgatum*), along with a diverse array of wildflowers, including milkweeds (*Asclepias* spp.), clovers (*Trifolium* spp.), and coneflowers (*Echinacea* spp.), which are crucial for pollinator populations (Hendrickson et al., 2021). The region is home to a suite of six native bumble bee species: American bumble bee, Southern Plains bumble bee, Black and Gold bumble bee (*B. auricomus*), Common Eastern bumble bee (*B. impatiens*), Brown-Belted bumble bee (*B. griseocollis*), and Two-spotted bumble bee (*B. bimaculatus*; Figure 1.1).

Fort Riley Military Reservation (FRMR) is one of the largest remaining areas of managed contiguous tallgrass prairie in the central United States, serving as a vital habitat for native bumble bees and other grassland-dependent pollinators (Jog et al., 2006; Kindscher et al., 2011). The ecological importance of FRMR lies in its diverse and relatively undisturbed landscape, which includes native prairie, shrublands, and woodland patches. This heterogeneity supports a wide range of bumble bee species, many of which use multiple habitat types throughout their life cycles (Hines & Hendrix, 2005; Williams et al., 2012). However, some *Bombus* species exhibit narrow ecological niches and rely on specific habitat types that are regionally rare or declining,

such as remnant prairie or early successional floral communities. These species tend to occur at low densities and are infrequently observed, especially in fragmented or degraded habitats (Colla et al., 2006; Grixiti et al., 2009; Hatfield et al., 2015).

Adaptive management frameworks are necessary for monitoring and sustaining pollinator populations in changing landscapes. Management actions at FRMR, including prescribed burning, haying, and invasive species control, are implemented across a complex mosaic of land cover types (Fort Riley INRMP, 2020). Because *Bombus* species exhibit scale-dependent responses to habitat structure and resource availability, assessing management effectiveness requires monitoring at multiple scales, including both larger landscape and unit levels, as well as local site levels (Winfrey et al., 2009; Tonietto & Larkin, 2018). Using these frameworks help ensure that conservation strategies adapt to species-specific habitat needs and fluctuations in floral resources over time and space (Lindenmayer & Likens, 2009; Williams et al., 2010).

Species respond to environmental cues across spatial scales that influence geographic distribution, home range area, patch occupancy, and resource selection (Johnson, 1980; Mayor et al., 2009; Morrison, 2013; Liczner & Colla, 2020). Monitoring species-habitat relationships facilitates interpretation of behavioral responses to resource distribution, habitat use, and selection processes aligned with fitness optimization. Accounting for ecological variables across spatial scales remains essential for evaluating how habitat quantity and quality influence pollinator communities. Spatial modeling enables identification of ecological thresholds (i.e., points where slight changes in habitat availability trigger disproportionate biological responses).

For instance, while initial increases in habitat extent may elevate persistence probabilities, gains beyond a specific threshold often yield limited benefits (Fahrig, 2001, 2002).

Identification of such nonlinear species-habitat relationships can guide resource prioritization in conservation planning by optimizing ecological returns per unit investment (Ficetola & Denoël, 2009). Thresholds are typically derived from capture data and associated habitat metrics, allowing for evidence-based management decisions across spatial gradients. Effective conservation and management of native bumble bees in Great Plains ecosystems require spatially and temporally integrated approaches that account for variability in habitat use, behavioral ecology, and population dynamics (Table 1.1). Given their ecological roles in both natural and agricultural systems, *Bombus* spp. exhibit multiscale habitat dependencies, from localized floral patches to broader structural landscape attributes (Niemuth et al., 2021).

A multiscale investigative approach offers a comprehensive structure for conserving native *Bombus* spp. populations amid rapidly changing landscapes. At landscape scales, population persistence relies on mosaics of complementary cover types that supply floral resources, nesting substrates, and movement corridors (Ricketts et al., 2008). At localized scales, *Bombus* spp. foraging behaviors depend on specific plant communities and microhabitat conditions (Goulson et al., 2008). Temporal variability in these ecological features introduces additional complexity, as *Bombus* spp. may exhibit sensitivity to annual changes in foraging habitat use driven by plant phenology (e.g., seasonality, blooming period). Multiscale monitoring and management frameworks address these challenges by integrating context-based data for conservation planning at both site and landscape scales.

With several *Bombus* species petitioned or considered for listing under the United States 1973 Endangered Species Act (i.e., American bumble bee and Southern Plains bumble bee),

FRMR provides a unique opportunity to study the relationship delineation among military land disturbance regimes (e.g., management practices and military activities) and associated landcover types with *Bombus* spp. habitat use across space and time. My research aimed to evaluate the status of native bumble bees in the tallgrass prairie, identify key ecological and management factors affecting their abundance and diversity, and address knowledge gaps to support conservation efforts for sustaining *Bombus* spp. populations.

Value of Local Conservation Efforts in the Great Plains

The Great Plains ecoregion, once dominated by extensive native tallgrass, mixed-grass, and short-grass prairies, has undergone significant land-use changes (i.e., >80% loss of native tallgrass prairie cover due to fragmentation and intensive management), driven by agricultural conversion, urban expansion, and infrastructure development (Samson & Knopf, 1994; Wright & Wimberly, 2013). These changes have led to widespread declines in grassland biodiversity, including notable decreases in abundance and diversity of native bumble bees, which depend on spatially and temporally diverse floral and nesting resources (Goulson et al., 2008; Tonietto et al., 2011; Koh et al., 2016). The ecological consequences of these changes are particularly severe in tallgrass and mixed-grass prairie ecoregions, where declining *Bombus* spp. populations reflect both regional habitat loss and disruption of plant-pollinator networks (Colla & Packer, 2008; Gixti et al., 2009; Cameron et al., 2011).

Local conservation initiatives are crucial for addressing factors that influence declines in bumble bee populations within working landscapes. Small-scale actions, such as planting native forbs, restoring natural prairies, and managing remnant patches, offer important opportunities to enhance site conditions (e.g., floral density, bloom duration, and nesting substrates) that are linked to *Bombus* spp. habitat use (Carvell et al., 2007; Kremen et al., 2007; Morandin &

Kremen, 2013; Tonietto & Larkin, 2018; Harmon-Threatt, 2020). For central-place foragers (i.e., *Bombus* spp.), the placement and quality of habitat within 500 to 750 m of the colony are critical for effective pollinator foraging and colony growth (Osborne et al., 2008; Knight et al., 2005). Consequently, focused management that increases nectar resources and minimizes disturbances within this foraging area can greatly support population stability and enhance reproduction (Williams et al., 2012; Jha & Kremen, 2013).

Local actions can buffer pollinator populations against broader environmental stressors, including pesticide exposure, invasive species encroachment, and climatic variability (Garibaldi et al., 2011; Gill et al., 2012). Conservation practices that incorporate native flowering plants, reduce mowing intensity, or promote heterogeneity through patch burning or rotational grazing have been shown to increase both abundance and species richness of native bee communities (Kearns & Oliveras, 2009; Morandin & Kremen, 2013). Benefits of these practices are enhanced when implemented near remnant prairie patches or within habitat corridors, where they improve connectivity and facilitate pollinator movement across fragmented landscapes (Kremen et al., 2007; Bennett & Isaacs, 2014).

The combined effect of coordinated local conservation efforts is important for ecological resilience on a larger scale. Modeling studies demonstrate that pollinator survival is most effective when conservation strategies are spatially distributed across the landscape, providing redundancy and connectivity during environmental stresses (Ricketts et al., 2008; Lonsdorf et al., 2009). In the Great Plains, where land is often privately owned and fragmented, successful conservation mainly relies on local actions supported by incentive-based programs like the Conservation Reserve Program (CRP), Environmental Quality Incentives Program (EQIP), and Partners for Fish and Wildlife (Otto et al., 2018; Niemuth et al., 2021). These programs can

encourage landowners to adopt practices that enhance native biodiversity while also maintaining agricultural sustainability.

A variety of habitat-related conservation treatments are available to support bumble bee populations across diverse landscapes, including grazing management, prescribed burning, mowing regimes, invasive species control, planting native forbs and grasses, sowing mass-flowering crops, and efforts to maintain or improve connectivity among habitat patches (Black et al., 2007; Longcore & Osborne, 2015, 2017; USFWS, 2017b; Niemuth et al., 2021). When properly implemented, these practices can significantly enhance floral abundance and diversity, as well as provide essential nesting substrates for *Bombus* spp. (Blake et al., 2011; Schweitzer et al., 2012). The selection of conservation measures should be tailored to specific landscape contexts (e.g., agricultural, urban, or natural environments) and aligned with prevailing resource conditions and ecological goals (Schweitzer et al., 2012).

Given a variety of provisions for conservation treatments, determining where to implement these actions across large, heterogeneous landscapes presents a significant challenge. When management decisions extend beyond local knowledge or scale, the ecological benefit of interventions may be diminished. The structure and persistence of native *Bombus* spp. communities are influenced by both local habitat conditions and broader landscape context, including spatial configuration, connectivity, and land cover composition (Kremen et al., 2007; Morandin et al., 2007; Dover & Settele, 2009; Bennett & Isaacs, 2014; Taron, 2015). Consequently, conservation planning must integrate multiscale ecological data to ensure that treatments are implemented in areas most likely to support sustainable pollinator populations.

Despite their ecological importance, bumble bee populations face numerous threats, including habitat loss, climate change, and invasive species (Potts et al., 2010; Goulson et al.,

2015). Understanding relationships between native bumble bees and tallgrass prairie ecosystems is essential for developing effective conservation and management strategies. Bumble bees are critical pollinators in prairie systems, contributing to reproductive success of native forbs and promoting plant community diversity and ecosystem resilience (Potts et al., 2010; Garibaldi et al., 2013). Their decline threatens essential ecological functions and services (Goulson et al., 2015; Cameron & Sadd, 2020). Addressing these challenges through targeted management practices (e.g., habitat conservation planning and restoration, prescribed fire, grazing, and invasive species control) is necessary to sustain both pollinator populations and the broader prairie ecosystem (Tonietto et al., 2011; Blumenthal et al., 2016). Continued ecological research on plant-pollinator dynamics, habitat structure, and species-specific responses to disturbance is vital for informing adaptive management that supports long-term ecosystem sustainability (Kearns & Inouye, 1997; Cane et al., 2006). Through an analysis of habitat structure, plant-pollinator dynamics, and the effect of bumble bees on ecosystem health, my research aims to communicate the significance of these pollinators in maintaining ecological balance and resilience of the tallgrass prairie.

Tallgrass Prairie Ecology

Tallgrass prairie is one of North America's most endangered and ecologically significant grassland ecosystems. Collectively, the tallgrass prairie ecoregion is primarily within the Great Plains of central United States, encompassing portions of Minnesota, Iowa, Missouri, North Dakota, South Dakota, Kansas, Nebraska, Oklahoma, and Texas. Historically spanning >69 million hectares across the central United States, <4% remains intact today (Samson & Knopf, 1994; Scholtz & Twidwell, 2022). The Konza Prairie Biological Station and Fort Riley Military Installation in northeastern Flint Hills of Kansas are among the most well-studied remnants of

native tallgrass prairie and serving as a key model for researching its structure, function, and management (Reichman, 1987). The region's temperate continental climate produces hot summers, cold winters, and pronounced interannual variability, making it a disturbance-adapted system (Knapp et al., 1998). Annual precipitation typically ranges from 750 to 1,200 mm, with most rainfall concentrated during the growing season, from April to September (Hayden, 1998). This seasonality governs the flowering phenology of native plants and strongly influences the availability of floral resources for foraging *Bombus* spp. colonies (Crone & Williams, 2016). Extended droughts and heatwaves associated with climate change have been shown to reduce bloom density and alter the synchrony between bee emergence and flowering periods, thereby affecting reproductive success (Bartomeus et al., 2011; Pyke et al., 2016). Soil types are predominantly mollisols, rich in organic matter due to the dense vegetation and periodic fires that contribute to their fertility (Gleason & Cronquist, 1991). Vegetation composition comprises a mixture of grasses, forbs (i.e., wildflowers), and shrubs, resulting in a heterogeneous landscape with varying microhabitats that are based on plant composition and structure and disturbance frequency. The presence of diverse floral resources and a complex plant community provides essential support for bumble bee populations.

The native plant community of tallgrass prairie is characterized by a dominance of warm-season C4 grasses, including big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and little bluestem (*Schizachyrium scoparium*), which contribute to a dense canopy structure and high belowground biomass (Reichman, 1987; Towne & Kemp, 2003). These grasses are interspersed with a diverse assemblage of forbs, such as purple prairie clover (*Dalea purpurea*), goldenrods (*Solidago* spp.), blazing stars (*Liatris* spp.), and sunflowers (*Helianthus* spp.), which provide essential floral resources for pollinators,

including *Bombus* species (Hopwood, 2008; Harmon-Threatt, 2020). Many tallgrass prairie plants have evolved traits that are specialized for their pollinators. As such, native pollinators contribute significantly to the ecological health of the tallgrass prairie ecoregion by supporting plant reproduction and maintaining plant diversity. Thus, efforts to conserve prairie communities require efficient pollinators, including native bees, for successful restoration.

Tallgrass prairies are disturbance-dependent ecosystems that have historically been maintained by fire and grazing, both of which influence bumble bee habitat quality (Collins & Wallace, 1990). Fire reduces woody encroachment, promotes herbaceous diversity, and increases forb richness following spring burns, enhancing floral resources for pollinators (Panzer, 2002; Towne & Kemp, 2003). However, growing season burns may temporarily eliminate blooms, reducing forage availability. To minimize these effects, rotational burning is commonly used to leave unburned refugia, creating a shifting mosaic of successional stages that support diverse pollinator communities (Fuhlendorf & Engle, 2001).

Historically, fire and grazing acted as co-evolved forces that maintained open-canopy conditions, recycled nutrients, and promoted habitat heterogeneity (Fuhlendorf & Engle, 2004; Collins & Calabrese, 2012). Today, prescribed burning and managed grazing are widely used to simulate these natural processes. Patch-burn grazing and rotational haying regimes promote spatial and temporal variation in vegetation structure, which has been positively associated with pollinator abundance and richness (Harmon-Threatt, 2020). In the absence of disturbance, prairie sites are highly susceptible to encroachment by woody vegetation such as eastern redcedar (*Juniperus virginiana*) and roughleaf dogwood (*Cornus drummondii*), which degrade open-prairie conditions, reduce light availability, and displace herbaceous flora required by native bumble bees (Briggs et al., 2005; Twidwell et al., 2013).

Historically shaped by American bison (*Bison bison*), modern grazing regimes now rely on cattle to simulate grazing pressure. Experimental patch-burn grazing has demonstrated that spatially heterogeneous fire and grazing patterns maintain habitat heterogeneity, increase structural diversity, and promote insect biodiversity (Fuhlendorf & Engle, 2004; Doxon et al., 2011). This dynamic mosaic of disturbance facilitates coexistence of multiple plant and pollinator species by generating variation in bloom timing, canopy cover, and microclimatic conditions (Harmon-Threatt, 2020).

Landcover complexity within prairie ecosystems (e.g., native prairie, shrubland, and early successional habitats) supports diverse pollinator assemblages by offering complementary resources across spatial and temporal scales (Carvell et al., 2006; Williams et al., 2012). However, widespread conversion to monoculture crops and non-native pasture has fragmented most prairie systems, limiting dispersal and nesting opportunities for *Bombus* species (Kremen et al., 2007; Morandin & Kremen, 2013). Conservation of tallgrass prairie requires not only the protection of remaining tracts but also the active restoration of native plant communities and reintegration of disturbance regimes to maintain the ecological conditions necessary for sustaining pollinator populations.

Military Lands: Provisions for Conservation Management

Military installations across the United States encompass a broad range of ecological systems, including grasslands, wetlands, forests, and arid zones. This ecological diversity results from varied topography, regional climate, and heterogeneous land-use histories, creating a mosaic of habitat types that support a diverse array of flora and fauna, including species of conservation concern (Sutter et al., 2002; Tazik et al., 1992). Notably, >300 federally listed species occur on Department of Defense (DoD) lands, positioning military installations as

important contributors to national biodiversity conservation (Stein et al., 2008). Under mandates such as the Sikes Act, military installations are required to prepare and implement Integrated Natural Resources Management Plans, which support proactive conservation planning and compliance with the Endangered Species Act (ESA; Department of Defense, 2021).

Pollinator decline presents a growing concern for military land managers, especially as multiple native bumble bee species have been petitioned or listed under the ESA (USFWS, 2021). Given the lack of baseline data on bee diversity and distribution across many DoD installations, limited understanding of pollinator presence may complicate future consultations and mission planning. Therefore, increased investment in long-term pollinator monitoring, especially for at-risk taxa, is essential for ensuring both ecological and operational resilience.

Military lands are uniquely positioned to support conservation due in part to restricted public access. Security protocols and training activities inherently limit human disturbance, often reducing pressures associated with recreation, development, and resource extraction found on surrounding lands (Nielsen et al., 2018; Frid & Dill, 2002). This limited access fosters refugia conditions for wildlife, including grassland birds, pollinators, and other disturbance-sensitive species. Moreover, land management practices such as rotational burning, prescribed grazing, and mowing are often implemented to maintain training infrastructure and visibility, inadvertently sustaining the open structure of native grasslands (Wilkinson et al., 2017). These activities, when guided by ecological best practices, help retain plant diversity, promote floral resource availability, and support early successional habitats critical to many grassland-dependent species.

Numerous landscape-level factors influence the distribution and abundance of native bumble bees in the tallgrass prairie and, specifically, FRMR. Floral resource availability,

particularly the presence and density of forb-dominated patches, plays a central role in determining habitat availability. Previous monitoring indicates substantial annual variability in forb cover across FRMR, with sampling sites exceeding 50% forb composition in 36% of cases in 2019, 5% in 2020, and 59% in 2021 (Gehrt, 2021). Notably, sites with increased forb presence were often associated with areas burned within the previous 24 months, suggesting that prescribed fire contributes to temporal pulses in floral abundance, a key determinant of bumble bee foraging activity (Panzer, 2002; Hartnett et al., 2004).

Collaborative efforts among DoD and conservation organizations have expanded the scope and success of biodiversity stewardship on military lands. Partnerships with the U.S. Fish and Wildlife Service, state wildlife agencies, and conservation nonprofits have led to the development of effective management strategies, including invasive species control, species translocation, ecological restoration, and adaptive monitoring (Miller et al., 2009; Tuggle et al., 2013). These initiatives demonstrate the value of integrating conservation goals with military readiness, and position DoD lands as strategic assets in national pollinator and habitat conservation planning. As anthropogenic pressures on native ecosystems increase, military lands offer an often overlooked but critical refuge for biodiversity. With continued collaboration, robust ecological monitoring, and adaptive management, these landscapes can play a pivotal role in safeguarding pollinators and sustaining the ecological integrity of species-rich habitats such as tallgrass prairie. Unfortunately, knowledge of the status and ecology of native bumble bees in the tallgrass prairie ecoregion and on embedded military lands is limited due to scarce data and information regarding occurrence, abundance and landcover associations of *Bombus* spp. throughout the ecoregion.

Integrating ecological data across multiple spatial scales provides a comprehensive

framework for identifying the drivers of bumble bee population dynamics (Kremen et al., 2007; Winfree et al., 2009). While local floral abundance and phenological diversity can support immediate foraging needs and colony development, long-term species persistence depends on landscape-scale attributes such as habitat connectivity, patch area, and disturbance regimes (Jha & Kremen, 2013; Bennett & Isaacs, 2014). Isolated or degraded patches may offer short-term resources but are often insufficient to support sustainable populations of *Bombus* spp., particularly those with large foraging ranges or specific nesting requirements (Hatfield et al., 2015; Harmon-Threatt, 2020). Consequently, conservation strategies must explicitly account for scale-dependent processes, ensuring that habitat quality is maintained at both local and landscape levels to promote population viability and resilience. This need is especially urgent for declining species of conservation concern experiencing habitat loss and changing land-use conditions.

Challenges and Limitations Related to Understanding *Bombus* Ecology

To fully understand drivers of *Bombus* spp. diversity and abundance across heterogeneous prairie landscapes and FRMR, a suite of environmental predictor variables should be assessed and structured across three spatial scales: landscape, intermediate (unit-level), and local (site-level; Figure 1.2; Table 2.1). This multiscale framework enables a robust assessment of how native bumble bee communities respond to nested environmental gradients and spatial configurations, consistent with ecological theory that pollinator dynamics are influenced by both proximate habitat features and broader landscape context (Hines & Hendrix, 2005; Buckles & Harmon-Threatt, 2019).

Landscape-Scale (Installation-Level) Predictors

At the landscape scale, predictor variables contextualize bumble bee populations within the broader ecological matrix as spatial heterogeneity of land cover and composition (e.g., native

prairie, woodland, and agricultural fields) serves as the backdrop for native bumble bee distribution. This scale reflects macro-patterns of where bees can exist, influenced by the spatial arrangement and proximity of habitat patches, disturbances, and barriers to movement. Variables include habitat connectivity metrics such as nearest-neighbor distances between prairie patches, edge density, and percent native prairie cover within buffer zones of 500 m to 2 km, based on foraging ranges observed in prior studies (Hines & Hendrix, 2005). Landcover composition can be assessed using remote sensing and classified by cover type (e.g., cropland, pasture, woodland, urban), as heterogeneous landscapes have been linked to increased pollinator persistence and seasonal resource continuity (Tonietto et al., 2017). Temporal dynamics are also integrated into this scale through interannual weather variables such as total growing season precipitation, mean maximum temperature, and drought severity indices. These weather predictors are critical for evaluating how long-term environmental change may influence bumble bee population stability, with increasing evidence that increasing temperature, precipitation extremes, and heat stress due to climate change will reduce *Bombus* spp. occupancy in the Great Plains (Cameron et al., 2011; Soroye et al., 2020).

Intermediate-Scale (Unit-Level) Predictors

Intermediate-scale predictors typically operate at the level of defined management units; for example, the 104 training areas across FRMR. Management units are subject to varying intensities of military mechanized training and represent a landscape mosaic of disturbance, restoration, and natural regeneration at FRMR. Extensive anthropogenic disturbance, such as military training intensity (e.g., frequency of tracked vehicle use), is also included as a potential stressor influencing habitat degradation or fragmentation within units.

This scale captures how bumble bees respond to intermediate-level variation in resource

abundance and phenology across the landscape. Ecologically, unit scale encompasses management-defined areas (e.g., military training zones) characterized by specific vegetation regimes, disturbance histories (e.g., haying, fire), and patch cover types. Within these units, floral resource availability, patch connectivity, and vegetation complexity vary in response to management practices. Metrics such as diversity of flowering plants and the proportion of forb cover provide insight into how resource heterogeneity supports different *Bombus* spp. assemblages (Lamke et al., 2022). For instance, prescribed fire may enhance floral diversity in one unit while mechanical disturbance suppresses it in another. These predictors are well-suited to capture spatial variation in native bumble bee communities arising from land management practices and provide a critical lens for assessing how local conservation efforts are nested within broader land-use regimes (Buckles & Harmon-Threatt, 2019).

Local-Scale (Site-Level) Predictors

At the local scale, predictor variables focus on immediate habitat conditions that directly affect bumble bee foraging, nesting, and microclimate site selection. These include floral resource availability, quantified through species richness and flowering density of forbs, as floral diversity has been shown to correlate positively with *Bombus* spp. abundance and richness in prairie systems (Kwaiser & Hendrix, 2008; Hemberger et al., 2021). Additional metrics include vegetation structure (e.g., percent cover of grasses and forbs), availability of nesting substrates such as grass thatch or rodent burrows, and site-specific environmental conditions (e.g., soil temperature and moisture), which have been linked to bumble bee nesting activity and local species composition (Buckles & Harmon-Threatt, 2019). Disturbance history, particularly fire and grazing regimes, is also included as a key local predictor. Patch-burn grazing and rotational prescribed fire are common management tools in Kansas grasslands and influence floral

phenology, bare ground availability, and habitat heterogeneity; all of which are important for supporting bumble bee colonies (LaRose et al., 2020). These localized measurements are critical for identifying priority sites for conservation actions, such as enhancing floral diversity or protecting nesting microhabitats.

Monitoring Status and Trends of *Bombus* spp.

Monitoring local resource use allows for understanding plant-pollinator interactions and determining species-specific floral use at foraging sites (i.e., floral colonies or patches). It is important to note that patch composition (e.g., plant species present, their structural complexity, bloom timing, and connectivity) can vary significantly. This variation affects how native bumble bees utilize the landscape, affecting their foraging efficiency and interactions with local plant communities. Therefore, simply preserving or expanding "natural" habitat is not a one-size-fits-all solution to address population declines. Bumble bees require accessibility between foraging and nesting sites, which is facilitated by diverse, semi-natural environments rather than isolated patches. At broader spatial scales, land-use patterns, climate variability, and historical disturbance regimes further affect bumble bee population viability and dynamics over time and space. Such assessments offer valuable insights into the effects of management practices (e.g., prescribed fire, grazing, and habitat restoration) on bumble bee communities at various spatial and temporal scales (Niemuth et al., 2021). Each scale uniquely contributes to patterns of bee presence, habitat use, and population persistence, particularly within working landscapes subject to anthropogenic disturbances and active land management.

At the local or habitat scale, analyses become most refined, focusing on bumble bee interactions within specific floral patches. In this context, *Bombus* species make foraging decisions based on floral type, density, and blooming stage. Understanding bumble bee habitat

use at this scale also involves examining microhabitat conditions (e.g., seasonal variation and management history) that are pertinent to species-specific habitat use and interspecific plant-pollinator interactions. Surveys conducted at this level assess species richness (n = number of species), abundance (n = number of individuals), and behavioral patterns (e.g., floral selection); thereby providing insights into species-specific foraging decisions.

Despite their capacity for long-distance foraging, *Bombus* spp. exhibit high site fidelity, often limiting their use of available habitat to areas within proximity to nesting sites (Bhattacharya et al., 2003). This behavioral trait has critical implications for habitat restoration, particularly in fragmented landscapes where small or isolated prairie remnants may remain inaccessible to pollinators. Structural barriers such as roads, croplands, and railways can further impede movement and gene flow, thereby reducing the efficacy of isolated restoration efforts (Haddad, 1999; Bhattacharya et al., 2003). Additionally, pollen limitation may constrain reproductive success of rare plant species when pollinator visitation rates are low, particularly in areas where bumble bee populations are sparse or declining (Knight et al., 2005).

These limitations emphasize the need for restoration and monitoring strategies that prioritize habitat connectivity and floral continuity for bumble bees across space and time. Adaptive management approaches (e.g., rotational burning, targeted planting of high-value nectar species, and spatial planning that enhances patch adjacency) can support bumble bee persistence in fragmented prairie systems (Kremen et al., 2007; Carvell et al., 2017).

At FRMR, conservation efforts are increasingly integrated with military land management practices through long-term monitoring and research. Such initiatives are critical not only for supporting existing *Bombus* spp. populations, but also for preparing robust documentation under the Sikes Act, should native bumble bees be listed under the ESA by the

U.S. Fish and Wildlife Service. Continued investment in ecological understanding by active monitoring, including the spatial and temporal dynamics of floral resources, is essential for informing adaptive management, addressing pollinator-specific limitations, and aligning restoration efforts with known behavioral ecology of *Bombus* spp. will be key to ensuring habitat resilience and favorable consultation outcomes on FRMR. Health of native bee communities is closely connected to broader environmental and economic concerns. The purpose of my study is to provide an assessment of native bumble bee species occurrence, habitat associations, and abundance found within the tallgrass prairie of the central Great Plains region. By examining species diversity, habitat use, and pollination dynamics, my research recognizes the importance of preserving these crucial pollinators amid ongoing environmental changes. My research goal was to assess the diversity and abundance of native bumble bee communities relative to tallgrass prairie management regimes and land cover types at Fort Riley Military Installation in the tallgrass prairie of Kansas. My primary objectives were to assess: (1) variation in *Bombus* spp. diversity and abundance relative to land cover, floral type, and prairie management practices, focusing on Southern Plains bumble bee and American bumble bee; (2) the potential for use of distance sampling to estimate bumble bee density; and (3) local-scale relationships between floral resource availability and *Bombus* spp. density through capture-mark-recapture methods. Through an analysis of occurrence, landcover associations, and abundance of native bumble bees, information on the status of these critical pollinators in maintaining the ecoregion's ecological balance and resilience will be provided.

Literature Cited

- American Bumble Bee (NPS National Capital Region Bees and wasps). iNaturalist.
- Bartomeus, I., Ascher, J. S., Wagner, D., Danforth, B. N., Colla, S., et al. (2011). Climate-associated phenological advances in bee pollinators and bee-pollinated plants. *Proceedings of the National Academy of Sciences of the United States of America*, 108(51), 20645–20649.
- Bendel, C. R., Gerges, M., & Villegas, A. G. (2019). Plant–pollinator networks in grassland working landscapes reveal seasonal shifts in network structure and composition. *Ecological Solutions and Evidence*, 1(3), e12006.
- Bennett, A. B., & Isaacs, R. (2014). Habitat enhancement favors wild bees in roadside buffer strips across an agricultural landscape. *Landscape and Urban Planning*, 118, 79–86.
- Bhattacharya, M., Primack, R. B., & Gerwein, J. (2003). Are roads and railroads barriers to bumble bee movement in a temperate suburban conservation area? *Biological Conservation*, 109 (1), 37–45.
- Black, S. H., Vaughan, M., & Shepherd, M. (2007). Pollinators in natural areas: A primer on habitat and best management practices. *Northwestern Naturalist*, 88(2), 1–8.
- Blake, R. J. (2011). Enhancing habitat to help the plight of the bumble bee. *Natural Product Reports*, 28(3), 426–427.
- Blumenthal, D. M., Jordan, N. R., & Svenson, E. L. (2016). Effects of invasive plant management on pollinator species and function. *Biological Invasions*, 18 (4), 1111–1123.
- Bommarco, R., Kleijn, D., & Potts, S. G. (2011). Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology & Evolution*, 26(4), 230–238.
- Briggs, J. M., Knapp, A. K., Blair, J. M., Heisler, J. L., Hoch, G. A., Lett, M. S., & McCarron, J. K. (2005). An ecosystem in transition: causes and consequences of the conversion of mesic grassland to shrubland. *BioScience*, 55 (3), 243–254.
- Cameron, S. A., Lozier, J. D., Strange, J. P., Koch, J. B., Cordes, N., Solter, L. F., & Griswold, T. L. (2011). Patterns of widespread decline in North American bumble bees. *Proceedings of the National Academy of Sciences of the United States of America*, 108(2), 662–667.
- Cameron, S. A., & Sadd, B. M. (2020). Global trends in bumble bee health. *Annual Review of Entomology*, 65, 209–232.
- Cane, J. H., Minckley, R. L., & Kervin, L. J. (2006). Sampling bees (Hymenoptera: Apiformes) for pollinator community studies: pitfalls of pan trapping. *Journal of the Kansas Entomological Society*, 79 (4), 282–231.

- Carvalho, L. G., et al. (2011). Natural and within-farmland biodiversity enhances crop productivity. *Ecology Letters*, 14(3), 251–259.
- Carvell, C., Roy, D. B., Smart, S. M., Pywell, R. F., Preston, C. D., & Goulson, D. (2006). Declines in forage availability for bumble bees at a national scale. *Biological Conservation*, 132(4), 481–489.
- Carvell, C., Meek, W. R., Pywell, R. F., Goulson, D., & Nowakowski, M. (2007). Comparing the efficacy of agri-environment schemes to enhance bumble bee abundance and diversity on arable field margins. *Journal of Applied Ecology*, 44(1), 29–40.
- Carvell, C., Bourke, A. F. G., Dreier, S., Freeman, S. N., Hulmes, S., Jordan, W. C., ... & Heard, M. S. (2017). Bumble bee family lineage survival is enhanced in high-quality landscapes. *Nature*, 543 (7646), 547–549.
- Center for Biological Diversity. (2022, July 27). Petition to list the southern plains bumble bee under the Endangered Species Act. Retrieved from [Center for Biological Diversity petition].
- Colla, S. R., Otterstatter, M. C., Gegear, R. J., & Thomson, J. D. (2006). Plight of the bumble bee: pathogen spillover from commercial to wild populations. *Biological Conservation*, 129(4), 461–467.
- Colla, S. R., & Packer, L. (2008). Evidence for decline in eastern North American bumble bees (Hymenoptera: Apidae), with special focus on *Bombus affinis* Cresson. *Biodiversity and Conservation*, 17(6), 1379–1391.
- Collins, S. L., & Wallace, L. L. (Eds.). (1990). *Fire in North American tallgrass prairies*. University of Oklahoma Press.
- Collins, S. L., & Calabrese, L. B. (2012). Effects of fire, grazing and topographic variation on vegetation structure in tallgrass prairie. *Ecology and Evolution*, 2(12), 3166–3168.
- Crone, E. E., & Williams, N. M. (2016). Bumble bee colony dynamics: Quantifying the importance of land use and floral resources for colony growth and queen production. *Ecology Letters*, 19(4), 460–468.
- Dauber, J., Petit, S., & Goulson, D. (2010). Effects of patch size and density on flower visitation. *Journal of Ecology*, 98(1), 188–196.
- Department of Defense. (2021). 2021 DoD Natural Resources Program Annual Report to Congress. Office of the Assistant Secretary of Defense for Sustainment.
- Fahrig, L. (2001). How much habitat is enough? *Biological Conservation*, 100(1), 65–74.
- Fahrig, L. (2002). Effect of habitat fragmentation on the extinction threshold. *Ecological Applications*, 12(2), 346–353.

- Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, 34, 487–515.
- Fandre, T. (2018, April 2). Brown-belted bumble bee (*Bombus griseocollis*). iNaturalist.
- Ficetola, G. F., & Denoël, M. (2009). Ecological thresholds: A tool for species–habitat relationships. *Biological Conservation*, 142(12), 2766–2771.
- Frid, A., & Dill, L. M. (2002). Human-caused disturbance stimuli as a form of predation risk. *Conservation Ecology*, 6(1), 11.
- Fuhlendorf, S. D., & Engle, D. M. (2001). Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns. *BioScience*, 51(8), 625–632.
- Fuhlendorf, S. D., & Engle, D. M. (2004). Application of the fire–grazing interaction to restore a shifting mosaic on tallgrass prairie. *Journal of Applied Ecology*, 41(4), 604–614.
- Garibaldi, L. A., Steffan-Dewenter, I., Kremen, C., Morales, J. M., Bommarco, R., Cunningham, S. A., Carvalheiro, L. G., & Klein, A.-M. (2011). Stability of pollination services decreases with isolation from natural areas despite honey bee visits. *Ecology Letters*, 14(10), 1062–1072.
- Garibaldi, L. A., Aizen, M. A., Klein, A.-M., Cunningham, S. A., & Harder, L. D. (2011). Global growth and stability of agricultural yield decrease with pollinator dependence. *Proceedings of the National Academy of Sciences*, 108(14), 5909–5914.
- Garibaldi, L. A., Steffan-Dewenter, I., Winfree, R., Aizen, M. A., Bommarco, R., Cunningham, S. A., ... & Klein, A. M. (2013). Wild pollinators enhance fruit sets of crops regardless of honeybee abundance. *Science*, 339(6127), 1608–1611.
- Gleason, H. A., & Cronquist, A. (1991). *Manual of vascular plants of northeastern United States and adjacent Canada* (2nd ed.). The New York Botanical Garden Press.
- Goulet, M. (2023, May 14). Two-spotted bumble bee (*Bombus bimaculatus*). iNaturalist.
- Goulson, D. (2008). Decline and conservation of bumble bees. *Annual Review of Entomology*, 53, 191–208.
- Goulson, D., Nicholls, E., Botías, C., & Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, 347(6229), 1255957.
- Grixti, J. C., Wong, L. T., Cameron, S. A., & Favret, C. (2009). Decline of bumble bees (*Bombus*) in the North American Midwest. *Biological Conservation*, 142(1), 75–84.
- Haddad, N. M. (1999). Corridor use predicted from behaviors at habitat boundaries. *American Naturalist*, 153(2), 215–227.

- Harmon-Threatt, A. N. (2020). Influence of nesting characteristics on health of wild bee communities. *Annual Review of Entomology*, 65, 39–56.
- Hartnett, D. C., Cochran, R. C., & Owensby, C. E. (2004). Grazing management: Ecosystem responses. In *Ecology and management of grassland and tallgrass prairie ecosystems*. Kansas State University Extension.
- Hegland, S. J., & Boeke, L. (2006). Relationships between the density and diversity of floral resources and flower visitor activity in a temperate grassland community. *Ecological Entomology*, 31(5), 532–538.
- Hemberger, J., Crossley, M. S., & Gratton, C. (2021). Historical decrease in agricultural landscape diversity is associated with shifts in bumble bee species occurrence. *Ecology Letters*, 24(8), 1800–1813.
- Hendrickson, E. B., Kline, J. W., & Crow, P. B. (2021). Pollinator diversity in tallgrass prairie ecosystems. *Ecological Applications*, 31(2), e02165.
- Hines, H. M., & Hendrix, S. D. (2005). Bumble bee (Hymenoptera: Apidae) diversity and abundance in tallgrass prairie patches: Effects of local and landscape floral resources. *Environmental Entomology*, 34(6), 1477–1484.
- Howe, H. F. (1994). Response of early- and late-flowering plants to fire season in experimental prairies. *Ecological Applications*, 4(1), 121–133.
- Jha, S., & Kremen, C. (2013). Urban land use limits regional bumble bee gene flow. *Molecular Ecology*, 22(9), 2483–2495.
- Jessica. (2015, July 28). Black-and-gold Bumble Bee (*Bombus auricomus*). iNaturalist.
- Johnson, D. H. (1980). The comparison of usage and availability measurements for evaluating resource preference. *Ecology*, 61(1), 65–71.
- Kerr, J. T., Pindar, A., Galpern, P., Packer, L., Potts, S. G., Roberts, S. M., ... & Colla, S. R. (2015). Climate change impacts on bumble bees converge across continents. *Science*, 349(6244), 177–180.
- Kieschnick, S. (2018, May 2). Southern plains bumble bee (*Bombus fraternus*). iNaturalist.
- Knight, T. M., Steets, J. A., Vamosi, J. C., Mazer, S. J., Burd, M., Campbell, D. R., ... & Ashman, T. L. (2005). Pollen limitation of plant reproduction: pattern and process. *Annual Review of Ecology, Evolution, and Systematics*, 36, 467–497.
- Koh, I., Lonsdorf, E. V., Williams, N. M., Brittain, C., Isaacs, R., Gibbs, J., & Ricketts, T. H. (2016). Modeling the status, trends, and impacts of wild bee abundance in the United States. *Proceedings of the National Academy of Sciences*, 113(1), 140–145.

- Kremen, C., Williams, N. M., & Thorp, R. W. (2007). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences*, 99(26), 16812–16816.
- Kwaiser, K. S., & Hendrix, S. D. (2008). Diversity and abundance of bees (Hymenoptera: Apiformes) in native and ruderal grasslands of agriculturally dominated landscapes. *Agriculture, Ecosystems & Environment*, 124(3), 200–204.
- Lamke, K. E., Wedin, D. A., & Wu-Smart, J. Y. (2022). Remnant prairies and high-diversity restorations work together to support wild bees all season. *Prairie Naturalist*, 54(Special Issue 1), 30–40.
- Larson, J. L., Kesheimer, A. J., & Potter, D. A. (2018). Pollinator assemblages on dandelions and white clover in turfgrass lawns. *Journal of Insect Conservation*, 18(5), 863–873.
- LaRose, J. P., Webb, E. B., & Finke, D. L. (2020). Comparing native bee communities on reconstructed and remnant prairies in Missouri. *Prairie Naturalist*, 52(2), 31–41.
- Liczner, A. R., & Colla, S. R. (2020). A systematic review of the nesting and overwintering habitat of bumble bees globally. *Journal of Insect Conservation*, 24(5), 805–820.
- Lindenmayer, D. B., & Likens, G. E. (2009). Adaptive monitoring: a new paradigm. *Trends in Ecology & Evolution*, 24(9), 482–486.
- Mayor, S. J., Schneider, D. C., Schaefer, J. A., & Mahoney, S. P. (2009). Habitat selection at multiple scales. *Écoscience*, 16(2), 238–247.
- Miller, B. J., Reading, R. P., Forrest, S. C., & Ceballos, G. (2009). The role of military lands in the conservation of biodiversity. *Conservation Biology*, 23(3), 588–590.
- Morandin, L. A., & Kremen, C. (2013). Bee species diversity and habitat quality. *Ecological Applications*, 23(4), 928–938.
- Morrison, M. L. (2013). *Restoring wildlife: ecological concepts and practical applications*. Island Press.
- Nielsen, S. E., Cranston, J., & Stenhouse, G. B. (2018). Identifying risk: modeling human disturbance to grizzly bears in a landscape of human access. *Ecology and Evolution*, 8(12), 6284–6298.
- Niemuth, N. D., et al. (2021). Conservation planning for pollinators in the U.S. Great Plains. *Ecological Solutions and Evidence*, 2, e12043.
- Osborne, J. L., Clark, S. J., Morris, R. J., Williams, I. H., Riley, J. R., Smith, A. D., Reynolds, D. R., & Edwards, A. S. (2008). Bumble bee flight distances in relation to the forage landscape. *Journal of Animal Ecology*, 77(2), 406–415.

- Otto, C.R.V., Zheng, H., Gallant, A.L., Iovanna, R., Carlson, B.L., Smart, M.D., and Hyberg, S., 2018, Past role and future outlook of the Conservation Reserve Program for supporting honey bees in the Great Plains: Proceedings of the National Academy of Sciences, 115(29), 7629–7634.
- Panzer, R. (2002). Compatibility of prescribed burning with the conservation of insects in small, isolated prairie reserves. *Conservation Biology*, 16(5), 1296–1307.
- Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution*, 25(6), 345–353.
- Pyke, G. H., Thomson, J. D., Inouye, D. W., & Miller, T. J. (2016). Effects of climate change on phenologies and distributions of bumble bees and the plants they visit. *Ecosphere*, 7(3), e01267.
- Rahimi, E., Hashemi, M., Rashedi, E., & Safari, R. (2021). Changes in pollinator visitation and foraging behavior in response to floral resource distribution in agricultural landscapes. *Environmental Entomology*, 50(4), 823–832.
- Reichman, O. J. (1987). *Konza Prairie: A Tallgrass Natural History*. University Press of Kansas.
- Ricketts, T. H., Regetz, J., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., Bogdanski, A., ... & Viana, B. F. (2008). Landscape effects on crop pollination services: Are there general patterns? *Ecology Letters*, 11(5), 499–515.
- Scholtz, R., & Twidwell, D. (2022). The Great Plains: a stronghold for North America's grassland biome. *Rangeland Ecology & Management*, 81, 58–66.
- Schweitzer, D. F., Capuano, N., Young, B. E., & Colla, S. R. (2012). Conservation and management of North American bumble bees (p. 10). *NatureServe and U.S. Forest Service*.
- Snfreeman. (2020, June 14). Common eastern bumble bee (*Bombus impatiens*). iNaturalist.
- Soroye, P., Newbold, T., & Kerr, J. T. (2020). Climate change contributes to widespread declines among bumble bees across continents. *Science*, 367(6478), 685–688.
- Stein, B. A., Scott, C., & Benton, N. (2008). Federal lands and endangered species: the role of military and other federal lands in sustaining biodiversity. *BioScience*, 58(4), 339–347.
- Steuter, A.A., Steinauer, E.M., Hill, G.L., Bowers, P.A., & Tieszen, L.L. (1995). Distribution and diet of bison and pocket gophers in a Sandhills Prairie. *Ecological Applications* 5:756–766.
- Sutter, R. D., Comer, P. J., & Braun, D. P. (2002). Ecological stewardship of military lands: integrating mission and conservation on Department of Defense lands in the United States. *Armed Forces & Society*, 29(2), 197–219.

- Thomann, M., Imbert, E., Devaux, C., & Cheptou, P.-O. (2013). Flowering plants under global pollinator decline. *Trends in Plant Science*, 18(7), 353–359.
- Tonietto, R., Fant, J., Ascher, J., Ellis, K., & Larkin, D. (2011). A comparison of bee communities of Chicago green roofs, parks and prairies. *Landscape and Urban Planning*, 103(1), 102–110.
- Tonietto, R. K., Ascher, J. S., Ellis, K., & Larkin, D. J. (2017). Bee communities along a prairie restoration chrono sequence: similar abundance and diversity, but distinct composition. *Ecological Applications*, 27(2), 705–717.
- Tonietto, R. K., & Larkin, D. J. (2018). Habitat restoration benefits wild bees: a meta-analysis. *Journal of Applied Ecology*, 55(2), 582–590.
- Towne, E. G., & Kemp, K. E. (2003). Vegetation dynamics from annually burning tallgrass prairie. *Journal of Range Management*, 56(2), 185–192.
- Tuggle, B. N., Packard, J. M., & Miller, P. S. (2013). Conserving species on Department of Defense lands: A strategic model for success. *Natural Areas Journal*, 33(1), 52–59.
- Twidwell, D., Rogers, W. E., Fuhlendorf, S. D., Wonkka, C. L., Engle, D. M., Weir, J. R., Kreuter, U. P., & Taylor Jr., C. A. (2013). The rising Great Plains fire campaign: Citizens' response to woody plant encroachment. *Frontiers in Ecology and the Environment*, 11(Online Issue 1), e64–e71.
- U.S. Fish and Wildlife Service (USFWS). (2021). Endangered Species Act status review: *Bombus pensylvanicus* (American bumble bee).
- U.S. Department of Agriculture (USDA). (2020). Introduced, invasive, and noxious plants. Natural Resources Conservation Service.
- Vanbergen, A. J., & the Insect Pollinators Initiative. (2013). Threats to an ecosystem service: Pressures on pollinators. *Frontiers in Ecology and the Environment*, 11(5), 251–259.
- Wilkinson, T. L., Maron, M., & Possingham, H. P. (2017). Opportunities for conserving threatened species on military lands. *Conservation Letters*, 10(6), 743–750.
- Williams, N. M., Crone, E. E., Roulston, T. H., Minckley, R. L., Packer, L., & Potts, S. G. (2010). Ecological and life-history traits predict bee species responses to environmental disturbances. *Biological Conservation*, 143(9), 2280–2291.
- Williams, P. H., Thorp, R. W., Richardson, L. L., & Colla, S. R. (2012). *Bumble bees of North America: An identification guide*. Princeton University Press.
- Winfree, R., et al. (2009). A meta-analysis of bees' responses to anthropogenic disturbance. *Ecology*, 90(8), 2068–2076.

- Winfree, R., Bartomeus, I., & Cariveau, D. P. (2011). Native pollinators in anthropogenic habitats. *Annual Review of Ecology, Evolution, and Systematics*, 42, 1–22.
- Wright, C. K., & Wimberly, M. C. (2013). Recent land use change in the Western Corn Belt threatens grasslands and wetlands. *Proceedings of the National Academy of Sciences of the United States of America*, 110(10), 4134–4139.



American bumblebee



Southern Plains bumblebee



Black and Gold bumblebee



Common Eastern bumblebee



Brown-Belted bumblebee



Two-spotted bumblebee

Figure 1. 1. Representative images of the six native bumble bee species documented within the tallgrass prairie ecoregion at Fort Riley Military Reservation, Kansas. Species depicted include: American bumble bee (*B. pensylvanicus*), Southern Plains bumble bee (*B. fraternas*), Black and Gold bumble bee (*B. auricomus*), Common Eastern bumble bee (*B. impatiens*), Brown-belted bumble bee (*B. griseocollis*), and Two-spotted bumble bee (*B. bimaculatus*).

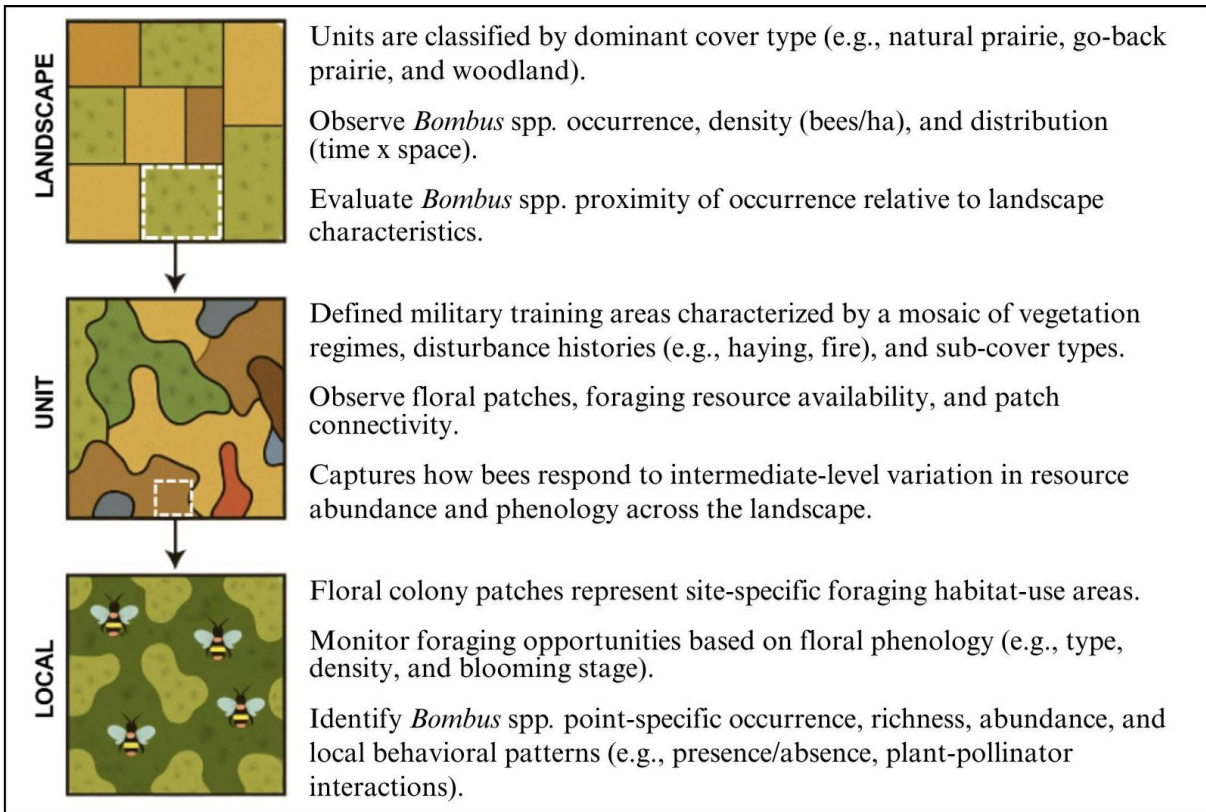


Figure 1. 2. Conceptual diagram illustrates the integration of spatial and temporal scales concerning native bumble bee (*Bombus* spp.) populations in prairie ecosystems. Local, unit, and landscape scales capture scale-specific responses to floral resources, habitat structure, and land cover configuration. This hierarchical approach supports spatially informed pollinator conservation (Hines & Hendrix, 2005; Buckles & Harmon-Threatt, 2019).

Table 1. 1. Framework outlining the hierarchical assessment of *Bombus* spp. ecology across three spatial scales: local (site-level), unit, and landscape. Highlighted are scale-specific management relevance, linking observational metrics to conservation applications such as floral enhancement (local), treatment timing (unit), and regional habitat prioritization (landscape).

	Local Scale (<i>Site-level</i>)	Unit Scale	Landscape Scale
Habitat Use	Determined by fine-scale floral availability, phenology, and habitat conditions, shaping foraging patterns and site use.	Influenced by resource patchiness, vegetation structure, and disturbance history (e.g., fire, haying).	Shaped by connectivity of foraging habitat, land cover composition, and distribution of remnant prairie patches.
Behavioral Indicators	Observed as floral richness, seasonal phenology, and species preference within patches.	Detected through species turnover across management types and floral patch aggregation.	Reflected in range-wide occupancy, dispersal limitation, and community structure along habitat gradients
Population Metrics	Total captures (n = individuals), richness (n = species), and site-level occurrence (e.g., species presence/absence).	Changes in <i>Bombus</i> spp. community composition in response to habitat conditions and management practices.	Patterns of species density and occupancy modeled across ecoregional land cover mosaics.
Dominant Drivers	Floral abundance, bloom frequency and phenology, and disturbance timing.	Vegetation heterogeneity, treatment history, edge effects, and floral resource continuity.	Habitat connectivity, prairie fragmentation, climate variability, and land use composition.
Management Relevance	Guides placement of floral enhancement and areas for conservation planning.	Informs scale and timing of prescribed burns, mowing, or invasive removal.	Supports landscape-level conservation planning and prioritization of core pollinator habitat.

Chapter 2 – Community Composition and Landcover Associations of Native Bumble bees (*Bombus* spp.) on Fort Riley Military Reservation

Introduction

Bumble bees (*Bombus* spp.) serve as essential pollinators of native grassland forbs and agricultural crops, supporting plant reproductive success, sustaining floral diversity, and enhancing ecosystem resilience (Goulson, 2010; Potts et al., 2010). Despite ecological significance, *Bombus* spp. have experienced substantial declines in abundance and distribution, prompting concern for pollinator conservation across Great Plains ecosystems (Biesmeijer et al., 2006; Burkle & Alarcón, 2011). Of conservation concern are Southern Plains bumble bee (*B. fraternus*) and American bumble bee (*B. pensylvanicus*), with an estimated 89% decline in population over the past 20 years (Richardson, 2020). In 2021, the United States Fish and Wildlife Service initiated formal reviews to assess population status of both species under Endangered Species Act provisions (USFWS, 2021). These evaluations, along with recent listing petitions for additional prairie-dependent pollinator species (e.g., regal fritillary, *Speyeria idalia*), reinforce concerns about grassland pollinator declines and need for spatially explicit monitoring frameworks to guide targeted conservation strategies within prairie ecosystems (USFWS, 2021; Wagner et al., 2021).

Bumble bees serve as effective indicator species for assessing environmental quality and habitat health, especially regarding species-specific ecological thresholds (Hatfield et al., 2015; Carvell et al., 2006). At the landscape level, *Bombus* species require diverse landcover mosaics across landscapes that provide floral foraging opportunities, nesting sites, and connectivity among habitat patches (Kremen et al., 2007; Ricketts et al., 2008). Greater heterogeneity in

landcover types is positively correlated with greater *Bombus* species richness, whereas the isolation of grassland remnants can create ecological traps, reducing species abundance and diversity (Hodgson et al., 2009; Prendergast et al., 2022). Contributing to the isolation of native grassland remnants, spread of exotic or invasive plant species degrades habitat quality, often decreasing the availability of key native flowers that are crucial for maintaining diverse bumble bee populations (Morandin & Kremen, 2013).

At finer spatial scales, such as within prairie patches or individual field plots, native bumble bees rely on specific plant species and microhabitat conditions that support foraging, nesting, and colony development (Goulson et al., 2008). Availability and distribution of these resources can fluctuate across seasons due to weather variability, land management practices, and natural phenological cycles (Devoto et al., 2014; Liczner & Colla, 2020). Because bumble bees exhibit seasonal foraging patterns aligned with the flowering phenology of native plants, shifts in bloom timing or floral availability may disrupt plant–pollinator interactions and compromise colony success (Hatfield & LeBuhn, 2007; Villanueva-Gutiérrez et al., 2015). Prioritizing conservation and restoration of temporally stable, florally diverse patches is therefore essential to support bumble bee persistence in prairie systems.

Variation in *Bombus* spp. abundance and distribution often reflect changes in land use, vegetation, and disturbance patterns, making them valuable for monitoring habitat degradation and evaluating the success of restoration efforts in grassland landscapes (Kearns & Thomson, 2001; Winfree et al., 2009; Williams et al., 2010; Goulson et al., 2015). Therefore, assessing bumble bee community composition and associations in relation to management practices and landscape characteristics is the initial step in the evaluation of *Bombus* spp. occurrence, density, and persistence within a specific area (Niemuth et al., 2021).

The American bumble bee is currently under formal review for listing under the 1973

Endangered Species Act due to widespread declines in range and abundance across much of its native habitat (USFWS, 2021). The Southern Plains bumble bee is designated as a Species of Greatest Conservation Need in multiple states and also under petition for federal listing, with populations considered critically imperiled due to habitat loss and fragmentation (Hatfield et al., 2015; USFWS, 2024). Given the documented and ongoing decline of native pollinators, including bumble bee species, the lack of baseline data on their occurrence, abundance, distribution, and landcover associations within tallgrass prairie ecosystems presents a concern, particularly regarding potential ecological effects on future military land use and management.

Fort Riley Military Reservation (hereafter Fort Riley), a 40,000-ha U.S. Army installation located in the Flint Hills of northeastern Kansas, provides a rare opportunity to study *Bombus* spp. in one of the largest remaining tracts of contiguous tallgrass prairie. Managed under the U.S. Army's Integrated Training Area Management (ITAM) framework, Fort Riley balances intensive land use, including mechanized training, infrastructure development, and vegetation management, with ecological monitoring and conservation objectives. Prairie units at Fort Riley are exposed to diverse disturbances, including prescribed burning, rotational haying, and military vehicle traffic. These activities result in a structurally heterogeneous landscape offering dispersed patches for *Bombus* spp. foraging and nesting opportunity. As mandated by the Sikes Act of 1960, the U.S. Department of Defense (DoD) is required to conserve and monitor natural resources on its lands while maintaining military readiness.

Pollinators contribute to vegetation regeneration, soil stabilization, and ecosystem resilience, all of which directly affect sustainability of training areas and fire management regimes. Monitoring native bumble bee populations in this setting helps fulfill DoD conservation mandates while identifying needs for at-risk species of concern. Understanding how *Bombus* spp. respond to disturbance and landcover variability on Fort Riley informs adaptive management

strategies that jointly support mission readiness and long-term ecological stewardship (DoD, 2021).

My objective was to evaluate *Bombus* spp. community composition and landcover associations on Fort Riley. Site-level occurrence and composition was quantified using standardized capture data across three field seasons (2022–2024). Landcover associations were determined based on environmental variables associated with capture sites. This study addressed three questions: (1) how *Bombus* spp. occurrence and abundance vary among landcover types; (2) how management regimes influence community composition; and (3) whether species of conservation concern differ in habitat use from common species. It was hypothesized that habitat use would vary among species, with specialists and at-risk taxa showing stronger fidelity to specific landcover types, while generalists occur across multiple habitats. Native prairie and floristically rich go-back grasslands were expected to support greater richness and abundance, and low-intensity or rotational management was predicted to benefit diversity. Additionally, recently burned or hayed sites were expected to have lower abundance initially but recover later in the season.

Methods

Study Area

Fort Riley is located in the northern Flint Hills of Kansas, covering 101,000 acres (40,725 ha), encompassing a great extent of the original tallgrass prairie (Figure 2.1). The Flint Hills is North America's largest remaining continuous area of tallgrass prairie (Scholtz & Twidwell, 2022). Most tallgrass prairie has been converted into farmland, resulting in habitat fragmentation and loss for many grassland species. However, Fort Riley has managed to preserve a significant part of this endangered prairie ecosystem due to its military status, which has limited large-scale

agricultural activities (Kahn, 2007). Approximately 31,000 ha within FRMR are used for military training, habitat conservation, wildlife management, and public recreation. Unlike surrounding privately owned lands, cattle grazing is prohibited on FRMR, resulting in less disturbance intensity and greater retention of native prairie structures.

Vegetation across FRMR includes native prairie remnants, go-back grasslands (i.e., formerly disturbed sites undergoing restoration), hayfields, and cultivated plots planted for wildlife. These areas provide critical floral and nesting resources for native *Bombus* species, which require continuous seasonal forage and undisturbed substrates for successful colony establishment (Collins & Smith, 2006; Harmon et al., 2011). I classified land cover into seven categories (Table 2.1): natural prairie, go-back prairie (i.e., previously cropland transitioning back to grassland through natural regeneration or restoration), cultivated areas (i.e., food plots), woodland/shrubland, early successional habitat, bare ground, and cool-season grasses. Additionally, fire and hay frequency represented land management categories across units.

Units were defined as 104 designated training areas, averaging 302 ha (range: 118–642 ha), representing the comprised study area (Figure 2.2). These units represent intermediate-scale zones used for military training activity and management regimes (e.g., fire and haying rotations). Prescribed burns are conducted from late winter through fall, primarily in early spring, to reduce woody encroachment and maintain vegetation heterogeneity. Fire return intervals vary considerably: 17% of area burns on a ≤ 2 -year interval, 70% burns every 2–4 years, 6% every 4–8 years, and 7% at > 8 -year intervals (Gehrt, 2021). Approximately 3,950 ha are burned annually. Wildfires occur irregularly, often initiated by lightning or military munitions during live training exercises.

Haying is conducted under rotational lease agreements administered by Fort Riley Environmental Division. Leases specify cutting schedules (annual, even-year, or odd-year

harvests) and target vegetation types (warm- or cool-season grasses) based on dominant cover. All haying activities occur between 15 July and 15 August, with vegetation mechanically removed (Gehrt, 2021). On average, haying affects 11,717 ha across 41 units, though annual area varies with weather and landowner participation (Fort Riley INRMP, 2015).

The climate of Fort Riley is temperate and continental, characterized by hot summers, cold winters, and moderate precipitation. Annual rainfall averages approximately 85 cm, with nearly 75% occurring between April and September. During 2022–2024, pronounced interannual climatic variation was observed. In 2022, growing season precipitation was near average (~64 cm), supporting stable floral conditions. In contrast, 2023 experienced an exceptionally wet spring and early summer, with April–June totals exceeding 70 cm (~15–20% above average) and accompanied by frequent convective storms. By 2024, precipitation declined sharply during late summer, resulting in moderate drought stress across multiple training areas. Maximum daytime temperatures from May through August consistently exceeded 32°C across all years, with multiple days surpassing 36°C, particularly during late June, potentially limiting mid-day foraging opportunities (NOAA, 2024; WeatherSpark, 2024).

***Bombus* spp. Capture Surveys**

I conducted site-level monitoring using standardized capture surveys to determine *Bombus* spp. community composition during 1 May to 30 August over three consecutive years: 2022 ($n = 12$ sites), 2023 ($n = 21$), and 2024 ($n = 11$), totaling 44 unique floral colony sites (Figure 2.3). Sites were selected based on preliminary floral surveys that identified high-density nectar-producing forb patches, referred to as floral colonies. Site selection was stratified to include variation in cover types and management histories, including burned, hayed, go-back, and native prairie units. At each floral colony sampling site, 3–4 capture series events were conducted within a week during each temporal sampling bout, each separated by at least 24

hours. Each series lasted three person-hours (one hour per individual across a three-person crew). Bumble bees were individually captured using insect nets, stored temporarily in waterproof vials on ice, and later identified to species and released at the capture site. Species richness and relative abundance were quantified at the site level and standardized by survey effort.

***Bombus* spp. Landcover Association**

To evaluate *Bombus* spp. landcover associations beyond point-specific floral patches, intermediate-scale assessments were conducted within Fort Riley's defined training units containing capture sites. These units, which represent spatially distinct management zones subject to heterogeneous land use, allowed evaluation of species occurrence in relation to unit-scale structural composition, management history, and floral resource availability.

Each capture site was georeferenced and assigned to its respective training unit using ArcGIS Pro. Spatial analyses incorporated vegetation and management data from Fort Riley's Integrated Natural Resources Management Plan, as well as landcover classifications from the National Land Cover Dataset and Fort Riley's Knowledge-based Environmental Management System (KEMS) vegetation layers inventory. To characterize the foraging-scale environment relevant to *Bombus* spp., a 500-m buffer was established around each capture site, consistent with known bumble bee foraging distances in fragmented or resource-limited systems (Darvill et al., 2004; Knight et al., 2005). These central-place foragers typically restrict activity to within 500–750 m of the nest, with greatest foraging effort concentrated within 500 m. Within each unit and buffer subset, proportional cover was calculated for seven primary landcover types: native prairie, go-back prairie, shrubland/woodland, early successional habitat, cool-season grasses, bare ground, and cultivated land (e.g., food plots; Table 2.1).

Management regime classifications included presence or absence of prescribed fire and haying, as well as their recurrence interval and spatial coverage. Fire regime history was

quantified as the mean fire frequency per buffer polygon, calculated as the total number of prescribed burns or wildfires over a 21- to 23-year period, depending on site-year availability. This metric served as a proxy for cumulative disturbance exposure. It was used in conjunction with landcover variables as a predictor in examining species-level responses to intermediate-scale environmental gradients. To evaluate landscape-level influences on *Bombus* spp. communities, all 104 training units at Fort Riley were classified into one of three dominant landcover types based on vegetation structure, land-use history, and dominant cover features: natural prairie ($n = 52$), go-back prairie ($n = 39$), and woodland/shrubland ($n = 13$; Figure 2.3). Classification was derived using Fort Riley KEMS vegetation layers and field verification of structural composition.

To examine multivariate associations between species composition and environmental gradients, I executed a Canonical Correspondence Analysis (CCA) using *cca()* function in *vegan* package in Program R. Capture data were ordinated against unit-level environmental predictors, including proportional landcover composition and documented management regimes (e.g., presence/absence of fire, haying, or restoration of disturbed areas), to visualize species–habitat associations and specialization patterns across Fort Riley’s landscape. Ordination axes represent gradients that explain the largest variation in species occurrence across sites. Species are displayed as points in multidimensional ordination space, where proximity reflects ecological similarity. Species clustered near one another exhibit shared affinities, while greater distance among points indicates divergent ecological preferences. Environmental variables are represented as vectors (arrows), where direction indicates increasing variable values and vector length represents strength of influence on species composition. Species oriented along the same trajectory as an environmental vector suggest a positive association with that gradient, whereas species opposing a vector exhibit weak or negative associations. Interpretation of ordination

results emphasized identification of dominant ecological gradients structuring *Bombus* spp. communities across Fort Riley.

Results

A total of 15,596 individual bumble bees were captured during three field seasons (2022–2024), across 44 unique sampling sites representing six native *Bombus* species: Brown-belted bumble bee, American bumble bee, Southern Plains bumble bee, Black and Gold bumble bee (*B. auricomus*), Two-spotted bumble bee (*B. bimaculatus*), and Common Eastern bumble bee (*B. impatiens*; Table 2.2). Across these sites, 37 unique floral colonies were identified: 10 in 2022, 18 in 2023, and 9 in 2024. Among these, five dominant floral types were most frequently observed across years and sample bouts: tall thistle (*Cirsium altissimum*), roundhead prairie clover (*Dalea multiflora*), wild bergamot (*Monarda fistulosa*), partridge pea (*Chamaecrista fasciculata*), and milkweed (*Asclepias* spp.).

Three bumble bee species accounted for >80% of all captures: Brown-belted bumble bee (5,618 individuals; 36%), Black and Gold bumble bee (3,826; 25%), and American bumble bee (3,412; 22%). Southern Plains bumble bee comprised 13% of total abundance, while Two-spotted and Common Eastern bumble bees each represented just 2% of individuals captured (Figure 2.5). Total bumble bee captures peaked in 2023 ($n = 8,543$), followed by 2022 ($n = 4,037$) and 2024 ($n = 3,016$). Despite this variation, site-level species richness remained consistently high across years and bouts, ranging from 4 to 6 species per site (mean $\pm$ SD = 5.0 ± 0.4), indicating strong community diversity and persistence of all six species across seasons for all floral colony types.

Seasonal patterns were identified across annual and bout-specific capture data. Early-season communities (i.e., May – June) were dominated by Brown-belted and American bumble

bees, while late-season (i.e., July – August) captures dominantly shifted toward Black and Gold bumble bee and Southern Plains bumble bee. Notably, Brown-belted bumble bee declined across all late-season surveys, while Black and Gold bumble bee doubled in abundance in the same period. Two-spotted and Common Eastern bumble bees remained rare across all years, each contributing <2% of total captures.

Of 104 units, 33 unique units contain capture sites, collectively encompassing 9,434.4 ha: 2022 (11 units), 2023 (20 units), and 2024 (10 units), with eight overlapping across field seasons. Total surveyed floral area across units equaled 60.76 ha: 37.87 ha in 2023 and 22.89 ha in 2024. Although surveyed floral patches represented <1% of the average management unit area, these patches serve as a lens for biologically significant zones of bumble bee habitat use. Within 500-m buffers surrounding each capture site, landcover composition and disturbance history varied across all 44 surveyed site-year combinations. Minor interannual fluctuations in cool-season grass and early successional vegetation were observed, but overall structure remained strongly dominated by native prairie types. The CCA plot revealed distinct species–habitat relationships among native *Bombus* spp. at Fort Riley (Figure 2.5). Results depict all six bumble bee species: the American bumble bee, Southern Plains bumble bee, Brown-belted bumble bee, Black and Gold bumble bee, Common Eastern bumble bee, and Two-spotted bumble bee. American bumble bee and Brown-Belted bumble bee both exhibited positive associations with native grass cover and sites with longer time since fire (i.e., mean fire return interval). The Southern Plains bumble bee exhibited a weak but positive association with cool-season grasses and a negative association with woodlands. Black and Gold bumble bee clustered near the plot origin, showing a more generalist distribution across cover types, although with a slight directional affinity toward bare ground and early successional land cover. Common Eastern bumble bee was positively associated with woodland cover but strongly separated from other *Bombus* spp. and

distanced from all other environmental variables. Two-Spotted was strongly associated with early successional shrubland cover and bare ground.

Discussion

This study documents the composition and landcover associations of six native *Bombus* species across Fort Riley Military Reservation from 2022–2024, providing one of the most comprehensive community-level assessments of tallgrass prairie bumble bees within the Flint Hills ecoregion. Results indicate that, despite regional declines in prairie-dependent pollinators, Fort Riley supports a diverse and stable *Bombus* assemblage across multiple years and management contexts. Variation in seasonal community structure and clear species-specific landcover associations suggest that both floral phenology and habitat configuration influence *Bombus* spp. occurrence at the site and unit scale.

Community Composition and Temporal Stability

Across three years, all six native *Bombus* species known to occur in the tallgrass ecoregion were detected, with site-level richness remaining consistently high (mean $\pm$ SD = 5.0 ± 0.4 species) despite variation in annual capture totals. This temporal stability suggests resilience of the *Bombus* community within Fort Riley, a landscape buffered from the intensive agricultural conversion and grazing pressures that dominate surrounding lands (Scholtz & Twidwell, 2022). The dominance of Brown-belted bumble bee, Black and Gold bumble bee, and American bumble bee, together accounting for >80% of all captures, parallels patterns observed in other Midwestern prairie systems where generalist foragers with broad floral diets maintain relatively larger abundances (Colla & Packer, 2008; Goulson et al., 2008).

Interannual variation in total captures likely reflects a combination of climatic and phenological factors. Captures peaked in 2023, corresponding with above-average spring

precipitation, which likely increased early-season floral resource availability and supported robust colony establishment. Conversely, 2024 capture numbers were lower, potentially due to late-summer drought stress limiting floral availability during peak reproductive phases. Such fluctuations emphasize the influence of interannual climatic variability on pollinator populations in prairie ecosystems (Burkle & Alarcón, 2011; Crone & Williams, 2016).

Seasonal Turnover and Floral Phenology

Clear seasonal turnover was detected in dominant species. Early-season communities were characterized by larger relative abundances of Brown-belted and American bumble bees, while late-season surveys recorded an increase in Black and Gold bumble bees and Southern Plains bumble bees. This shift likely reflects species-specific phenologies, with early-season species exploiting spring and early summer blooms, and later-emerging species benefiting from mid- to late-summer forbs such as tall thistle and partridge pea (Williams et al., 2012; Harmon-Threatt, 2020). The decline in Brown-belted bumble bee abundance during late-season bouts, concurrent with increases in Black and Gold bumble bee, underscores the role of temporal floral resource succession in structuring *Bombus* community composition. Maintaining a heterogeneous floral phenology across the landscape is therefore critical for supporting the full seasonal breadth of bumble bee activity.

Landcover Associations and Habitat Preferences

Results from the canonical correspondence analysis revealed distinct landcover associations among species, suggesting varying degrees of habitat specialization. American bumble bee and Brown-belted bumble bee showed positive associations with native prairie cover dominated floral colonies and sites with longer fire return intervals. These associations may reflect selection for structurally mature prairie with stable nesting substrates and sustained floral

availability, conditions that may be reduced under frequent burning regimes (Carvell et al., 2007).

Southern Plains bumble bee, a species of conservation concern, exhibited a weak positive association with cool-season grasses and a negative association with woodland cover. While the cool-season grass association may be incidentally reflecting the presence of floral patches embedded within managed grasslands, it is notable that this species avoided more wooded units, aligning with its known selection for open grassland habitats (Colla et al., 2012).

Black and Gold bumble bee displayed a more generalist distribution, consistent with its documented ability to exploit a wide range of floral and nesting resources (Gixti et al., 2009). Its slight affinity toward bare ground and early successional cover may indicate use of disturbed sites where nesting opportunities are more available. The rare Two-spotted and Common Eastern bumble bees exhibited the most specialized associations. Two-spotted bumble bee aligned strongly with early successional shrubland and bare ground, while Common Eastern bumble bee associated with woodland cover, suggesting niche partitioning at the landscape scale.

Management Implications

The land management framework on Fort Riley, characterized by rotational prescribed fire, haying, and retention of large prairie remnants, likely plays a central role in maintaining the observed community diversity. Native prairie units, especially those with longer fire intervals, appear to support larger occurrences of multiple species, including the American bumble bee and Brown-belted bumble bee. While fire is essential for preventing woody encroachment, overly frequent burns may disadvantage late-emerging species by reducing late-season floral resources. Similarly, haying during mid-summer removes floral cover and could limit foraging resources during critical reproductive stages; however, rotational schedules may mitigate these effects by

creating a patchwork of floral availability across the installation (Fuhlendorf & Engle, 2004; Williams et al., 2010).

The persistence of Southern Plains bumble bee within Fort Riley is particularly significant given its sharp declines elsewhere in the Great Plains (Richardson, 2020). Maintaining open grassland cover, reducing encroachment by woody vegetation, and ensuring continuous floral availability from early spring to late summer will be essential for supporting Southern Plains bumble bee and other sensitive species.

Conservation Significance

Findings from this study highlight Fort Riley as a regional stronghold for native bumble bees within an otherwise fragmented and degraded tallgrass prairie system. By integrating landcover and management history into community composition analyses, this work provides a framework for identifying habitat features most strongly associated with at-risk species. These results reinforce the value of large, heterogeneous landscapes, particularly those with management regimes that balance disturbance and resource continuity in sustaining diverse *Bombus* spp. communities.

Conclusion

This multi-year assessment demonstrates that Fort Riley Military Reservation supports a full complement of native bumble bee species known from the Flint Hills ecoregion, with consistently high site-level richness across varied landcover and management contexts. Community composition was not static; instead, distinct seasonal shifts in dominant species reflected phenological differences in foraging activity and resource use. Brown-belted and

American bumble bees characterized early-season communities, while Black and Gold and Southern Plains bumble bees increased in prominence during late summer.

Species-specific associations with landcover and disturbance history highlight the importance of habitat heterogeneity at the unit scale. Native prairie cover, longer fire return intervals, and retention of early successional patches all emerged as factors influencing species occurrence. The persistence of Southern Plains bumble bee within this landscape is particularly notable given its decline across much of its range. Such patterns underscore the value of large, intact prairie remnants managed under a mosaic of fire frequencies and haying regimes.

That concentrated floral colonies—covering <1% of surveyed units—supported the potential full species assemblage reinforces their ecological significance. These patches function as critical foraging hubs and should be recognized as high-priority conservation features within the broader management framework. Interannual differences in abundance, particularly the drought-associated decline in capture during 2024, illustrate the vulnerability of prairie bumble bee communities to climatic variability, further emphasizing the need for adaptive management strategies that account for changing environmental conditions.

Overall, Fort Riley represents a regional refuge for prairie-dependent pollinators within a largely fragmented Great Plains landscape. Continued monitoring, coupled with targeted management to preserve floral continuity and structural diversity, will be essential for sustaining this diversity into the future. Patterns documented during this study provide a foundation for integrating pollinator conservation objectives into long-term land management planning, ensuring that this landscape remains both ecologically functional and operationally compatible with its military mission.

Literature Cited

- Biesmeijer, J. C., Roberts, S. P. M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., ... & Kunin, W. E. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, 313(5785), 351–354.
- Burkle, L. A., & Alarcón, R. (2011). The future of plant–pollinator diversity: Understanding interaction networks across time, space, and global change. *American Journal of Botany*, 98(3), 528–538.
- Carvell, C., Roy, D. B., Smart, S. M., Pywell, R. F., Preston, C. D., & Goulson, D. (2006). Declines in forage availability for bumble bees at a national scale. *Biological Conservation*, 132(4), 481–489.
- Center for Biological Diversity et al. (2021). Petition to list the American Bumble Bee (*Bombus pensylvanicus*) under the Endangered Species Act. Submitted to U.S. Fish and Wildlife Service, September 2021.
- Collins, S. L., & Smith, M. D. (2006). Scale-dependent interaction of fire and grazing on community heterogeneity in tallgrass prairie. *Ecology*, 87(5), 1253–1263.
- Crone, E. E., & Williams, N. M. (2016). Bumble bee colony dynamics: Quantifying the importance of land use and floral resources for colony growth and queen production. *Ecology Letters*, 19(4), 460–468.
- Darvill, B., Knight, M. E., & Goulson, D. (2004). Use of genetic markers to quantify bumble bee foraging range and nest density. *Oikos*, 107(3), 471–478.
- Devoto, M., Bailey, S., Craze, P., & Memmott, J. (2014). Understanding and planning ecological restoration of plant–pollinator networks. *Ecology Letters*, 15(4), 319–328.
- Devoto, M., Bailey, S., & Memmott, J. (2014). Ecological changes affecting the temporal dynamics of plant–pollinator networks. *Oecologia*, 174(2), 441–453.
- DoD. (2021). Department of Defense instruction 4715.03: Natural resources conservation program. U.S. Department of Defense.
- Fort Riley INRMP. (2015). Integrated Natural Resources Management Plan for Fort Riley Military Installation, Kansas, 2015–2019. U.S. Army Garrison Fort Riley, Environmental Division.
- Gehrt, J. A. (2021). Response of greater prairie-chickens to natural and anthropogenic disturbance on Fort Riley (M.S. thesis, Kansas State University).
- Goulson, D. (2010). *Bumble bees: behaviour, ecology, and conservation* (2nd ed.). Oxford University Press.

- Goulson, D., Hanley, M. E., Darvill, B., Ellis, J. S., & Knight, M. E. (2008). Causes of rarity in bumble bees. *Biological Conservation*, 122(1), 1–8.
- Goulson, D., Nicholls, E., Botías, C., & Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, 347(6229), 1255957.
- Hanberry, B. B., DeBano, S. J., & Kaye, T. N. (2021). Pollinators of the Great Plains: disturbances, stressors, management, and research needs. *Rangeland Ecology & Management*, 78(2), 220–234.
- Harmon, J.P., A.C. Ganguli, & M.J. Solga. (2011). An overview of pollination in rangelands: who, why, and how. *Rangelands*, 33(3), 4–8.
- Harmon-Threatt, A. N., & Chin, K. (2016). Common methods for tallgrass prairie restoration and their potential effects on bee diversity. *Natural Areas Journal*, 36(4), 448–456.
- Hatfield, R. G., & LeBuhn, G. (2007). Patch and landscape factors shape community assemblage of bumble bees, *Bombus* spp. (Hymenoptera: Apidae), in montane meadows. *Biological Conservation*, 139(1–2), 150–158.
- Hatfield, R., Jepsen, S., Thorp, R., Richardson, L., & Colla, S. (2015). IUCN assessments for North American bumble bees. IUCN Bumble bee Specialist Group.
- Hodgson, J. A., Thomas, C. D., Wintle, B. A., & Moilanen, A. (2009). Climate change, connectivity and conservation decision making: back to basics. *Journal of Applied Ecology*, 46(5), 964–969.
- Jacobson, M. M., Tucker, E. M., Mathiasson, M. E., & Rehan, S. M. (2018). Decline of bumble bees in northeastern North America, with special focus on *Bombus terricola*. *Biological Conservation*, 217, 437–445.
- Kahn, C. (2007). Fort Riley: Sustaining the mission, conserving the environment. U.S. Army Environmental Command.
- Kearns, C. A., & Thomson, J. D. (2001). The natural history of bumble bees: a sourcebook for investigations. University Press of Colorado.
- Knight, M. E., Martin, A. P., Bishop, S., Osborne, J. L., Hale, R. J., Sanderson, R. A., & Goulson, D. (2005). An interspecific comparison of foraging range and nest density of four bumble bee (*Bombus*) species. *Molecular Ecology*, 14(6), 1811–1820.
- Kremen, C., Williams, N. M., & Thorp, R. W. (2002). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences*, 99(26), 16812–16816.
- Liczner, A. R., & Colla, S. R. (2020). A systematic review of the nesting and overwintering habitat of bumble bees globally. *Journal of Insect Conservation*, 24(5), 695–713.

- Morandin, L. A., & Kremen, C. (2013). Hedgerow restoration promotes pollinator populations and exports native bees to adjacent fields. *Ecological Applications*, 23(4), 829–839.
- NOAA. (2024). National climatic data for Kansas: 2022–2024 seasonal summaries. National Oceanic and Atmospheric Administration.
- Niemuth, N. D., et al. (2021). Conservation planning for pollinators in the U.S. Great Plains. *Ecological Solutions and Evidence*, 2, e12043.
- Ogilvie, J. E., Griffin, S. R., Gezon, Z. J., Inouye, B. D., Underwood, N., Inouye, D. W., & Irwin, R. E. (2017). Interannual bumble bee abundance is driven by indirect climate effects on floral resource phenology. *Ecology Letters*, 20(12), 1507–1515.
- Pindar, A., Smith, R. F., & Goodwin, B. J. (2020). Short-term responses of bumble bee communities to prescribed burning in tallgrass prairie. *Biological Conservation*, 241, 108377.
- Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology & Evolution*, 25(6), 345–353.
- Prendergast, K. S., Dixon, K. W., & Bateman, P. W. (2022). A global review of determinants of native bee assemblages in urbanized landscapes. *Insect Conservation and Diversity*, 15(4), 385–405.
- Richardson, L. L. (2020). Status review for the American bumble bee (*Bombus pensylvanicus*). U.S. Fish and Wildlife Service.
- Ricketts, T. H., Regetz, J., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., Bogdanski, A., ... & Viana, B. F. (2008). Landscape effects on crop pollination services: are there general patterns? *Ecology Letters*, 11(5), 499–515.
- Scholtz, R., & Twidwell, D. (2022). North America's grasslands and the role of military lands in conservation. *Great Plains Research*, 32(1), 1–17.
- USFWS. (2021). Endangered and threatened wildlife and plants; 90-day findings for petitions to list 10 species as endangered or threatened. *Federal Register*, 86(178), 51993–51996.
- USFWS. (2024). Species status assessment: Southern Plains bumble bee (*Bombus fraternus*). U.S. Fish and Wildlife Service.
- Villanueva-Gutiérrez, R., Roubik, D. W., & Colli-Ucán, W. (2015). Extinction of *Melipona beecheii* and traditional beekeeping in the Yucatan Peninsula. *Bee World*, 92(2), 35–41.
- WeatherSpark. (2024). Average weather at Fort Riley, Kansas.
- Williams, P. H., Osborne, J. L., & Corbet, S. A. (2010). Bumble bee vulnerability and conservation worldwide. *Apidologie*, 31(2), 193–211.

Winfree, R., Aguilar, R., Vázquez, D. P., LeBuhn, G., & Aizen, M. A. (2009). A meta-analysis of bees' responses to anthropogenic disturbance. *Ecology*, 90(8), 2068–2076.

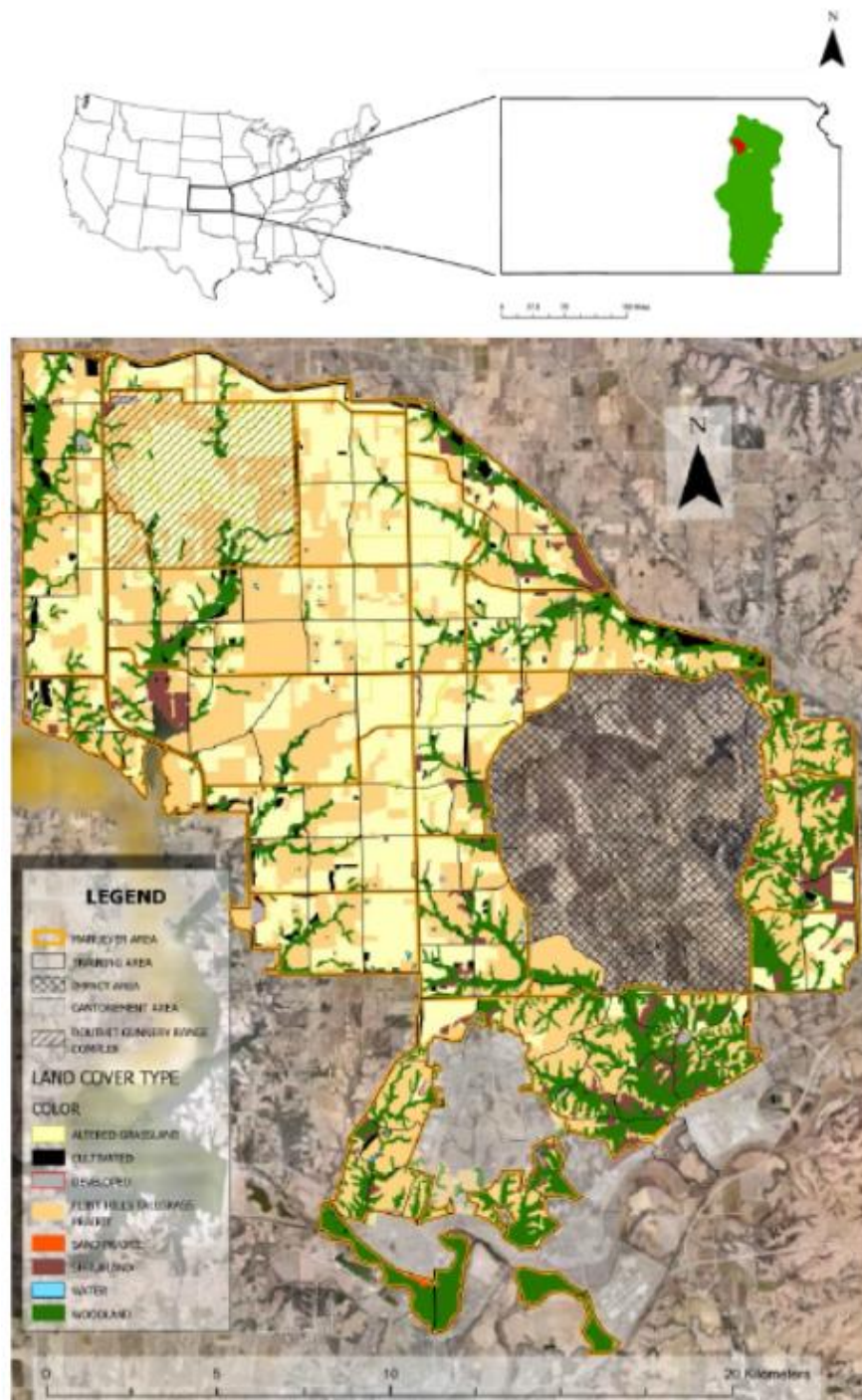


Figure 2. 1. Location of Fort Riley in the northern Flint Hills (green) of Kansas (upper panel) and broad land use and land cover characteristics of the >40,000 ha installation (lower panel). Individual polygons represent designated training units (n = 104).

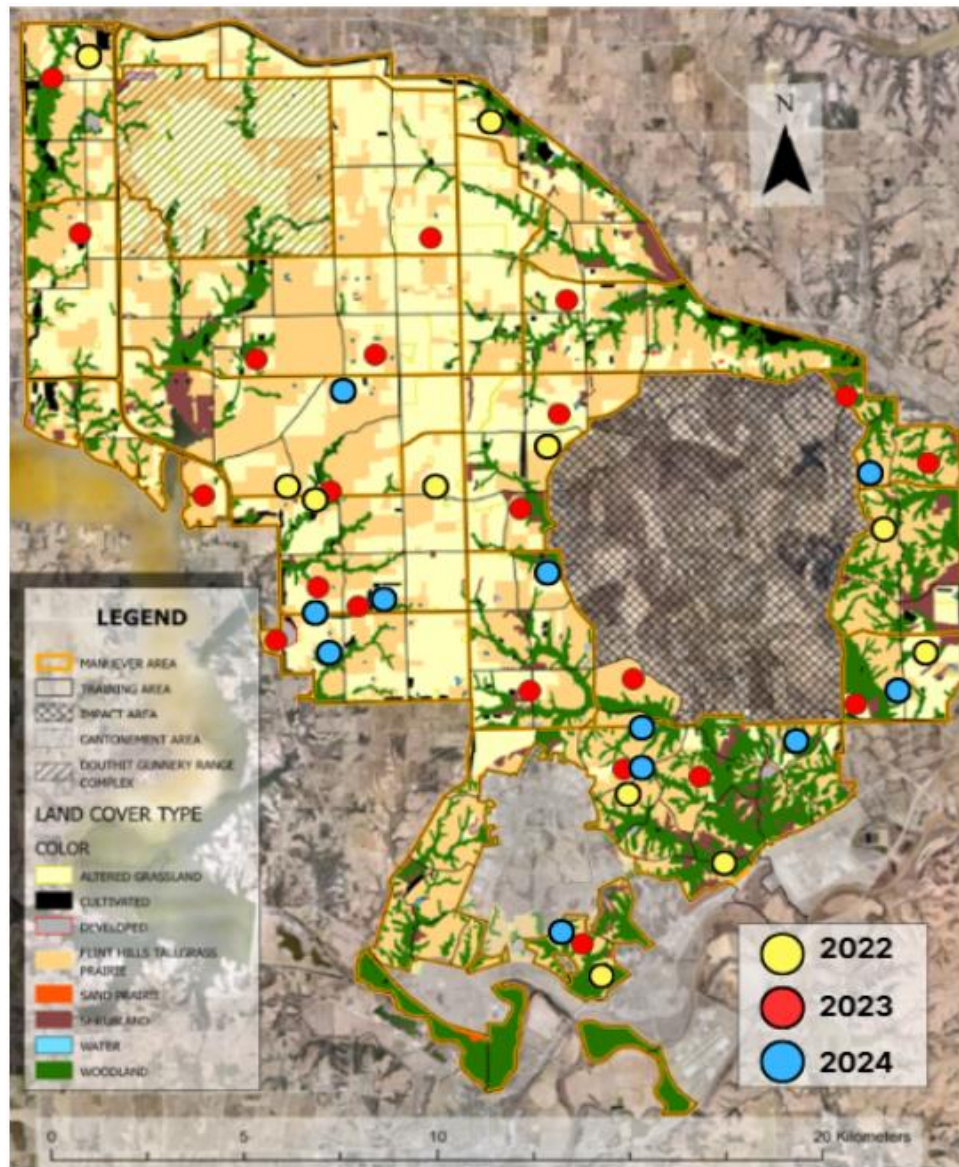


Figure 2. 2. Spatial distribution of *Bombus* spp. capture sites (n = 44) surveyed across Fort Riley Military Reservation, Kansas, from 2022 to 2024. Colored circles represent sampling years: yellow (2022, n = 12 sites), red (2023, n = 21), and blue (2024, n = 11).

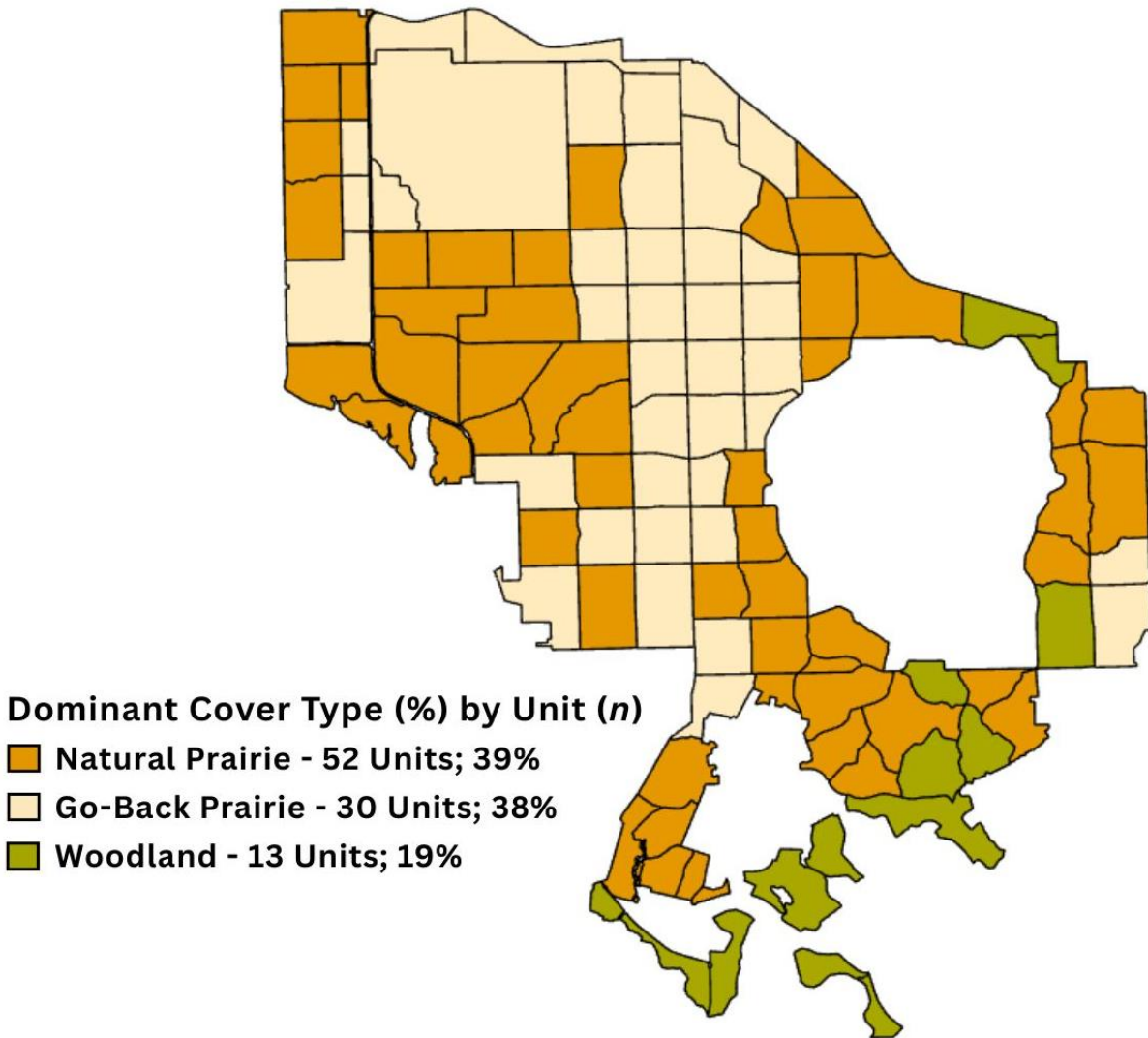


Figure 2. 3. Dominant vegetation cover types across 104 management units at Fort Riley Military Reservation, Kansas. Each unit (polygon) is classified by associated dominant land cover type based on percentage cover: Natural Prairie (orange; 52 units, 39%), Go-Back Prairie (tan; 30 units, 38%), and Woodland (green; 13 units, 19%).

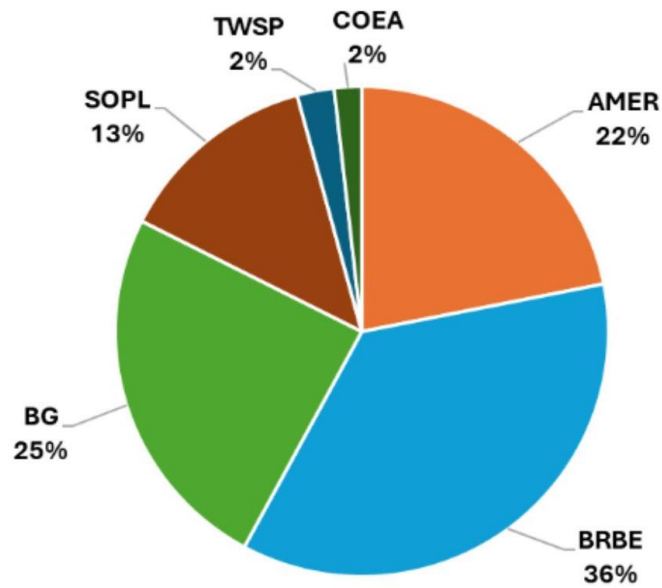


Figure 2. 4. Proportional captures of *Bombus* spp. across all sampling efforts from 2022 to 2024 at Fort Riley Military Reservation, Kansas. Brown-belted bumblebee (BRBE) represented the largest proportion of captures (36%), followed by Black and Gold bumblebee (BG; 25%), American bumblebee (AMER; 22%), and Southern Plains bumblebee (SOPL; 13%). Two-Spotted bumblebee (TWSP) and Common Eastern bumblebee (COEA) were least abundant, each accounting for 2% of total captures. Capture data reflect pooled counts across 44 unique capture sites sampled over three field seasons.

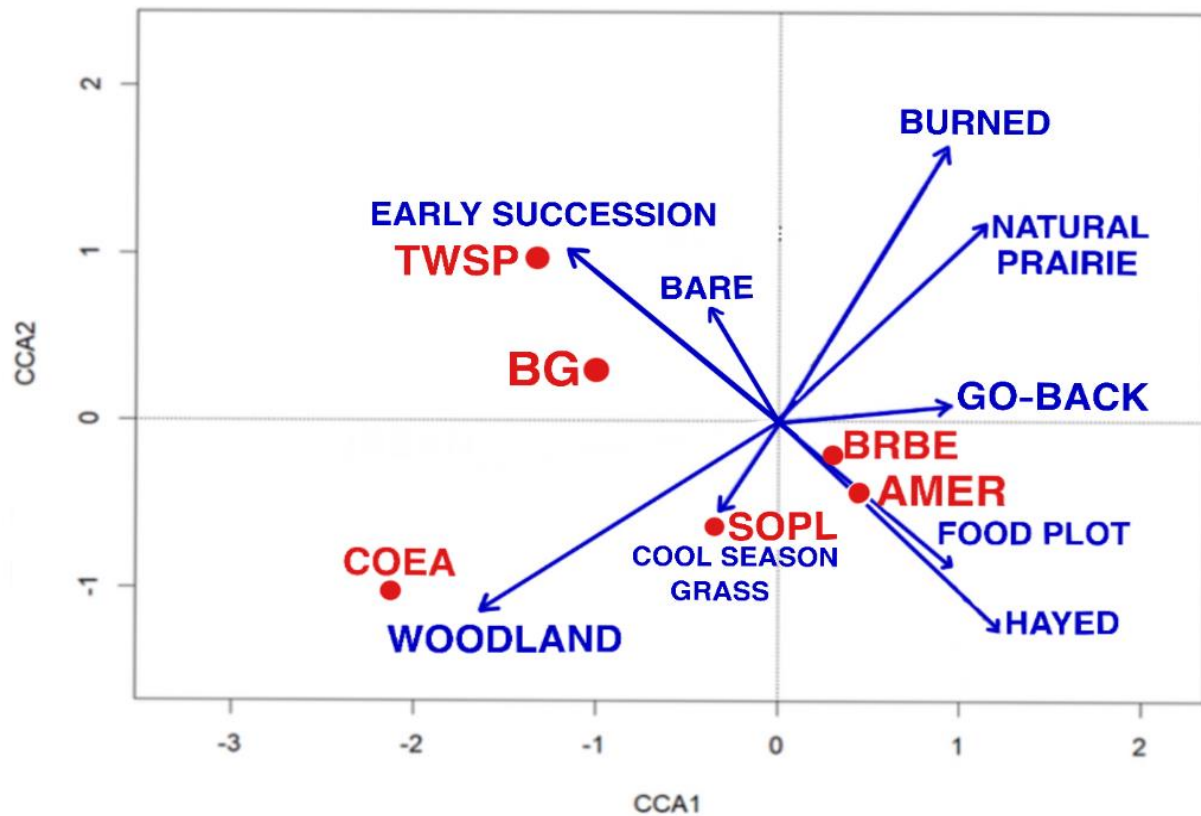


Figure 2. 5. Canonical Correspondence Analysis (CCA) plot visualizes relationships among seven land cover types and management regime intensities relative to *Bombus* spp. occurrence based on capture data across Fort Riley (2022-2024). Illustrated are all six bumble bee species: American bumble bee (AMER), Southern Plains bumble bee (SOPL), Brown Belted bumble bee (BRBE), Black and Gold bumble bee (BG), Two Spotted bumble bee (TWSP), and Common Eastern bumble bee (COEA).

Table 2. 1. Land Cover Types and Land Management Practices on Fort Riley

	Description	Management Practices/Utility
Natural Prairie	Dominated by tallgrass vegetation, providing habitats for diverse flora and fauna.	Prescribed burns, invasive species control, and periodic assessments to maintain ecological balance and biodiversity.
Hayed Areas	Established hay lease areas; dominated by brome grass (<i>Bromus inermis</i>) and timothy (<i>Phleum pratense</i>).	Invasive species control, maintain soil health, balance agricultural and ecological needs.
Go-Back Land	Previously used for agriculture and now undergoing ecological recovery, often reverting to prairie conditions.	Active management; native species seeding, invasive species control, and prescribed burns to accelerate recovery.
Cool Season Grasses	Non-native grasses (e.g., tall fescue, smooth brome) that establish early in the growing season and outcompete native warm-season flora.	Targeted herbicide application, overseeding with native species, and timing of management to suppress early growth.
Early Succession	Areas recently disturbed or recovering from management, supporting opportunistic native forbs and grasses.	Adaptive management to enhance floral diversity, monitor colonization, and support early-stage pollinator habitat.
Crop/Cultivated Land	Agricultural cropland (e.g., corn, soybeans, and wheat); food plots (e.g., foraging resources for native fauna and bees).	Conservation tillage, crop rotation, cover cropping, and soil erosion prevention to balance productivity and environmental impacts.
Woody/Tree Areas	Woodland areas, including tree and shrub encroachment.	Chemical and mechanical removal, replanting native species, and monitoring biodiversity and ecological health.

Table 2. 2. Total number of *Bombus* spp. captured across three field seasons (2022–2024) at Fort Riley Military Reservation, Kansas. Species include American bumble bee (AMER), Brown-belted bumble bee (BRBE), Black and Gold bumble bee (BG), Southern Plains bumble bee (SOPL), Two-spotted bumble bee (TWSP), and Common Eastern bumble bee (COEA). Annual totals and cumulative counts are reported across all sampling sites (n = 44 sites).

	AMER	BRBE	BG	SOPL	TWSP	COEA	TOTAL
2022	374	1722	385	1359	4	193	4037
2023	2390	2781	2665	455	183	67	8543
2024	648	1115	776	265	192	20	3016
TOTAL	3412	5618	3826	2079	379	280	15596

Chapter 3 – Evaluation of Distance Sampling to Estimate Density of Native Bumble bees (*Bombus* spp.) on Fort Riley Military Reservation

Introduction

Native bumble bee (*Bombus* spp.) populations have experienced widespread and ongoing declines, prompting increasing concern for pollinator conservation and stability of grassland ecosystems across the Great Plains (Biesmeijer et al., 2006; Burkle & Alarcón, 2011). Of conservation concern are Southern Plains bumble bee (*B. fraternushas*) and American bumble bee (*B. pensylvanicus*), with an estimated 89% population decline over the last 20 years (Richardson, 2020). Both species are integral to prairie ecosystem function, serving as primary pollinators for a broad range of native forbs and agricultural crops. These species exhibit strong fidelity to floristically rich, intact habitats and contribute significantly to the reproductive success of native forbs and wildflowers. Due to their responsiveness to changes in habitat structure and floral resource availability, they serve as sensitive indicators of environmental change across prairie landscapes (Glenn & Collins, 1990; Howe, 1994; Steuter et al., 1995; Larson et al., 2018). As of 2021, both species are under review by the federal government for listing under the 1973 Endangered Species Act (USFWS, 2021). These and other recent listing decisions highlight a growing concern for grassland pollinators and the need for spatially explicit monitoring across prairie landscapes to inform targeted conservation efforts.

The Great Plains host six native bumble bee species: American bumble bee, Southern Plains bumble bee, Brown-belted bumble bee (*B. griseocollis*), Black and Gold bumble bee (*B. auricomus*), Two-Spotted bumble bee (*B. bimaculatus*), and Common Eastern bumble bee (*B. impatiens*), which have adapted to the region's changing environmental conditions (Cameron et

al., 2011). These species require a combination of floral resources for foraging, undisturbed substrates for nesting, and continuous access to these elements throughout their colony cycle (Hatfield & LeBuhn, 2007; Williams et al., 2012). However, such requirements are not evenly distributed across prairie landscapes, especially in areas experiencing landcover change and fragmentation. Landscape composition influences *Bombus* spp. occurrence and abundance (Licznier & Colla, 2020; Jha & Kremen, 2013). Additionally, patch area, isolation, and structural heterogeneity affect bumble bee movement and population persistence, particularly for species with limited dispersal abilities (Goulson et al., 2010; Zurbuchen et al., 2010). These relationships are further affected by the timing of floral resource availability and presence of available nesting microhabitats across spatial scales (Krewenka et al., 2011). As native prairie remnants continue to decline, understanding spatial patterns of habitat use by native bumble bees across landscapes is crucial for prioritizing conservation areas and guiding management efforts that support pollinator communities across multiple scales.

Understanding how bumble bee populations respond to landscape features requires accurate density estimates that account for spatial variability in detection. In open habitats like tallgrass prairie, detection probability can vary with vegetation structure, observer visibility, and the species' behavioral traits. Bumble bees present challenges for field estimates of detection due to their quick, irregular flight patterns and small size, which reduce visibility at greater distances from transect lines (Henry et al., 2021). If uncorrected, these detection limitations can bias estimates of relative abundance or habitat use. Distance sampling addresses incomplete detection by modeling the decline in detection probability as distance from the observer increases, enhancing the accuracy and consistency of density estimates across sites (Buckland et al., 2001; Thomas et al., 2010). Distance sampling may be especially useful for estimating density at large spatial scales for species like *Bombus* spp., which exhibit patchy distributions in diverse

grassland environments. Integrating a detection function into statistical models can produce more reliable density estimates and better identify ecological responses to land management practices (e.g., prescribed fire, haying, and invasive species control). In prairie systems, where visual obstruction and habitat complexity vary significantly, applying distance sampling methods may enable standardized assessments of pollinator populations and support long-term monitoring efforts.

Distance sampling has been widely applied in wildlife monitoring systems to estimate population density and abundance across taxa, including birds, mammals, reptiles, and butterflies (Buckland et al., 2001; Thomas et al., 2010). This method is particularly effective for species that are detectable over a range of distances from a transect or point, allowing for corrections in detection probability based on distance from the observer. In grassland systems, it has been successfully used to monitor prairie bird populations, small mammal communities, and certain conspicuous insect taxa, providing standardized data that can be compared across sites and years.

Key advantages of distance sampling include the ability to estimate density without the need for complete enumeration, incorporation of detectability into statistical models, and potential for repeated measures across broad spatial scales with minimal disturbance to the study organisms. Additionally, this method reduces handling time compared to netting; thereby minimizing stress to individuals and decreasing the risk of injury or mortality. Unlike netting, which may be biased toward more easily captured individuals and requires extensive handling, distance sampling captures variation in detectability related to habitat structure, weather, and observer position. Limitations include the need for accurate distance measurements, potential difficulty in identifying individuals to species at greater distances, and reduced applicability for cryptic or less detectable species. Observer experience and training are critical, as errors in distance estimation or species identification can introduce bias into detection functions.

Furthermore, in structurally complex habitats with dense vegetation, detectability may decline sharply with distance, potentially requiring additional methodological adjustments or model refinements. Despite these challenges, the ability of distance sampling to account for imperfect detection and generate density estimates that are directly comparable across management regimes may offer distinct advantages over traditional netting approaches in prairie pollinator monitoring.

Fort Riley Military Reservation (FRMR), Kansas, offers a unique opportunity to understand bumble bee populations of the tallgrass ecoregion and facilitates restoration efforts for species of conservation concern (e.g., American bumble bee and Southern Plains bumble bee). Conservation efforts on FRMR are guided by an adopted Integrated Natural Resource Management Plan (INRMP), a policy-mandated framework developed in accordance with the Sikes Act of 1960. The INRMP outlines adaptive strategies that integrate military readiness with long-term ecological stewardship, emphasizing habitat restoration, species monitoring, and sustainable land management (U.S. Army, 2018). As a cornerstone of ecological policy on military lands, the INRMP facilitates conservation of native species, including *Bombus* spp., on Fort Riley through rotational fire regimes, mechanical treatments, and restoration of native plant communities. These management actions aim to maintain ecological integrity while supporting military operations. Objectives include preserving habitat for species of conservation concern such as Southern Plains bumble bee and American bumble bee. Development of a technique to estimate density of *Bombus* spp. is necessary to develop conservation goals and monitor population patterns and trends, including responses to management strategies.

Further, federal mandates, including the Endangered Species Act (ESA), Migratory Bird Treaty Act, and National Environmental Policy Act, further compel military installations to inventory and manage sensitive species. These statutes and associated policies, while

occasionally constraining military training activities, also promote ecosystem sustainability and reinforce the value of integrated management. By assessing bumble bee populations within this context, resulting information contributes to broader Department of Defense goals for balancing conservation and mission readiness (DoD, 2020). As such, land management on military installations can contribute to the persistence of sensitive species and the habitats on which they depend. In the Great Plains, where prairie loss and fragmentation are widespread, evaluating *Bombus* spp. populations on military lands provide an important opportunity to understand native pollinator dynamics within one of the last remaining strongholds of tallgrass prairie. I assessed bumble bee community status at Fort Riley Military Reservation, Kansas, located within the Flint Hills tallgrass prairie ecoregion. My objective was to determine if distance sampling can be used for monitoring native bumbles in tallgrass prairie by providing reliable and repeatable results that can be used to inform conservation efforts. My primary goal was to provide reliable density estimates of bumble bees across Fort Riley using distance sampling methods. This approach may enable further insights into where *Bombus* spp. occur across a given area and species-habitat relationships.

Methods

Study Area

Fort Riley Military Reservation is located in the northern Flint Hills of Kansas, spanning 101,000 acres (40,725 ha), encompassing a significant portion of the original tallgrass prairie. The Flint Hills is North America's largest remaining contiguous area of tallgrass prairie (Scholtz & Twidwell, 2022). Historically, much of the tallgrass prairie has been converted into row-crop farmland, resulting in habitat fragmentation and loss for many grassland species. Fort Riley, however, has managed to preserve a significant portion of this endangered prairie due to its

military designation, which has restricted large-scale agricultural activities (Kahn, 2007).

Approximately 31,000 ha within FRMR are managed for military training, habitat conservation, wildlife management, and public recreation. In contrast to surrounding privately owned lands, cattle grazing is prohibited, resulting in lower disturbance intensity and greater retention of native prairie structure.

Vegetation across FRMR includes native prairie remnants, go-back grasslands (i.e., formerly disturbed sites undergoing restoration), hayfields, and cultivated plots planted for wildlife. These areas provide critical floral and nesting resources for native *Bombus* species, which require continuous seasonal forage and undisturbed substrates for successful colony establishment (Collins & Smith, 2006; Harmon et al., 2011). I classified land cover into seven categories: natural prairie, go-back prairie, cultivated areas (i.e., food plots), woodland/shrubland, early successional habitat, bare ground, and cool-season grasses (Table 2.1). Additionally, fire and hay frequency represented land management categories across units.

Units were defined as 104 designated training areas, averaging 302 ha (range: 118–642 ha), representing the comprised study area (Figure 2.1). These units represent intermediate-scale zones used for military training activity and management regimes (e.g., fire and haying rotations). Prescribed burns are conducted from late winter through fall, primarily in early spring, to reduce woody encroachment and maintain vegetation heterogeneity. Fire-return intervals vary considerably: 17% of area burns on a ≤ 2 -year interval, 70% burns every 2–4 years, 6% every 4–8 years, and 7% at > 8 -year intervals (Gehrt, 2021). Approximately 3,950 ha are burned annually. Wildfires occur irregularly, often initiated by lightning or military munitions during live training exercises.

Haying is conducted under rotational lease agreements administered by Fort Riley Environmental Division. Leases specify cutting schedules (annual, even-year, or odd-year

harvests) and target vegetation types (warm- or cool-season grasses) based on dominant cover. All haying activities occur between 15 July and 15 August, with vegetation mechanically removed (Gehrt, 2021). On average, haying affects 11,717 ha across 41 units, though annual area varies with weather and landowner participation (Fort Riley INRMP, 2015).

The climate of FRMR is temperate and continental, characterized by hot summers, cold winters, and moderate precipitation. Annual rainfall averages approximately 85 cm, with nearly 75% of the total occurring between April and September. During 2022–2024, pronounced interannual climatic variation was observed. In 2022, growing season precipitation was near average (~64 cm), supporting stable floral conditions. In contrast, 2023 experienced an exceptionally wet spring and early summer, with April–June totals exceeding 70 cm (~15–20% above average) and accompanied by frequent convective storms. By 2024, precipitation declined sharply during late summer, resulting in moderate drought stress across multiple training areas. Maximum daytime temperatures from May through August consistently exceeded 32°C across all years, with multiple days surpassing 36°C, particularly during late June, potentially limiting mid-day foraging opportunities by native bumble bees (NOAA, 2024; WeatherSpark, 2024).

Estimating *Bombus* spp. Distribution and Density: Distance Surveys

I employed 151 randomly stratified walking line transects, 500 m in length in 104 training units across Fort Riley to estimate distribution and density of *Bombus* spp. at landscape scales (Figure 3.1). Transects were randomly distributed across the installation to reduce sampling bias and record species occurrence data across multiple cover types and management regimes beyond the context of floral patches. Bumble bee surveys were conducted over three years (2022–2024), with each year divided into two seasonal bouts to account for temporal variation in floral phenology and bumble bee foraging activity: Bout 1 (early summer: May 1 – June 30) and Bout 2 (late summer: July 1 – August 31). Surveys were conducted between 0800 and 1600 under

favorable weather conditions (temperature range: 18–32°C; wind speed <24 km/hr; no active precipitation). At the start of each transect survey, observers recorded the following using a formatted ‘DS *Bombus*’ Google Survey on a mobile device (e.g., smartphone): Transect ID (1-151), date, cloud cover, wind speed, temperature, and start time.

During distance sampling surveys, trained observers used a handheld Trimble Global Navigation Satellite System device, programmed with pre-loaded transect coordinates, to navigate and record bumble bee detections. Observers followed a georeferenced transect line displayed on the device and conducted visual searches for bumble bees along each transect. Upon detecting an individual, observers approached the point of initial observation to minimize spatial bias and recorded detection location using the integrated mapping interface of the Trimble unit. At each bumble bee observation, the individual species and associated spatial plot point were recorded. Observers recorded additional ecological information for each detection, such as behavioral state (e.g., nectaring, flying, resting) and floral association when relevant. Floral associations were identified by noting the flowering plant species where bumble bees were observed nectaring or resting. After completing each transect, observers documented whether bumble bees were observed (i.e., yes or no), presence or absence of carpenter bees (*Xylocopa virginica*) and any additional field notes (e.g., apparent management practices, observations of bumble bee habitat use, notable site conditions). Perpendicular distance from the transect line to each detection was computed in Program DISTANCE using the recorded spatial coordinates of the transect path and each observation point, allowing standardized measurement of detection distance for model fitting.

Data Analysis

Distance data were analyzed using package ‘DISTANCE’ in Program R, with detection functions fitted separately for each bout to estimate density for all *Bombus* spp. at transect and

landscape levels. Distance sampling models estimated detection probability by calculating the perpendicular distance from each bumble bee observation to the transect line and fitting a detection function that characterizes decline in detectability with increasing distance from the observer. To assess temporal variation in bumble bee density and distribution, distance sampling results were stratified by early-season (Bout 1: May–June) and late-season (Bout 2: July–August) bouts for 2023 and 2024. Density estimates (individuals/ha) were multiplied by the total area that was available to bumble bees within Fort Riley’s landscape, providing a site-scale (i.e., entirety of Fort Riley) measure of *Bombus* spp. population size.

Stratifying distance sampling results by seasonal bout allows detection functions to account for temporal variation in detectability driven by phenology, weather conditions, and habitat structure. Early-season surveys often coincide with cooler temperatures, lower floral abundance, and reduced vegetation height, which can increase detection probability by enhancing visibility and concentrating foraging activity (Carvell et al., 2006; Kuhlmann et al., 2021). In contrast, late-season conditions typically involve greater vegetation density and more widely distributed floral resources, potentially decreasing detectability and influencing species-specific foraging ranges (Potts et al., 2003; Goulson, 2010). Partitioning analyses by bout therefore improves the accuracy of density estimates by reducing bias from seasonal changes in detection probability and ensures that observed trends represent true variation in abundance rather than artifacts of detectability. This approach follows established recommendations in pollinator monitoring, where accounting for seasonal variation has been shown to strengthen

inference on habitat associations and population trends (Westphal et al., 2008; Wood et al., 2016).

Results

Distance Sampling Detection Models

Across all survey years (2022–2024), distance sampling models produced robust estimates of *Bombus* spp. density, abundance, and detection probability (p). Model selection was based on Cramér–von Mises (CVM) goodness-of-fit statistics and Akaike’s Information Criterion (AIC). In each year, the half-normal key function with cosine adjustments provided the best fit, meeting assumptions of monotonicity and indicating acceptable model performance (CVM $p > 0.25$). Detection probability declined with increasing perpendicular distance from the transect line across all survey years (Figures 3.1–3.3). In 2022, fitted detection function exhibited a steep drop beyond 10 m, with few detections recorded beyond 40 m (Figure 3.1). Conversely, 2023 displayed a broader detection shoulder (Figure 3.3). Average detection probability (p) varied across years and bouts (Table 3.1). For models pooling data across bouts, estimated detectability was greatest in 2023 (0.330 ± 0.013 SE), intermediate in 2022 (0.241 ± 0.011), and lowest in 2024 (0.206 ± 0.009). Early-season detection was consistently larger than late-season detection across all years except 2022, with the most pronounced decline occurring in 2024, where p fell from 0.246 (Bout 1) to 0.176 (Bout 2; Table 3.1).

Interannual Trends in *Bombus* spp. Density and Abundance

Bombus spp. density estimates increased across all years (Table 3.1). In pooled models, mean density rose from 1.36 individuals/ha (± 0.25 SE) in 2022 to 1.49 individuals/ha (± 0.18) in 2023 and reached 1.85 individuals/ha (± 0.20) in 2024. These increases represent a 36% rise in *Bombus* spp. density over the study period, with the sharpest annual gain (24.2%) occurring

between 2023 and 2024. Corresponding abundance estimates for Fort Riley followed a similar trend, increasing from 38,618 individuals ($\pm 7,097$ SE) in 2022 to 42,376 ($\pm 5,364$) in 2023 and 52,691 ($\pm 5,745$) in 2024. The coefficient of variation (CV) for these estimates declined over time (2022: 0.18; 2023: 0.13; 2024: 0.11).

Seasonal Dynamics of Density, Abundance, and Detection

Bumble bee density and abundance consistently increased from early (Bout 1) to late season (Bout 2) across all years (Table 3.1, 3.2). In 2022, density increased from 1.11 individuals/ha (± 0.21 SE) in Bout 1 to 1.38 individuals/ha (± 0.37) in Bout 2 (24% seasonal increase). In 2023, density rose from 1.40 (± 0.217 SE) to 1.53 individuals/ha (± 0.311 ; +9.4%). The greatest seasonal change occurred in 2024, when density increased from 1.67 (± 0.228 SE) to 2.02 individuals/ha (± 0.366), a 21% increase. These increases reflect peak colony expansion and foraging activity during mid to late summer. Detection probabilities generally declined between early and late-season bouts in 2023 and 2024, despite increased *Bombus* spp. density and abundance.

Discussion

My results demonstrate the feasibility of using distance sampling to monitor *Bombus* spp. at landscape scales in tallgrass prairie systems. Application of line-transect distance sampling allowed for estimation of density while accounting for bumble bee detectability, an approach rarely applied to mobile pollinators (Isaacs et al., 2011). Stratification by season (Bout 1 vs. Bout 2) would further enable evaluation of colony phenology and detection performance across the foraging period. Bout 2 data consistently revealed greater estimates of bumble bee density. I would suggest that future studies prioritize late-season surveys for monitoring *Bombus* spp. populations using distance sampling methods.

Density estimates indicated substantial interannual increases in *Bombus* spp. across the study period, with total density rising from 1.36 individuals/ha in 2022 to 1.85 individuals/ha in 2024. Abundance estimates across FRMR also increased from 38,618 individuals in 2022 to >52,000 in 2024, despite variable climatic conditions. This upward trajectory may reflect cumulative effects of stable habitat structure or high floral continuity; factors known to promote pollinator productivity in prairie ecosystems (Carvell et al., 2007; Williams & Lonsdorf, 2018). It is also possible that favorable nesting conditions in preceding years compounded recruitment, producing larger colonies in subsequent seasons, a pattern documented in other long-term bee monitoring programs (Roulston & Goodell, 2011). While density estimates in this study align with the upper range reported for bumble bees in floristically rich grasslands, they exceed those observed in more fragmented or agriculturally dominated landscapes (Knight et al., 2009), reinforcing the conservation value of large, intact prairie complexes like Fort Riley.

Interannual differences in abundance, particularly the drought-associated decline observed in late 2024 surveys, illustrate the vulnerability of prairie bumble bee communities to climatic variability, further emphasizing the need for adaptive management strategies that account for changing environmental conditions. Overall, Fort Riley represents a regional refuge for prairie-dependent pollinators within a largely fragmented Great Plains landscape. Continued monitoring, coupled with targeted management to preserve floral continuity and structural diversity, will be essential for sustaining this diversity into the future. Documented patterns provide a foundation for integrating pollinator conservation objectives into long-term land management planning, ensuring that this landscape remains both ecologically functional and operationally compatible with its military mission.

Seasonal trends further emphasize phenological shifts in bumble bee activity. In each year, late-season (Bout 2) surveys yielded consistently larger density and abundance than early-

season (Bout 1) surveys. This trend aligns with expected increases in worker population size as *Bombus* colonies reach peak activity in midsummer (Williams et al., 2012; Harmon-Threatt, 2020). The greatest seasonal increase occurred in 2024, with Bout 2 density estimates rising to 2.02 individuals/ha, the largest recorded during the study. These seasonal increases are particularly significant for conservation, as they highlight periods of heightened foraging activity and colony productivity when resources are most critical for reproductive success and overwintering preparation (Kleijn et al., 2015).

Although *Bombus* spp. density and abundance increased over time, detection probability did not follow a parallel trajectory. Average detection probability was greatest in 2023 ($p = 0.33$), intermediate in 2022 ($p = 0.24$), and lowest in 2024 ($p = 0.21$). This inverse relationship may reflect variability in vegetation height, floral structure, or observer visibility. Detection curves revealed more pronounced declines in detectability beyond 20 m in 2024, likely driven by changes in vegetation composition and structure due to drought (Hatfield & LeBuhn, 2007). Detection probability also declined seasonally, particularly in 2024, when late-season detectability decreased to 0.18. These findings emphasize the importance of incorporating detection functions into pollinator monitoring, particularly in structurally complex grasslands where visual obstruction may bias encounter rates (Henry et al., 2021).

The seasonal decline in detection probability, despite increasing *Bombus* spp. density, indicates that uncorrected count-based surveys may underestimate true abundance during peak foraging periods. While observer skill and survey timing were standardized, visibility constraints likely affected detection beyond 30 m, especially in late summer. These limitations reinforce the value of distance sampling in capturing detection-corrected estimates of density and abundance across variable field conditions. Findings from this study have critical implications for the monitoring of declining bumble bee species in North American prairie systems, particularly

American bumble bee and Southern Plains bumble bee, both of which are experiencing rapid population declines and under review for federal protection (USFWS, 2021). While species-specific analysis was beyond the scope of this chapter, the significant increases in landscape-level density and encounter rates suggest that Fort Riley continue to provide habitat that supports viable *Bombus* spp. populations, including species of conservation concern.

The landscape of Fort Riley, managed through an Integrated Natural Resource Management Plan, provides a mosaic of native prairie, go-back grassland, and early successional habitat maintained through rotational burning and haying. These management regimes promote structural heterogeneity and floral diversity, both essential to *Bombus* spp. nesting and foraging requirements (Hines & Hendrix, 2005; Kearns et al., 1998). Military lands, though intensively used for training, may serve as important refugia for prairie pollinators due to limited agricultural conversion, absence of livestock grazing, and active land stewardship (Nafus et al., 2017; Wilkinson et al., 2017). The estimated densities and observed increase in *Bombus* spp. density and abundance across all three years support the hypothesis that Fort Riley represents a stronghold of intact pollinator habitat within a region otherwise characterized by landscape fragmentation and grassland decline.

Management Implications

Results indicate that habitat management program of Fort Riley is sustaining some of the largest bumble bee densities reported in the Great Plains. The persistence of multiple *Bombus* species, including the American bumble bee and Southern Plains bumble bee, suggests that large, contiguous tracts of tallgrass prairie managed with rotational burning and selective haying can provide the structural and floral diversity needed for both nesting and foraging. Patterns observed during late summer, when densities reached their seasonal peak, highlight the importance of maintaining abundant and diverse nectar sources from July through August. Management actions

such as delaying hay harvest in high-use floral areas, ensuring adequate post-burn recovery time for late-blooming forbs, and increasing forb diversity in restoration plantings could help sustain peak-season resource availability.

The location of Fort Riley within a largely fragmented prairie landscape means its bumble bee populations may function as a source for adjacent lands or disproportionately rely on site-specific conditions across the installation. Coordinating management strategies with surrounding landowners, conservation groups, and state agencies could extend conservation benefits beyond the installation's boundaries. Maintaining a consistent, long-term monitoring program will be essential for tracking population changes, evaluating the effectiveness of management practices, and adapting strategies to address climate variability and other emerging challenges to prairie pollinator conservation.

Conclusion

This three-year distance sampling study provides one of the first landscape-scale, detection-corrected estimates of bumble bee density and abundance in the Flint Hills, demonstrating both the feasibility of the method and the ecological value of the prairie landscape associated with Fort Riley. Estimated densities rose from 1.36 individuals/ha in 2022 to 1.85 individuals/ha in 2024, representing a 36% increase, with corresponding abundance exceeding 52,000 individuals in the final year. These increases occurred despite pronounced climatic variability, suggesting that stable habitat structure, high floral continuity, and absence of livestock grazing have provided consistent foraging and nesting opportunities. Similar to patterns reported for other floristically rich grasslands (e.g., Carvell et al., 2007; Williams & Lonsdorf, 2018), density estimates at Fort Riley exceeded those documented in fragmented or intensively

farmed landscapes (Knight et al., 2009), underscoring the conservation significance of large, intact prairie complexes.

Seasonal trends were equally notable. Across all years, late-season (Bout 2) densities surpassed early-season (Bout 1) values, reflecting expected colony growth and peak worker activity during midsummer. The largest seasonal increase occurred in 2024, when densities reached 2.02 individuals/ha in Bout 2. These periods represent critical foraging windows when colonies accumulate resources for reproduction and overwintering, making late summer a priority for monitoring and habitat protection.

Collectively, these results indicate that Fort Riley serves as a regional refuge for prairie-dependent *Bombus* spp., including species of conservation concern such as the American bumble bee and Southern Plains bumble bee. The installation's management framework, characterized by rotational burning, selective haying, and retention of native prairie, appears to support both the abundance and diversity of sustainable bumble bee populations at a scale uncommon in the Great Plains. Continued application of distance sampling within an adaptive monitoring framework will provide a valuable tool for tracking long-term population trends, informing targeted management actions, and ensuring that Fort Riley remains both operationally functional and ecologically resilient.

Literature Cited

- Biesmeijer, J. C., Roberts, S. P. M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., ... & Kunin, W. E. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, 313(5785), 351–354.
- Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., & Thomas, L. (2001). *Introduction to distance sampling: Estimating abundance of biological populations*. Oxford University Press.
- Burkle, L. A., & Alarcón, R. (2011). The future of plant–pollinator diversity: Understanding interaction networks across time, space, and global change. *American Journal of Botany*, 98(3), 528–538.
- Cameron, S. A., Lozier, J. D., Strange, J. P., Koch, J. B., Cordes, N., Solter, L. F., & Griswold, T. L. (2011). Patterns of widespread decline in North American bumble bees. *Proceedings of the National Academy of Sciences*, 108(2), 662–667.
- Collins, S. L., & Smith, M. D. (2006). Scale-dependent interaction of fire and grazing on community heterogeneity in tallgrass prairie. *Ecology*, 87(8), 2058–2067.
- DoD (U.S. Department of Defense). (2020). DoD instruction 4715.03: Natural resources conservation program.
- Fort Riley Integrated Natural Resources Management Plan (INRMP). (2015). *Integrated Natural Resources Management Plan 2015–2019: Fort Riley, Kansas*. U.S. Army Garrison Fort Riley Environmental Division.
- Gehrt, J. A. (2021). *Response of greater prairie-chickens to natural and anthropogenic disturbance on Fort Riley* (M.S. thesis, Kansas State University).
- Glenn, S. M., & Collins, S. L. (1990). Patch structure in tallgrass prairies: Dynamics of satellite species. *Oikos*, 57(2), 229–236.
- Goulson, D., Lye, G. C., & Darvill, B. (2010). Decline and conservation of bumble bees. *Annual Review of Entomology*, 53, 191–208.
- Harmon-Threatt, A. N., et al. (2011). Pollinators of the Great Plains: disturbances, stressors, management, and research needs. *Rangeland Ecology & Management*, 78(2), 220–234.
- Harmon, J. P., Moran, M. D., & Ives, A. R. (2011). Species response to environmental change: Impacts of food web interactions and evolution. *Science*, 334(6056), 552–555.
- Hatfield, R., & LeBuhn, G. (2007). Patch and landscape factors shape community assemblage of bumble bees, *Bombus* spp. (Hymenoptera: Apidae), in montane meadows. *Biological Conservation*, 139(1–2), 150–158.

- Henry, M., Rodet, G., & Couvillon, M. J. (2021). Bumble bee foraging distance depends on landscape context and forager size. *Ecological Entomology*, 46(6), 1311–1320.
- Hines, H. M., & Hendrix, S. D. (2005). Bumble bee (Hymenoptera: Apidae) diversity and abundance in tallgrass prairie patches: Effects of local and landscape floral resources. *Environmental Entomology*, 34(6), 1477–1484.
- Howe, H. F. (1994). Response of early- and late-flowering plants to fire season in experimental prairies. *Ecological Applications*, 4(1), 121–133.
- Jha, S., & Kremen, C. (2013). Urban land use limits regional bumble bee gene flow. *Molecular Ecology*, 22(9), 2483–2495.
- Kahn, D. M. (2007). Tallgrass prairie management and restoration at Fort Riley, Kansas (M.S. thesis, Kansas State University).
- Kearns, C. A., & Inouye, D. W. (1997). Pollinators, flowering plants, and conservation biology. *BioScience*, 47(5), 297–307.
- Krewenka, K. M., Holzschuh, A., Tschardt, T., & Dormann, C. F. (2011). Landscape elements as potential barriers and corridors for bees, wasps, and parasitoids. *Biological Conservation*, 144(6), 1816–1825.
- Larson, J. L., Kesheimer, A. J., & Potter, D. A. (2018). Pollinator assemblages on dandelions and white clover in turfgrass lawns. *Journal of Insect Conservation*, 18(5), 863–873.
- Liczner, A. R., & Colla, S. R. (2020). Landscape-scale variation of *Bombus* (Hymenoptera: Apidae) pollinator communities relates to floral resources and land use. *Insect Conservation and Diversity*, 13(5), 488–502.
- NOAA. (2024). National Centers for Environmental Information: Climate data online.
- Richardson, L. L. (2020). American bumble bee (*Bombus pensylvanicus*) species status assessment. U.S. Fish and Wildlife Service.
- Scholtz, R., & Twidwell, D. (2022). The Great Plains: a stronghold for North America's grassland biome. *Rangeland Ecology & Management*, 81, 58–66.
- Steuter, A. A., Grygiel, C. E., & Buhl, D. A. (1995). A strategy for fire management of the Fort Niobrara National Wildlife Refuge. *Prairie Naturalist*, 27(3), 115–126.
- Thomas, L., Buckland, S. T., Rexstad, E. A., Laake, J. L., Strindberg, S., Hedley, S. L., ... & Burnham, K. P. (2010). Distance software: Design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology*, 47(1), 5–14.
- U.S. Army. (2018). Integrated Natural Resources Management Plan: Fort Riley, Kansas (2018–2022). Fort Riley Environmental Division.

- USFWS (U.S. Fish and Wildlife Service). (2021). Endangered Species Act status reviews: *Bombus pensylvanicus* and *Bombus fraternus*.
- WeatherSpark. (2024). Fort Riley climate and weather year-round.
- Williams, P. H., Thorp, R. W., Richardson, L. L., & Colla, S. R. (2012). Bumble bees of North America: An identification guide. Princeton University Press.
- Wilkinson, T. L., Maron, M., & Possingham, H. P. (2017). Opportunities for conserving threatened species on military lands. *Conservation Letters*, 10(6), 743–750.
- Zurbuchen, A., Landert, L., Klaiber, J., Müller, A., Hein, S., & Dorn, S. (2010). Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances. *Biological Conservation*, 143(3), 669–676.

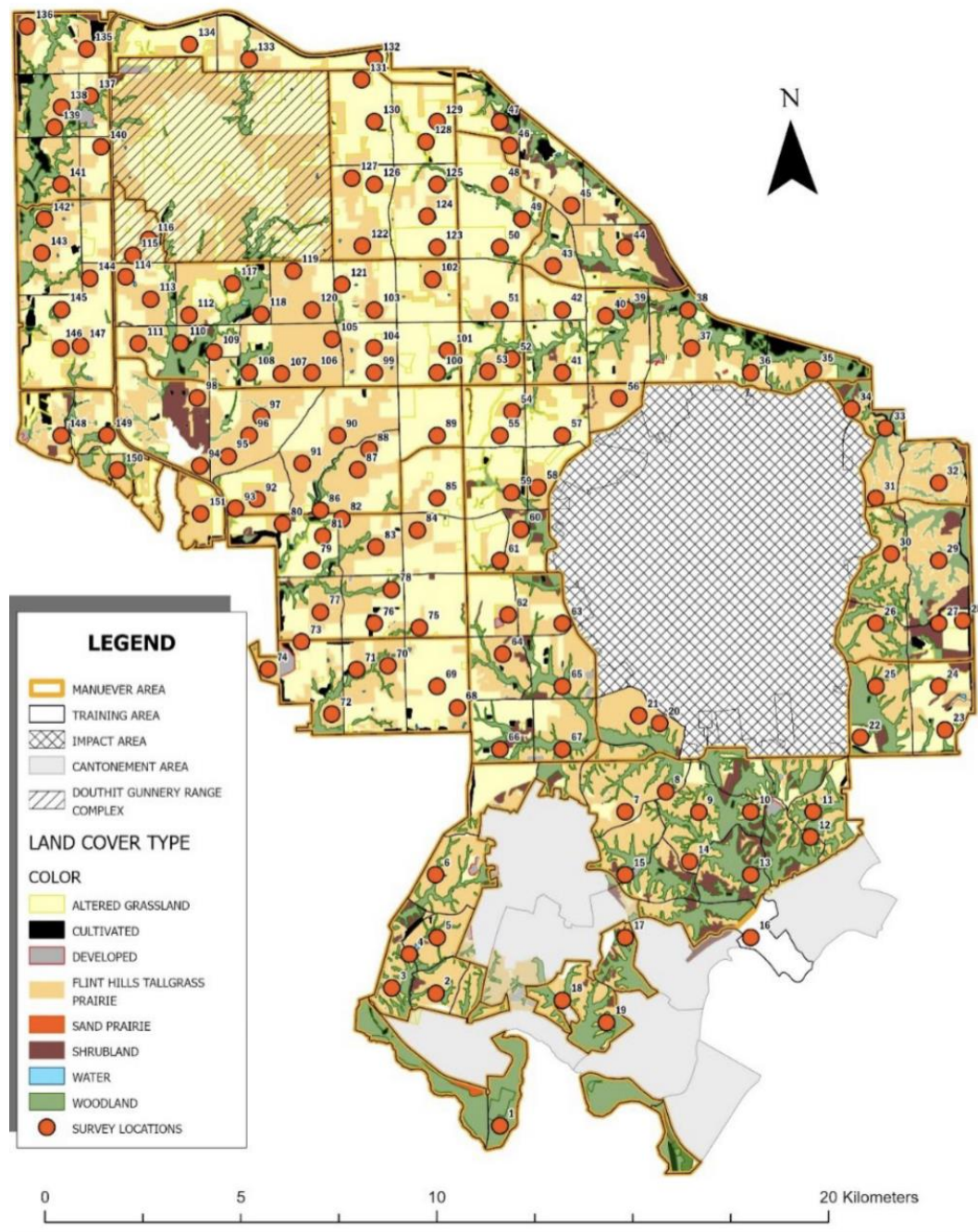


Figure 3. 1. 151 randomized distance transects across Fort Riley, Kansas. Points reference individual walking transects for 500-m distance surveys for bumblebee detection surveys. All transects were sampled twice per field season; once for bout 1 (01 May- 30 July) and once for bout two (01 July – 30 August) across 2022- 2024.

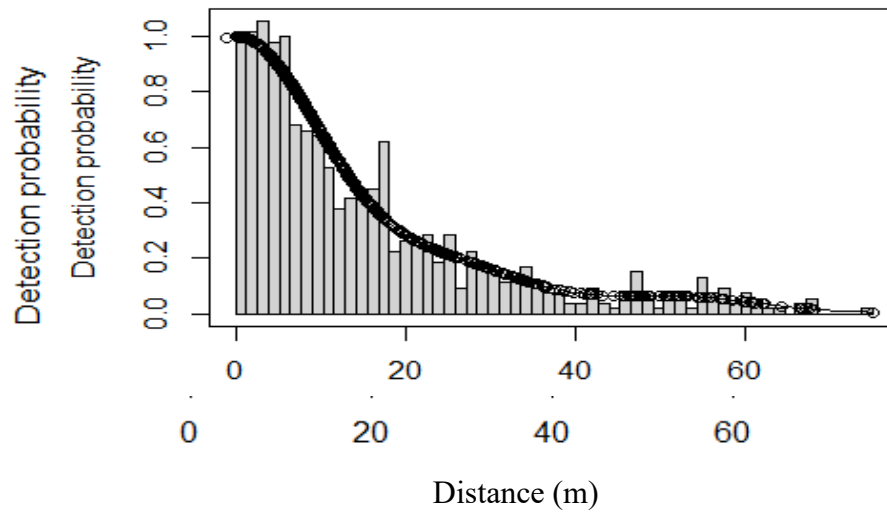


Figure 3. 2. Cumulative annual detection function fitted to *Bombus* spp. distance sampling data in 2022 (01 May – 30 August) using a half-normal key function with cosine adjustments. Vertical bars represent a histogram of detection distances; the fitted line represents the modeled detection probability across increasing distance from the observer. Fitted detection function followed a steep decline, with majority of detections occurring within 20 m of the transect.

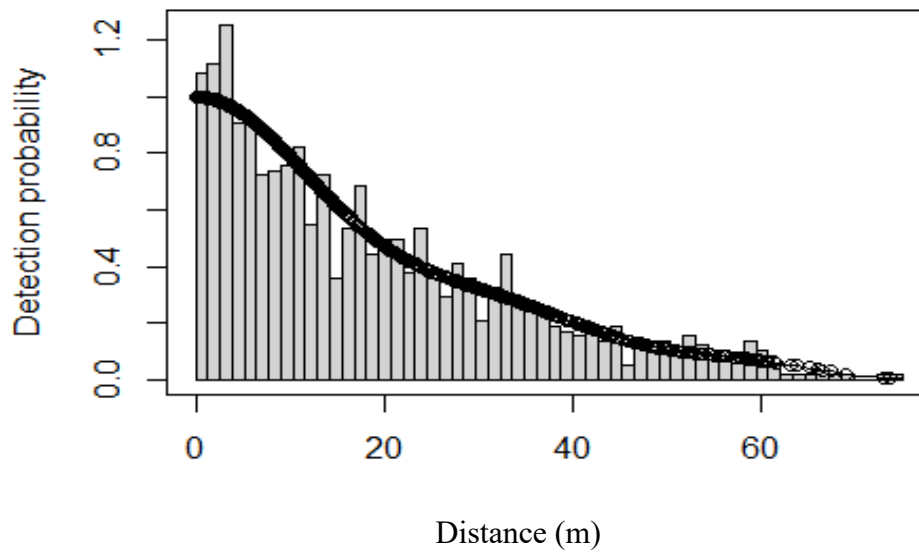


Figure 3. 3. Cumulative annual detection function fitted to *Bombus* spp. distance sampling data in 2023 (01 May – 30 August) using a half-normal key function with cosine adjustments. Vertical bars represent a histogram of detection distances; the fitted line represents the modeled detection probability across increasing distance from the observer. Model shows a broader detection shoulder, suggesting higher detectability at intermediate distances compared to other years.

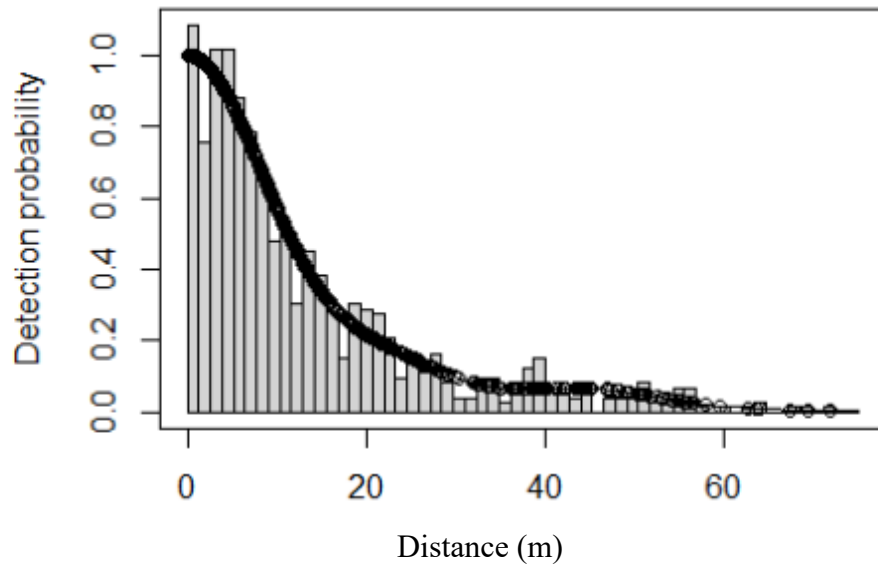


Figure 3. 4. Cumulative annual detection function fitted to *Bombus* spp. distance sampling data in 2024 (01 May – 30 August) using a half-normal key function with cosine adjustments. Vertical bars represent a histogram of detection distances; the fitted line represents the modeled detection probability across increasing distance from the observer. A steeper detection curve and reduced shoulder indicate lower overall detectability.

Table 3. 1. Estimates ($\pm$ SE) and 95% confidence intervals of density (bees/ha) and detection probability (ρ) for native bumble bee (*Bombus* spp.) using distance sampling for 151 transects for two survey bouts (bout 1 = May 1 – June 30, bout 2 = July 1 – August 30) sampled during 2022–2024 at the Fort Riley Military Reservation, Kansas.

Year	Survey Bout 1			Survey Bout 2		
	Density $\pm$ SE	95% CI	$\rho \pm$ SE	Density $\pm$ SE	95% CI	$\rho \pm$ SE
2022	1.11 $\pm$ 0.21	0.77-1.59	0.22 $\pm$ 0.01	1.38 $\pm$ 0.37	0.81-2.34	0.29 $\pm$ 0.01
2023	1.40 $\pm$ 0.22	1.03-1.90	0.37 $\pm$ 0.02	1.53 $\pm$ 0.31	1.02-2.27	0.31 $\pm$ 0.02
2024	1.66 $\pm$ 0.23	1.27-2.18	0.25 $\pm$ 0.01	2.01 $\pm$ 0.31	1.50-2.71	0.17 $\pm$ 0.01

Table 3. 2. Estimated abundance and 95% confidence intervals of native bumble bees (*Bombus* spp.) using distance sampling for 151 transects for two survey bouts (bout 1 = May 1 – June 30, bout 2 = July 1 – August 30) sampled during 2022–2024 at the Fort Riley Military Reservation, Kansas.

Year	Survey Bout 1		Survey Bout 2	
	Abundance $\pm$ SE	95% CI	Abundance $\pm$ SE	95% CI
2022	31,515 $\pm$ 5,877	21,881-45,290	39,228 $\pm$ 10,675	23,137-66,510
2023	39,864 $\pm$ 6,162	29,442-53,957	43,345 $\pm$ 8,835	29,105-64,550
2024	47,307 $\pm$ 6,480	36,150-61,906	57,192 $\pm$ 8,675	42,477-77,005

Chapter 4 - Local-Scale Assessments of *Bombus* spp. Abundance on Fort Riley Using Mark-Recapture Techniques

Introduction

Widespread declines in native bumble bee (*Bombus* spp.) populations have raised concerns about pollinator conservation and ecosystem health across the Great Plains (Biesmeijer et al., 2006; Burkle & Alarcón, 2011). Southern Plains bumble bee (*B. fraternus*) and American bumble bee (*B. pensylvanicus*) are especially at risk. Both have experienced severe range contractions and population declines, with an estimated >89% in the past two decades (Richardson, 2020). These species are vital pollinators in prairie ecosystems. They provide pollination services that support native forbs and wildflowers; furthermore, their sensitivity to disturbances makes them good indicators of environmental changes (Glenn & Collins, 1990; Howe, 1994; Steuter et al., 1995; Larson et al., 2018). Both species have been under federal consideration since 2021 for listing under the 1973 Endangered Species Act (USFWS, 2021). These and listing decisions related to other pollinators highlight a growing concern for grassland pollinators and the need for spatially explicit monitoring across prairie landscapes to inform targeted conservation efforts.

Native bumble bees play a significant role in plant-pollinator networks in temperate ecosystems. They have strong site fidelity, long foraging times, and act as generalist foragers (Ollerton et al., 2011). However, many species also have specific floral preferences. Their population dynamics closely relate to flowering phenology, which is the seasonal timing of bloom events vital for colony growth and reproduction (Villanueva-Gutiérrez et al., 2015). When there are mismatches between bumble bee needs and the availability of flowering plants, whether

caused by habitat fragmentation, climate change, or land use, it can limit food sources and reproductive success (Roubik, 2014; Mathiasson & Rehan, 2020).

Military lands provide a unique opportunity for pollinator conservation, particularly for rare and declining species. Across the United States, Department of Defense installations collectively encompass >11 million acres of land, many of which support diverse grassland and prairie habitats (Miller et al., 2009; Tuggle et al., 2013). These lands often experience reduced human access and disturbance, functioning as refugia for sensitive wildlife, including pollinators (Frid & Dill, 2002; Nielsen et al., 2018). Furthermore, military installations are legally required under the Sikes Act to inventory and manage species of conservation concern, offering a structured framework for pollinator monitoring and habitat management (U.S. Department of Defense, 2021). Restricted access to military lands limits habitat degradation, while management practices such as rotational burning, mowing, or establishing food plots may support heterogeneous plant communities that benefit native bumble bee populations (Sutter et al., 2002).

Collaborative conservation efforts among military agencies, academic institutions, and non-governmental organizations have led to enhanced pollinator habitat restoration, improved monitoring protocols, and protection of federally listed species (Tuggle et al., 2013). Given the petitioning and consideration of bumble bee species under the Endangered Species Act, military lands can play a key role in regional and national recovery efforts for at-risk pollinators (Miller et al., 2009). However, estimates of native bumble bee abundance at the scale of floral colony (unique, delineated forb-dominated patches) are needed to monitor trends and responses to management actions of native bumble bee populations. My objective was to evaluate the potential use of mark-recapture methods to estimate abundance of native bumble bees, *Bombus* spp., within delineated floral colonies at Fort Riley Military Reservation, Kansas.

Methods

Study Area

Fort Riley Military Reservation (FRMR), located in northeastern Kansas, encompasses approximately 101,000 acres (40,725 ha) of heterogeneous terrain within Flint Hills ecoregion of central Great Plains. The Flint Hills represents the largest remaining expanse of intact tallgrass prairie in North America, a biome globally imperiled by agricultural conversion and habitat fragmentation (Scholtz & Twidwell, 2022). Approximately 31,000 ha within FRMR are managed for military training, habitat conservation, wildlife management, and public recreation. In contrast to surrounding privately owned lands, cattle grazing is prohibited, resulting in lower disturbance intensity and greater retention of native prairie structure.

Vegetation across FRMR includes native prairie remnants, go-back grasslands (i.e., formerly disturbed sites undergoing restoration), hayfields, and cultivated plots planted for wildlife (Table 2.1). These areas provide critical floral and nesting resources for native *Bombus* species, which require continuous seasonal forage and undisturbed substrates for successful colony establishment (Collins & Smith, 2006; Harmon et al., 2011).

Fort Riley is divided into 104 training units, averaging 302 ha (range: 118–642 ha). These units represent intermediate-scale zones used for military training activity and management regimes (e.g., fire and haying rotations). Prescribed burns are conducted from late winter through fall, primarily in early spring, to reduce woody encroachment and maintain vegetation heterogeneity. Fire return intervals vary considerably: 17% of area burns on a ≤ 2 -year interval, 70% burns every 2–4 years, 6% every 4–8 years, and 7% at > 8 -year intervals (Gehrt, 2021). Approximately 3,950 ha are burned annually. Wildfires occur irregularly, often initiated by lightning or military munitions during live training exercises.

Haying is conducted under rotational lease agreements administered by Fort Riley Environmental Division. Leases specify cutting schedules (annual, even-year, or odd-year harvests) and target vegetation types (warm- or cool-season grasses) based on dominant cover. All haying activities occur between 15 July and 15 August, with vegetation mechanically removed (Gehrt, 2021). On average, haying affects 11,717 ha across 41 units, though annual area varies with weather and landowner participation (Fort Riley INRMP, 2015).

The climate at Fort Riley is temperate and continental, characterized by hot summers, cold winters, and moderate rainfall throughout the year. Annual precipitation averages approximately 85 cm, with nearly 75% falling between April and September. From 2022 to 2024, notable yearly variations in climate occurred. In 2022, the growing season rainfall was near average (~64 cm), supporting stable plant growth. In contrast, 2023 saw an exceptionally wet spring and early summer, with April–June totals >70 cm (~15–20% above average) and frequent convective storms. By 2024, rainfall sharply declined during late summer, leading to moderate drought stress across the area. Maximum daytime temperatures from May through August consistently >32°C each year, with several days >36°C, especially in late June, which could limit midday foraging opportunities (NOAA, 2024; WeatherSpark, 2024).

Capture-Mark-Recapture (CMR) Surveys of *Bombus* spp.

Site-level monitoring was conducted using standardized capture surveys from 1 May to 30 August over three consecutive years: 2022 ($n = 12$ sites), 2023 ($n = 21$), and 2024 ($n = 11$), totaling 44 unique floral colony sites (Figure 4.1). Sites were selected based on preliminary floral surveys that identified high-density nectar-producing forb patches, referred to as floral colonies. Site selection was stratified to include variation in cover types and management histories, including burned, hayed, go-back, and native prairie units (Table 2.1).

At each floral colony sampling site, 3–4 capture series events were conducted within a week during each temporal sampling bout, each separated by at least 24 hours. Each series lasted three person-hours (one hour per individual across a three-person crew). Bumble bees were individually collected using insect nets, stored temporarily in waterproof vials on ice, identified to species, marked with a nontoxic marker with color specific to the capture event, and released at the capture site. Species richness and relative abundance were quantified at the site level and standardized by survey effort. Floral colony area (ha^2) was estimated per site using GPS and visual boundaries to calculate relative *Bombus* spp. density (individuals per ha^2).

Following initial capture surveys at each site, floral colony boundaries were delineated to estimate area (ha) based on blooming flower density and spatial extent of sampling effort. Site edges were identified by walking or driving a UTV around flowering patches while recording GPS coordinates using a mobile device (e.g., smartphone) equipped with Google Maps. Coordinates were uploaded and digitized into geospatial polygons in Google Maps. Each polygon represented total floral colony extent and was used to calculate sampling area for subsequent estimates of bumble bee relative abundance and density.

Abundance and Density Calculations

Descriptive statistics were generated in Microsoft Excel to summarize variation in *Bombus* spp. capture, floral colony area (ha), and density (individuals ha^{-1}) across sites, years, and sampling bouts. Summary tables were developed to visualize interspecific differences and site-level variation in *Bombus* spp. occurrence and habitat characteristics. Closed capture models in Program MARK were used to estimate abundance for each floral colony. Data used for analysis was comprised of capture data for marked *Bombus* spp. individual capture histories for each site (i.e., recorded initial marking and subsequent recapture events). These data provided abundance estimates of bumble bee populations at local scales (i.e., floral colonies) and were

used to derive density estimates suitable for identifying site-specific trends (abundance/floral colony area). The primary benefit of these data are to provide a snap shot of bumble bee populations for a specific site and time.

Results

Species Abundance and Temporal Trends (2022–2024)

From 2022 to 2024, a total of 15,596 *Bombus* spp. individuals were captured across 44 unique sampling sites at Fort Riley, Kansas, including both unique captures and recaptures (Figure 4.1). Six native species were identified, including American bumble bee, Southern Plains bumble bee, Brown Belted bumble bee (*B. griseocollis*), Black and Gold bumble bee (*B. auricomus*), Two-Spotted bumble bee (*B. bimaculatus*), and Common Eastern bumble bee (*B. impatiens*; Table 4.1). Six native bumble bee species were documented each year, though their relative abundances and temporal distributions differed among years.

Brown-belted bumble bee exhibited greatest capture overall, comprising 36% of total captures ($n = 5,618$). This species dominated all survey years but peaked in 2023 with 2,781 captured individuals. Similarly, Black and Gold bumble bee was consistently abundant, with a high of 2,665 captured individuals in 2023 and reduced captures in 2022 ($n = 385$) and 2024 ($n = 776$). Together, Brown-belted and Black and Gold bumble bees accounted for >50% of individuals observed across the study period. American bumble bee demonstrated notable interannual variation. While only 374 individuals were captured in 2022, captures rose sharply in 2023 ($n = 2,390$), then declined again in 2024 ($n = 648$). Despite these fluctuations, American bumble bee represented 21.9% of all captures, making it third most abundant species overall. In contrast, Southern Plains bumble bee exhibited consistently low abundance. Capture of Southern Plains bumble bee peaked in 2022 with 1,359 individuals, declining sharply in 2023 ($n = 455$)

and further in 2024 ($n = 265$). Two-Spotted bumble bee and Common Eastern bumble bee were consistently rare across all survey years, accounting for only 2.4% and 1.8% of total captures, respectively. Capture of Common Eastern bumble bees was greatest in 2022 ($n = 193$), declining to 67 in 2023, and nearly absent in 2024 ($n = 20$). Capture of Two-Spotted bumble bees followed a similar pattern, with a modest rise in late-season detections in 2024 ($n = 192$), though overall abundance remained low ($n = 379$ total).

Seasonal Patterns by Sampling Bout

Results from three consecutive years of bumble bee capture revealed pronounced interannual and seasonal variability in relative capture of species. The relatively larger total capture in 2023 was driven primarily by increased captures of American, Brown-belted, and Black and Gold bumble bees. Both Southern Plains and American bumble bees showed strong bout-specific activity concentrated in late summer, while capture of Two-Spotted bumble bees remained confined to early season.

When capture data were partitioned by temporal bout, distinct seasonal patterns emerged (Tables 4.3, 4.4). Bout 1 (early season: May–June) accounted for 5,506 individuals across all years, while Bout 2 (mid-to-late season: July–August) yielded 10,090 individuals, representing nearly 65% of total captures. It is important to note that 2022 capture data were exclusive to Bout 2. This pattern of greater abundance in Bout 2 was consistent across all species, though especially pronounced for Southern Plains and American bumble bees, both of which exhibited late-season peaks. For example, Southern Plains bumble bees were scarcely captured in early season surveys ($n = 198$ across three years) but comprised a much larger percentage of captures in Bout 2 ($n = 1,881$), comprising >90% of their total observations. A similar trend was observed for capture of American bumble bee, which increased from 1,271 individuals in Bout 1 to 2,141 in Bout 2. This phenological structuring suggests a strong association between flowering period

dynamics and peak *Bombus* spp. activity for these late-emerging species. Conversely, capture of Brown-belted and Black and Gold bumble bees was broadly distributed across both bouts, though still more abundant in Bout 2 (Brown-belted: $n = 3,649$; Black and Gold: $n = 2,136$) than in Bout 1 (Brown-belted: $n = 1,969$; Black and Gold: $n = 1,690$). Capture of Two-spotted bumble bees, which is typically associated with early bloom conditions, was overwhelmingly during Bout 1 ($n = 337$), with only 42 individuals recorded in Bout 2. This clear divergence reinforces the utility of temporal stratification for capturing species-specific emergence patterns.

Program MARK Analysis

Closed-capture models implemented in Program MARK produced site-level estimates of *Bombus* abundance that was used to derive density within delineated floral colonies at Fort Riley. Across years, 44 colonies were sampled; however, only 31 colonies were suitable for model fit to produce biologically significant estimates (2022: $n = 6$; 2023: $n = 16$; 2024: $n = 9$; Table 4.5). Floral colony area spanned 0.09–10.20 ha (median = 1.61 ha). Floral resources represented a mixture of native and non-native taxa; the most frequently sampled colony type was tall thistle ($n = 6$), with additional representation including round-headed prairie-clover (*Dalea multiflora*), wild bergamot (*Monarda fistulosa*), and milkweed species (*Asclepias* spp.); other categories representing food plot and other blooming species.

Pooled across all sites and years, estimated abundance averaged 281.39 (SE = 25.27) bumble bees per colony (range = 29–599; Table 4.4). Variation in abundance was greatest in 2022, with a coefficient of variation of 78%, compared to 39% in 2023 and 65% in 2024. The largest site-specific abundance ($n = 599$ individuals) was recorded in 2024 within a colony of moderate size (2.45 ha), while the lowest ($n = 29$ individuals) occurred in 2022 in a 3.66-ha site.

Densities were expressed as estimated bumble bees per hectare using the Program MARK abundance estimate and mapped colony area. Pooled across all sites and years, density

averaged 630.12 (SE =121.81; range = 8.37–3,062.62) bees/ha (Table 4.4). The largest density estimate (3,062.62 bees/ha) was observed in 2023 from a 0.16 ha *Penstemon digitalis* floral colony patch. Conversely, the lowest density (8.37 bees/ha) occurred in 2022 in a 3.66 ha *Asclepias verticillata* colony.

Discussion

This study represents one of the first applications of closed capture-mark–recapture methods to estimate abundance and derive density of native bumble bees at the floral colony scale within the tallgrass prairie ecoregion. Across three years of sampling (2022–2024) at Fort Riley Military Reservation, site-specific estimates generated in Program MARK demonstrated that mark–recapture protocols can produce quantitative abundance metrics for local floral patches. The ability to generate such estimates is valuable for evaluating pollinator population status in targeted habitats, enabling detection of changes over time and potential responses to management interventions.

Precision of estimates, reflected in standard errors and confidence intervals, varied considerably among sites and years. Colonies with greater recapture frequencies and balanced recapture rates tended to produce narrower confidence intervals, indicating stronger model performance. Colonies with low recapture probabilities yielded inflated standard errors, sometimes producing biologically unrealistic upper confidence limits. Adjustments to survey design, such as increasing capture occasions, standardizing sampling intervals, and targeting peak bloom periods, could improve detectability and model fit (Williams et al., 2002). Density estimates, derived by scaling abundance to colony area, exhibited greater variability than abundance alone. This pattern results from area heterogeneity: small colonies with moderate counts produce greater bees per hectare density values than larger colonies with similar

abundance. Therefore, abundance is the more consistent primary measure for colony-scale inference, with density best interpreted when colony boundaries are defined using consistent mapping rules and minimum-area thresholds. With the assumption of closed populations during deployment, demographic closure is most defensible over short timeframes aligned with peak bloom, but movement of bumble bees into or out of colonies between capture occasions and behavioral responses to capture may introduce bias. Heterogeneity in individual capture probability likely occurs when floral structure varies within colonies or among floral types.

However, results also highlight methodological considerations that must be addressed for consistent application in prairie systems. Considerable variability in density estimates among floral colonies, particularly in 2022 and 2023, was strongly influenced by the interaction between high estimated abundance and small colony area, which inflated bees/ha values. Small patches with concentrated floral resources may support disproportionately high rate of recaptures within limited space, resulting in extreme density estimates. Conversely, larger colonies with lower bee counts yielded more moderate density estimates and narrower confidence intervals, suggesting that colony area should be incorporated as a covariate in future modeling to improve estimate stability (Otto et al., 2018).

From a management perspective, these findings suggest that mark–recapture methods can be integrated into Fort Riley’s pollinator monitoring framework to generate colony-scale abundance indices, especially for at-risk species such as the American bumble bee and Southern Plains bumble bee. Given the mosaic of grassland types, floral patches, and management regimes on Fort Riley, this approach could help evaluate the effectiveness of habitat treatments, such as rotational burning, haying, and invasive species control, on local bumble bee abundance. In particular, repeated monitoring of floral colonies with relatively large densities of native bumble

bees could help identify floral resources and vegetation structures that are most beneficial for sustaining robust populations.

Care should be taken to avoid over interpretation of density estimates in extremely small colonies, as these may over-represent site productivity when scaled to a per-hectare metric. Where feasible, abundance rather than density should be emphasized for small-patch monitoring, and density metrics should be reserved for larger, ecologically representative floral colonies. Combining mark–recapture with complementary monitoring methods—such as distance sampling or transect-based relative abundance surveys—could provide a more complete picture of *Bombus* population status at both local and installation-wide scales (Roulston & Goodell, 2011). Overall, while the mark-recapture approaches to monitor native bumble bee populations demonstrates promise, refinement of site selection criteria, sampling protocols, and model parameterization will be critical to maximize its utility for long-term pollinator conservation at Fort Riley. When appropriately applied, closed capture-mark–recapture approaches can enhance the precision and ecological relevance of pollinator monitoring, guiding adaptive management to maintain and restore high-quality bumble bee habitats across the tallgrass prairie landscape.

Phenological Timing and Bout-Specific Dynamics

Strong phenological turnover in community composition was observed between early and late season capture bouts. Across all species and years, late-season surveys (Bout 2) accounted for nearly two-thirds of all individuals captured, suggesting that most native bumble bee species reach peak colony and foraging activity during midsummer. This pattern was particularly evident for species of conservation concern (American bumble bee and Southern Plains bumble bee), which were overwhelmingly observed in Bout 2. Number of captures of Southern Plains bumble bee, for example, increased from Bout 1 ($n = 198$) to Bout 2 ($n = 1,881$), suggesting a narrow late-summer flight window consistent with delayed colony emergence and reproductive

phenology. Similarly, capture of American bumble bee more than doubled between bouts (1,271 vs. 2,141), peaking in late July and August.

In contrast, capture of Two-spotted bumble bees was strongly associated with early-season surveys, with 89% of detections occurring in Bout 1. Phenology of Two-spotted bumble bees likely coincides with early-blooming forbs and ephemeral spring resources, underscoring the importance of maintaining floral availability across the full growing season. Generalist species such as Brown-belted and Black and Gold bumble bees were detected across both bouts. Still, they showed increased abundance later in the season, supporting the interpretation that floral availability and colony development are tightly coupled to seasonal dynamics in temperate grassland systems.

Interannual Fluctuations and Environmental Sensitivity

Capture surveys during 2023 were characterized by strong representation by American, Brown-belted, and Black and Gold bumble bees, accounting for 91% of all individuals captured that year. Further, increased captures across most species suggest particularly favorable environmental conditions in 2023, likely due to increased rainfall, longer bloom periods, or successful overwintering. In contrast, the notable decline in captures during 2024, especially for American bumble bees (down 73%) and Southern Plains bumble bees (down 42%), may be caused by drought stress or variations in floral timing. Common Eastern bumble bee was only sparingly encountered as capture numbers declined sharply over three years ($n = 193$ in 2022 to $n = 20$ in 2024). Continued rarity of Common Eastern bumble bees in this landscape suggests that Fort Riley either represents the western edge of its ecological range or that it is less suited to open grassland environments with limited tree canopy or nesting substrates.

Species-Specific Habitat and Management Considerations

Observed patterns reinforce the importance of considering species-specific life histories and ecological requirements in conservation planning. Late-season emergence and declining trend in capture numbers for Southern Plains bumble bees suggest that its populations may be susceptible to disturbance regimes that eliminate late-blooming forbs (e.g., fire, haying, or mowing in July–August). Similarly, the strong late-season activity of American bumble bees indicates reliance on sustained nectar resources through colony reproductive phases. Habitat units with rotational burning or patchy haying schedules may inadvertently support these late-stage foragers by maintaining floristic heterogeneity and bloom continuity. The restricted early-season activity for Two-spotted bumble bees highlights the need for spring floral resources, including early-blooming composites and legumes, which are often underrepresented in grassland restoration seed mixes. Conservation strategies should ensure that restored or managed habitats include both early- and late-flowering species to support the full phenological diversity of native *Bombus* species.

Ecological Implications and Monitoring Recommendations

Collectively, these results emphasize that the intersection of temporal phenology, species-specific emergence strategies, and annual environmental variability shapes native bumble bee communities on Fort Riley. Multi-bout, multi-year monitoring is essential for capturing short-term pulses in activity, local and landscape-scale habitat use, and long-term population trends. Single-season snapshots risk overlooking conservation-relevant dynamics, particularly for species like Southern Plains and American bumble bees, which may fluctuate dramatically in abundance from year to year or shift their phenological peaks. Finally, continued monitoring across Fort Riley and other prairie remnants will be critical to detecting broader trends associated

with climate change, land use, and resource continuity. Conservation of native *Bombus* species in the Great Plains will depend on habitat management that supports temporal floral diversity, minimizes disturbance during key life cycle windows, and maintains the structural heterogeneity needed for successful nesting and colony development.

Conclusion

This multi-year study of native bumble bee communities at Fort Riley Military Reservation revealed clear patterns in seasonal activity, interannual variation, and species-specific responses to environmental conditions. Over three growing seasons from 2022 to 2024, six native bumble bee species were documented, including two of particular conservation concern: American bumble bee and Southern Plains bumble bee. These two species showed strong late-season activity, with most individuals captured during mid-to-late summer surveys, highlighting their dependence on sustained floral resources beyond the early bloom period.

Generalist species such as the Brown-belted bumble bee and Black and Gold bumble bee were abundant across all seasons and years, indicating a broader phenological window and likely greater resilience to changing resource conditions. In contrast, American and Southern Plains bumble bees showed high variability in abundance among years and were often absent from early-season surveys. These patterns suggest that conservation efforts targeting these species should prioritize mid- to late-season floral availability and limit land-use disturbances such as mowing or burning during their peak activity periods. Two-spotted bumble bee was detected almost exclusively in early-season surveys, emphasizing the importance of spring-blooming forbs in supporting its limited activity window. Common Eastern bumble bee remained scarce throughout the study. It was nearly absent in recent years, suggesting that open prairie habitats of Fort Riley may not provide optimal conditions for its persistence.

Importantly, my study demonstrates the value of temporally stratified monitoring frameworks. Sampling across both early and late-season periods was essential for capturing the full range of bumble bee activity and avoiding underrepresentation of species with narrow phenological niches. Interannual variation in bees captured, including the dramatic rise in 2023 and sharp decline in 2024, further illustrates the importance of multi-year datasets in evaluating population trends and informing long-term conservation. Sustaining native bumble bee diversity in the central Great Plains will require habitat management strategies that support floral diversity throughout the growing season, promote spatial heterogeneity in vegetation structure, and align disturbance regimes with ecological needs of key species. Continued monitoring and adaptive conservation planning will be critical to maintaining bumble bee populations under changing climatic and land-use conditions.

Closed capture-mark-recapture at floral-colony scale is a feasible tool for monitoring native bumble bees at Fort Riley when deployed in short, standardized windows during peak floral bloom. Density provides a robust primary metric for patch-level evaluation; abundance is informative where colony mapping and area thresholds are consistent. Implementation as a recurring, colony-focused module, paired with unit-scale transects, will allow conservation management protocols to (i) test short-term effects of fire and haying on local *Bombus* spp. numbers, (ii) prioritize high-value native floral patches for protection and expansion, and (iii) monitor patches supporting conservation-priority species.

Literature Cited

- Biesmeijer, J. C., Roberts, S. P. M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., ... & Kunin, W. E. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, 313(5785), 351–354.
- Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., & Thomas, L. (2001). *Introduction to distance sampling: Estimating abundance of biological populations*. Oxford University Press.
- Burkle, L. A., & Alarcón, R. (2011). The future of plant–pollinator diversity: Understanding interaction networks across time, space, and global change. *American Journal of Botany*, 98(3), 528–538.
- Cameron, S. A., Lozier, J. D., Strange, J. P., Koch, J. B., Cordes, N., Solter, L. F., & Griswold, T. L. (2011). Patterns of widespread decline in North American bumble bees. *Proceedings of the National Academy of Sciences*, 108(2), 662–667.
- Collins, S. L., & Smith, M. D. (2006). Scale-dependent interaction of fire and grazing on community heterogeneity in tallgrass prairie. *Ecology*, 87(8), 2058–2067.
- DoD (U.S. Department of Defense). (2020). DoD instruction 4715.03: Natural resources conservation program.
- Fort Riley Integrated Natural Resources Management Plan (INRMP). (2015). *Integrated Natural Resources Management Plan 2015–2019: Fort Riley, Kansas*. U.S. Army Garrison Fort Riley Environmental Division.
- Gehrt, J. A. (2021). *Response of greater prairie-chickens to natural and anthropogenic disturbance on Fort Riley* (M.S. thesis, Kansas State University).
- Glenn, S. M., & Collins, S. L. (1990). Patch structure in tallgrass prairies: Dynamics of satellite species. *Oikos*, 57(2), 229–236.
- Goulson, D., Lye, G. C., & Darvill, B. (2010). Decline and conservation of bumble bees. *Annual Review of Entomology*, 53, 191–208.
- Harmon-Threatt, A. N., et al. (2011). Pollinators of the Great Plains: disturbances, stressors, management, and research needs. *Rangeland Ecology & Management*, 78(2), 220–234.
- Harmon, J. P., Moran, M. D., & Ives, A. R. (2011). Species response to environmental change: Impacts of food web interactions and evolution. *Science*, 334(6056), 552–555.
- Hatfield, R., & LeBuhn, G. (2007). Patch and landscape factors shape community assemblage of bumble bees, *Bombus* spp. (Hymenoptera: Apidae), in montane meadows. *Biological Conservation*, 139(1–2), 150–158.

- Henry, M., Rodet, G., & Couvillon, M. J. (2021). Bumble bee foraging distance depends on landscape context and forager size. *Ecological Entomology*, 46(6), 1311–1320.
- Hines, H. M., & Hendrix, S. D. (2005). Bumble bee (Hymenoptera: Apidae) diversity and abundance in tallgrass prairie patches: Effects of local and landscape floral resources. *Environmental Entomology*, 34(6), 1477–1484.
- Howe, H. F. (1994). Response of early- and late-flowering plants to fire season in experimental prairies. *Ecological Applications*, 4(1), 121–133.
- Jha, S., & Kremen, C. (2013). Urban land use limits regional bumble bee gene flow. *Molecular Ecology*, 22(9), 2483–2495.
- Kahn, D. M. (2007). Tallgrass prairie management and restoration at Fort Riley, Kansas (M.S. thesis, Kansas State University).
- Kearns, C. A., & Inouye, D. W. (1997). Pollinators, flowering plants, and conservation biology. *BioScience*, 47(5), 297–307.
- Krewenka, K. M., Holzschuh, A., Tschamtker, T., & Dormann, C. F. (2011). Landscape elements as potential barriers and corridors for bees, wasps, and parasitoids. *Biological Conservation*, 144(6), 1816–1825.
- Larson, J. L., Kesheimer, A. J., & Potter, D. A. (2018). Pollinator assemblages on dandelions and white clover in turfgrass lawns. *Journal of Insect Conservation*, 18(5), 863–873.
- Liczner, A. R., & Colla, S. R. (2020). Landscape-scale variation of *Bombus* (Hymenoptera: Apidae) pollinator communities relates to floral resources and land use. *Insect Conservation and Diversity*, 13(5), 488–502.
- NOAA. (2024). National Centers for Environmental Information: Climate data online.
- Otto, C. R. V., Roth, C. L., Carlson, B. L., & Smart, M. D. (2018). Land-use change reduces habitat suitability for supporting managed honey bee colonies in the Northern Great Plains. *Proceedings of the National Academy of Sciences*, 115(29), 7626–7631.
- Richardson, L. L. (2020). American bumble bee (*Bombus pensylvanicus*) species status assessment. U.S. Fish and Wildlife Service.
- Roulston, T. H., & Goodell, K. (2011). The role of resources and risks in regulating wild bee populations. *Annual Review of Entomology*, 56, 293–312.
- Scholtz, R., & Twidwell, D. (2022). The Great Plains: A stronghold for North America's grassland biome. *Rangeland Ecology & Management*, 81, 58–66.
- Steuter, A. A., Grygiel, C. E., & Buhl, D. A. (1995). A strategy for fire management of the Fort Niobrara National Wildlife Refuge. *Prairie Naturalist*, 27(3), 115–126.

- U.S. Army. (2018). Integrated Natural Resources Management Plan: Fort Riley, Kansas (2018–2022). Fort Riley Environmental Division.
- USFWS (U.S. Fish and Wildlife Service). (2021). Endangered Species Act status reviews: *Bombus pensylvanicus* and *Bombus fraternus*.
- WeatherSpark. (2024). Fort Riley climate and weather year-round.
- Williams, B. K., Nichols, J. D., & Conroy, M. J. (2002). Analysis and management of animal populations: Modeling, estimation, and decision making. Academic Press
- Williams, P. H., Thorp, R. W., Richardson, L. L., & Colla, S. R. (2012). Bumble bees of North America: An identification guide. Princeton University Press.
- Wilkinson, T. L., Maron, M., & Possingham, H. P. (2017). Opportunities for conserving threatened species on military lands. *Conservation Letters*, 10(6), 743–750.

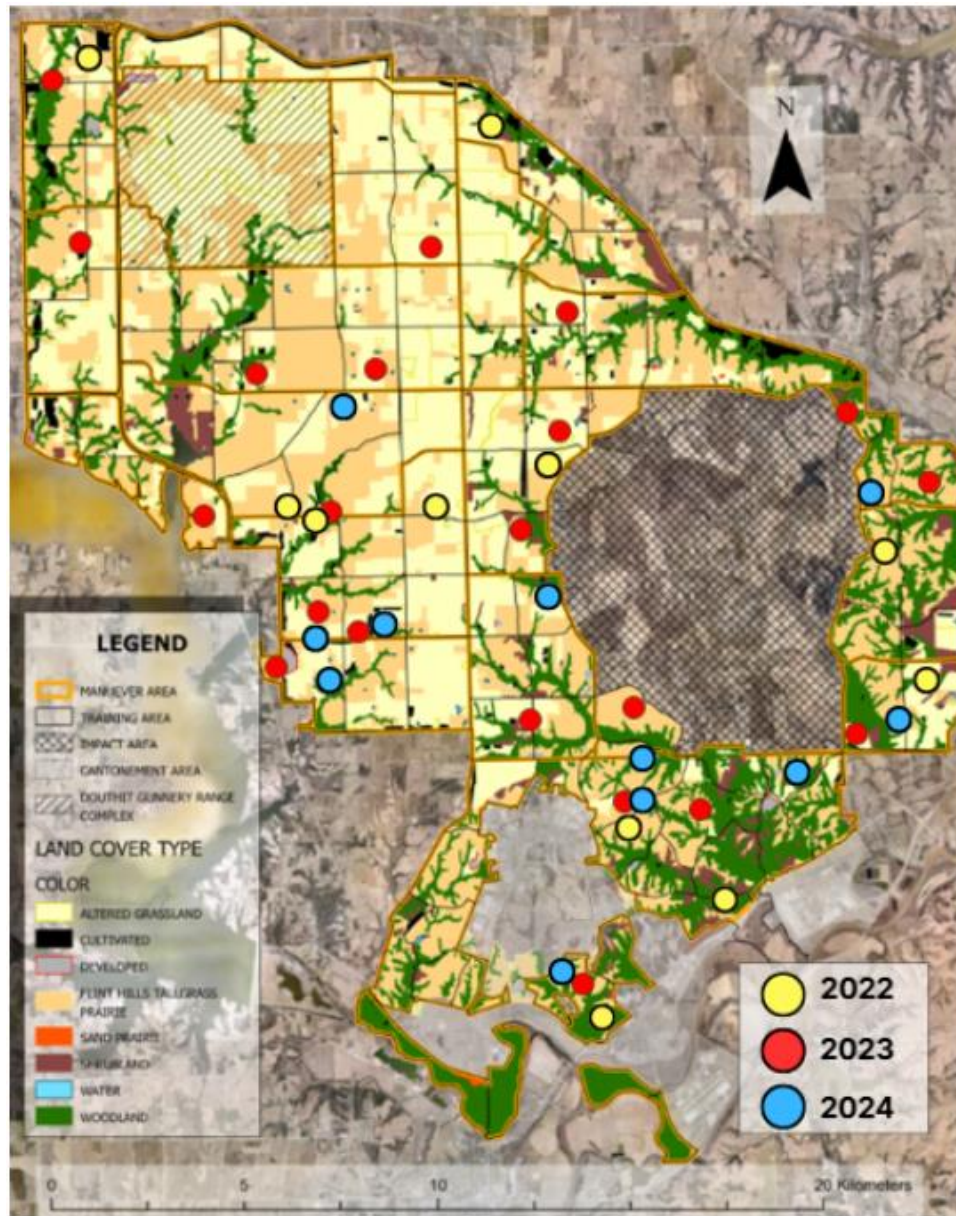


Figure 4. 1. Spatial distribution of *Bombus* spp. capture sites ($n = 44$) surveyed across Fort Riley Military Reservation, Kansas, from 2022 to 2024. Colored circles represent sampling years: yellow (2022, $n = 12$ sites), red (2023, $n = 21$), and blue (2024, $n = 11$). Sampling sites were distributed across 41 unique training units within the installation, with 2022 surveys conducted in 10 units, 2023 in 21 units, and 2024 in 10 units. Site locations span multiple landcover types, including altered grassland, native prairie, shrubland, and woodland, and overlap with designated military zones such as maneuver areas, training areas, and impact zones. Landcover classifications and boundaries were derived from Fort Riley’s Knowledge-based Environmental Management System (KEMS) and the National Land Cover Dataset (NLCD).

Table 4. 1. Total *Bombus* spp.¹ captures, including recaptures at Fort Riley, Kansas, during 2022- 2024, by species and year.

Year	AMER	BRBE	BG	SOPL	TWSP	COEA	Total
2022	374	1,722	385	1,359	4	193	4,037
2023	2,390	2,781	2,665	455	183	67	8,543
2024	648	1,115	776	265	192	20	3,016
Total	3,412	5,618	3,826	2,079	379	280	15,596

¹AMER = American bumble bee (*B. pensylvanicus*), BRBE = Brown-belted bumble bee (*B. griseocollis*), BG = Black and Gold bumble bee (*B. auricomus*), SOPL = Southern Plains bumble bee (*B. fraternus*), TWSP = Two-spotted bumble bee (*B. bimaculatus*), COEA = Common Eastern bumble bee (*B. impatiens*).

Table 4. 2. Total abundance of *Bombus* spp.¹ individuals captured (excluding recaptures) at Fort Riley, Kansas, during 2022-2024, by species and year.

Year	AMER	BRBE	BG	SOPL	TWSP	COEA	Total
2022	307	1,457	356	1,164	4	168	3,470
2023	1,635	2,314	1,975	413	123	54	6,481
2024	536	998	668	246	148	20	2,616
Total	2,478	4,769	2,999	1,823	275	242	12,567

¹AMER = American bumble bee (*B. pensylvanicus*), BRBE = Brown-belted bumble bee (*B. griseocollis*), BG = Black and Gold bumble bee (*B. auricomus*), SOPL = Southern Plains bumble bee (*B. fraternus*), TWSP = Two-spotted bumble bee (*B. bimaculatus*), COEA = Common Eastern bumble bee (*B. impatiens*).

Table 4. 3. Total *Bombus* spp. captured on Fort Riley, Kansas, during 2022-2024, separated by bout 1 (left; May-June) and bout 2 (right: July-August).

Bout 1 <i>Bombus</i> spp. ¹ Capture							
Year	AMER	BRBE	BG	SOPL	TWSP	COEA	Total
2022	NA	NA	NA	NA	NA	NA	NA
2023	211	246	689	84	192	16	1,438
2024	1,060	1,723	1,001	114	145	25	4,068
TOTAL	1,271	1,969	1,690	198	337	41	5,506

Bout 2 <i>Bombus</i> spp. ¹ Capture							
Year	AMER	BRBE	BG	SOPL	TWSP	COEA	Total
2022	374	1,722	385	1,359	4	193	4,037
2023	437	869	87	181	0	4	1,578
2024	1,330	1,058	1,664	341	38	42	4,475
TOTAL	2,141	3,649	2,136	1,881	42	239	10,090

¹AMER = American bumble bee (*B. pensylvanicus*), BRBE = Brown-belted bumble bee (*B. griseocollis*), BG = Black and Gold bumble bee (*B. auricomus*), SOPL = Southern Plains bumble bee (*B. fraternus*), TWSP = Two-spotted bumble bee (*B. bimaculatus*), COEA = Common Eastern bumble bee (*B. impatiens*).

Table 4. 4. Total capture of *Bombus* spp.1 on Fort Riley, Kansas, during 2023-2024 for Bout 2 (July-August).

Year	AMER	BRBE	BG	SOPL	TWSP	COEA	Total
2022	NA	NA	NA	NA	NA	NA	NA
2023	437	869	87	181	0	4	1,578
2024	1,330	1,058	1,664	341	38	42	4,475
TOTAL	1,767	1,927	1,751	522	38	46	6,053

¹AMER = American bumble bee (*B. pensylvanicus*), BRBE = Brown-belted bumble bee (*B. griseocollis*), BG = Black and Gold bumble bee (*B. auricomus*), SOPL = Southern Plains bumble bee (*B. fraternus*), TWSP = Two-spotted bumble bee (*B. bimaculatus*), COEA = Common Eastern bumble bee (*B. impatiens*).

Table 4. 5. Dominant plant type and area of 31 floral colonies where capture-mark-recapture occasion data sampled over 3-4 capture events were used estimate native bumble bee abundance on Fort Riley, Kansas, during 2022–2024.

Year	PID	Floral Type	Area (ha)	Abundance	Bee Density (abundance/area)
2022	7	white prairie clover	2.95	267	90.51
2022	19	roundhead prairie clover	3.05	246	80.66
2022	24	whorled milkweed	3.66	29	7.92
2022	56	tall thistle	1.12	447	399.11
2022	135t	sunflower	1.61	114	70.81
2022	135s	tall thistle	0.09	76	844.44
2023	7.2	Dalea multiflora	3.47	377	108.65
2023	21	bergamot	2.21	321	145.25
2023	22	bergamot	6.91	429	62.08
2023	32	false indigo	3.17	85	26.81
2023	42	tall thistle	0.58	272	468.97
2023	57	tall thistle	0.36	382	1061.11
2023	60	tall thistle	0.69	389	563.77
2023	77	bergamot	2	162	81.00
2023	81	Dalea multiflora	0.85	309	363.53
2023	99	Sullivant's milkweed	0.83	315	379.52
2023	108	Dalea multiflora	1.25	292	233.60
2023	123	Sullivant's milkweed	0.88	473	537.50
2023	FP124	winter pea (food plot)	2.79	355	127.24
2023	I 31	wild bergamot	0.49	310	632.65
2023	N75	Penstemon digitalis	0.3	366	1220.00
2023	TA12	tube penstemon	2.61	505	193.49
2024	65	tall thistle	0.28	99	353.57
2024	A73	roundhead prairie clover	1.36	300	220.59
2024	D78	Penstemon digitalis	1.98	161	81.31

2024	I31	Rosinweed	0.25	279	1116.00
2024	TA3	sweet clover	10.2	75	7.35
2024	TA12	Penstemon digitalis	2.25	109	48.44
2024	TA14	green milkweed	2.25	280	124.44
2024	TA6	bee balm	2.7	599	221.85
2024	TA62	wooly verbena	0.36	300	833.33
