Transmission Lines as Tall-grass Prairie Habitats: Local Mowing, Spraying, and Surrounding Urbanization as Determinants of Wildlife Richness and Abundance

by

Lionel Leston

A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

in partial fulfillment of the requirements of the degree of

Doctor of Philosophy

Clayton H. Riddell Faculty of Environment, Earth, and Resources

Natural Resources Institute

University of Manitoba

Winnipeg

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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Abstract

To manage underused urban grassy spaces like transmission lines as tall-grass prairie habitats or other endangered ecosystems, ecologists need to know how mowing, spraying and surrounding urban lands affect species richness and numbers of plants and animals along transmission lines. I conducted surveys along 48 transmission lines in Winnipeg, Manitoba in 2007-2009 to answer these questions, and I concluded that mowing and spraying should be reduced, but not eliminated, to increase butterflies and other arthropods, resources for butterflies and other arthropods, and arthropod prey for birds. However, the amount of nearby urban land reduced plant species richness and grassland bird abundance along lines more strongly than mowing or spraying, suggesting that lines with less neaby urban land should be selected for management as grassland bird habitats. Mowing and spraying can then be reduced along these lines to benefit other species, enabling urban lands like transmission lines to contribute to conservation.

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Field work was conducted by Dong-jie Bao, Alley Krause-Danielsen, Praepun Khattiyakornjaroon, Kimberley Madsen, Chelsea May, Ellen Reid, and Jennifer Tran.

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Vegetation at my experimental sites was mowed by Manitoba Hydro personnel (Wayne Ortiz, Spencer Heaman) and Neil van Ryssel (agricultural producer, Oakbank, Manitoba).

I also wish to thank Jim Rivers (Oregon State University) for advice on what bill dimensions to measure, Emily Pipher (University of Manitoba) for collecting bill dimensions from Savannah Sparrow nestlings in Grasslands National Park, and Dr. Randy Mooi, (Manitoba Museum of Man and Nature) for providing grassland bird specimens from which I obtained bill measurements for this study.

Dedication

This thesis is dedicated to my father (Lionel Leonard Vernon Leston), mother (Christine Margaret Evans-Leston), stepmother (Nancy Leston), siblings (Carl, Elizabeth, Shane), and partner (David Diakowich).

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Chapter 1. Introduction

Background

Urban transmission lines are usually frequently mowed and sprayed to control weeds, but could be restored and managed as critically endangered ecosystems such as tall-grass prairie (Faminow 1993). Only 1% of tall-grass prairie remains from what occurred 200 years ago (Samson and Knopf 1994). There are few opportunities to protect tall-grass prairies in reserves (Hoekstra *et al*. 2005), but tall-grass prairie has been successfully restored for butterflies along roadside rights-of-way (Ries *et al*. 2001). Transmission lines provide larger areas than roadsides for low-growing habitats that are compatible with power transmission (Baker 1999, Yahner 2004). These areas will need to be restored in the future to counter the threat of expanding urbanization on biodiversity (Macdonald *et al*. 2008), make cities more hospitable for wildlife (Dearborn and Kark 2010), and complement and connect existing protected areas (Young 2000).

Effects of Mowing and Spraying on Plants and Animals Along Transmission Lines

Frequently mowed and sprayed transmission lines are probably suboptimal or hostile environments for many grassland plants and animals. Mowing removes nest cover for and destroys nests of ground-nesting birds (Kershner and Bollinger 1996), shelter habitat for arthropods (Swengel 2001, Kruess and Tscharntke 2002), and taller or slower-growing prairie plant species (e.g. Schippers and Joenje 2002, Hovd and Skogen 2005). Spraying kills forbs or woody plants that are larval host-plants for butterflies or nectar-plants for adult butterflies (Munguira and Thomas 1992). However, infrequent mowing could maintain higher plant species richness by reducing taller competing species (Parr and Way 1988) and benefit herbivorous arthropods that feed on nutritious, recently cut vegetation (Seastedt 1985). Infrequent mowing could also maintain nesting and foraging habitat for grassland birds (Murray and Best 2003, Atkinson *et al*. 2004, Roth *et al* 2005). Therefore, ecologists require mowing studies to design mowing regimes that benefit the most species along transmission lines and similar, underused urban grassy spaces.

Ecologists require strong evidence of negative effects of mowing and spraying on plants and animals to justify reductions in mowing and spraying along urban transmission lines. First, there are strong social pressures and legal obligations for urban vegetation managers to control populations of weeds (Byrne 2005). Second, prairie restoration can be expensive relative to the short-term costs of continued mowing and spraying along lines (Morgan *et al*. 1995). Third, mowing frequency and extent are greater in urban landscapes (Byrne 2005), meaning that negative effects of mowing on wildlife may actually be due to negative environmental effects of surrounding urban lands. Thus, to identify and distinguish negative effects of mowing from those of surrounding urban lands, I experimentally manipulated mowing regimes along urban and rural transmission lines to decouple these effects.

Aside from benefiting wildlife and prairie restoration, reductions in mowing and spraying along transmission lines may also have economic and other ecological benefits for humans. These additional benefits for humans include lower management costs and reductions in resource consumption and pollution associated with mowing and spraying, which could provide other reasons for restoring prairie vegetation along transmission lines and other rights-of-way.

Effects of Surrounding Built-up Lands and Other Land Uses on Plants and Animals Along Transmission Lines

Land uses surrounding transmission lines must be considered when selecting transmission lines to manage as wildlife habitats, because these land uses determine which species reach or settle along and benefit from these habitats. For example, prairie birds are less likely to settle in urban landscapes (Chace and Walsh 2006) or wooded landscapes (Cunningham and Johnson 2006, Winter *et al*. 2006). Urban lands surrounding wildlife habitats also reduce settlement of those habitats by butterflies and other arthropods as well (Bolger *et al*. 2000, Clark *et al*. 2007, Bergerot *et al*. 2010). Conversion of wildlife habitat to built-up urban lands (buildings, roads, concrete) reduces mean remnant habitat area (McKinney 2002) and usually increases the physical distance between remnant habitats (Fahrig 2003). Built-up lands may be impassable barriers or sources of mortality for animals that attempt to cross them (Forman and Alexander 1998), and organisms may be unable to replenish declining populations of their species in isolated habitat fragments (MacArthur and Wilson 1967, Levins 1969). However, habitats along transmission lines may extend for kilometres (Morgan *et al*. 1995), and are separated from similar habitats along lines by no more than single roads. In this case, habitats along lines are probably not isolated for most species and most lines can be managed as wildlife habitats.

Adverse environmental conditions along the boundaries of transmission lines (edge effects) might make urban lines less hospitable for plants and animals, negating efforts to create new habitats. Built-up lands can be sources of traffic noise and pollution

(Lindenmayer and Fischer 2006) and exotic plants that can invade urban grasslands (Reichard *et al*. 2001). As edge effects may extend hundreds of metres into patches (Lindenmayer and Fischer 2006), most transmission lines should be entirely dominated by edge habitats, which might make them less attractive sites for grassland birds (Helzer and Jalinski 1999). If surrounding urban lands prevent species from using habitats along transmission lines, after accounting for local mowing, then mowing reduction and prairie restoration to create wildlife habitats should be limited to transmission lines with less nearby urban lands.

Theoretical Frameworks and Definitions

I conducted my study within the theoretical framework of landscape ecology (Forman 1995), because I predicted that land use near study sites would influence whether or not organisms were able to reach or reached and chose to remain and breed in given habitats. Within this framework, my study sites were contained within *landscapes*, which are physical spaces that encompass multiple discrete areas of two or more ecosystems or land uses – including the study site – in a repeating pattern. The *matrix* is the physically most interconnected ecosystem or land use in a landscape, and is often but not always predominant in terms of proportional cover of the landscape. Within my study, matrices could be built-up lands (e.g. buildings, roads, cement), tilled croplands, wooded lands (forests, shrublands), or grasslands (mowed, hayed, pastured, fallow). The matrix may or may not be hostile to the species being studied, but it is usually assumed to be a non-habitat that can impede the movement of species between discrete units of habitat (or *patches*; Forman 1995).

I used the proportion of land within a specified distance of transmission lines to measure amounts of habitat and non-habitat in this study. I did not treat habitats as islands in a sea of hostile non-habitat (*island-model*: MacArthur and Wilson 1967) or as patches connected by corridors surrounded by impassable matrix (*patch-matrix-corridor model*: Forman 1995). I did this because many birds, plants and arthropods in my study may use a variety of habitats (*variegation model*: McIntyre and Barrett 1992), and might not perceive land uses like roads separating grassland habitats as habitat boundaries. Also, many species (e.g. birds, butterflies) could easily cross built-up lands and other matrix habitats (McIntyre and Barrett 1992).

I did not explore edge effects and habitat isolation influences on wildlife in my study, although they are important concepts within landscape ecology (Forman 1995) and are detrimental to wildlife (McKinney 2002). I thought all of my study sites would be similarly dominated by edge effects, because they were long, linear habitats (Lindenmayer and Fischer 2006). Thus, I did not think there would be sufficient variation in the strength of edge effects to be able to test for such effects along transmission lines in this study.

At the scale of individual study sites, I predicted animals would increase at sites with more resources (Fretwell and Lucas 1969), and that plants and resources for arthropods and birds would be strongly influenced by mowing regime along transmission lines. By exploring how mowing affected species richness and numbers of different animals and plants, I could determine if mowing caused butterflies and other arthropods to increase or decrease along transmission lines due to increases or declines in resource plants. Similarly, I could determine if mowing caused prairie birds to increase or decrease along transmission lines due to increases or declines in arthropod prey or tall vegetation for nesting. I could also determine if resources for arthropods and birds were reduced more by surrounding urban land than by mowing. In either case, I identified a mechanism – mowing and spraying, or habitat isolation by built-up lands - that explained changes in plant and animal abundance along urbanized transmission lines.

Purpose

For my PhD thesis, I explored how and where urban transmission lines might be managed as habitats for tall-grass prairie plants and animals. To gain answers, I conducted three studies (Objectives 1-3) to investigate influences of mowing, vegetation structure, arthropod abundances, and surrounding land uses upon species richness and abundances of prairie plants and animals. I also assessed ecological and economic costs and benefits of different vegetation management options along urban transmission lines, including prairie restoration (Objective 4).

Objectives

1: To compare the effects of the usual mowing frequency along transmission lines – with and without haying – and the amount of surrounding urban land on species richness and numbers of plants, butterflies, other arthropods, and prairie birds that live along transmission lines. I also assessed the effect of a one-year change in mowing frequency on plants and animals as part of a mowing experiment.

2: To determine if arthropod prey for prairie birds decreased along urban lines, and whether or not decreases were due to surrounding urban lands or to changes in resource plants caused by mowing. I also explored whether or not prairie birds increased along transmission lines with more arthropod prey.

3: To determine if butterfly numbers and species richness decreased along urban lines, and whether or not decreases were due to surrounding urban lands or to changes in resource plant abundance. I also explored whether or not resource plants were affected more by mowing or by surrounding urban lands.

4: To describe ecological and economic benefits of restoring prairie and reducing mowing and spraying along urban transmission lines, and outline a strategy for determining where to reduce mowing and restore prairie, and how to manage transmission lines after restoration.

Methods

Power Analysis

I used G-POWER power analysis software (Faul and Erdfelder 1992) to calculate the minimum number of study sites required to detect an effect size of 20% with a power of 80% (α =0.10, β=0.2, Cohen 1988). Minimum required sample size was based on a multiple regression *F*-test, because many predictors and response variables could be modeled as continuous.

I required a sample size of approximately 50 sites to incorporate six independent variables that might influence habitat use and species richness along transmission lines. For the study questions of my PhD thesis, most models had fewer than six predictors.

Study Area and Study Sites

Surveys were conducted over three years (2007 – 2009) along 52 transmission lines within 200 km of Winnipeg, Manitoba (49.90˚ N, 97.14˚ W). I used lines with grassy rights-of-way that were at least 30 m wide, and most lines (except two) were long enough to contain a 500-m transect. In addition to the 52 transmission lines, I also conducted surveys at two urban remnant prairies ("Living Prairie Museum", "Regent Park") and two rural remnant prairies ("Prime Meridian Trail","Oak Hammock") where vegetation was managed with controlled burns rather than by mowing (Table 1.1). However, to remove some confounding factors from the study, I ultimately dropped the four remnant prairies, two transmission line sections that were too short for a 500-m transect ("Garven D", "Manitoba Hydro"), and two transmission line sections in Marchand Provincial Park ("Marchand A", "Marchand B") that were a two-hour drive from other sites and located in forested landscapes far from other grasslands. This left me with 48 sites for most analyses.

Measuring Surrounding Land Use Around Study Sites

Study sites differed in mowing regime (annual mowing and spraying frequency, with or without haying) and proportions of built-up urban lands and other land uses within 100 – 1000 m of a 500-m transect at each site. I quantified different land uses with

ArcGIS 8.3 (ESRI 2002) by analyzing digital orthophoto and LANDSAT data for southern Manitoba (Manitoba Conservation 2006).

Mowing frequency and the proportion of built-up urban land within 100 m of the 48 analyzed sites were strongly correlated in 2007 - 2008 (ρ =0.61). This meant if mowing frequency and urbanization both positively or both negatively affect a species of interest, their effects could be confounded with each other. To decouple their effects, I arranged with Manitoba Hydro to leave five normally mowed and sprayed urban sites unmowed and unsprayed for one year (July, 2008 – July, 2009), and to mow but not spray three normally unmowed sites in agricultural landscapes twice between July, 2008 and July, 2009. Thanks to this adjustment in 2009, mowing frequency was no longer significantly correlated with urban land around the 48 sites (ρ =0.19).

Surveys

I conducted different surveys to measure species richness and numbers of plants and animals along transmission lines. I measured plant species richness, vegetation density, and cover of individual plant species and ground cover types in two 20 X 50 m plots, each with ten subplots (Robel 1970, Kalkhan and Stohlgren 2000). To survey arthropods, I used Pollard transects for butterflies and grasshoppers (Pollard 1977), sweep-nets for foliage-dwelling arthropods and grasshopper species richness (in part) (Cooper and Whitmore 1990), and pitfall traps for terrestrial arthropods, grasshopper species richness (in part), and carabid species richness (Cooper and Whitmore 1990). I used spot-mapping protocol (Bibby *et al*. 1992) to estimate territory densities of prairie birds per year at each site from three visits per site per year.

I chose the species I surveyed for several reasons. First, butterflies, birds, and carabid beetles are valuable as indicator species due to their responses to environmental changes (e. g. butterflies: Blair and Launer 1997; birds: Carignan and Villard 2002; carabid beetles: Rainio and Niemela 2003). By observing how individual species vary with transmission line management and surrounding land use, wildlife managers can determine how and where to manage transmission lines to benefit the most species. However, species surveys of multiple taxa were necessary because managing transmission lines for wildlife based on the needs of species in one taxon (e. g. birds) may not create sufficient habitat for other taxa (e. g. Panzer and Schwartz 1998, Carignan and Villard 2002, Rainio and Niemela 2003). Second, plants, butterflies, and birds of grassland habitat were also selected because I wanted to know if my study sites supported any declining species found in native tall-grass prairies (e. g. plants: Robson 2010; butterflies: Shuey *et al*. 1987, Orwig 1990, Schlict *et al*. 2009; birds: Herkert 1994, Peterjohn and Sauer 1999). Finally, I identified plants, carabid beetles, and grasshoppers to species because particular species may vary in suitability as resources for other organisms (e. g. plants as resources for insects: Panzer and Schwartz 1998; carabid beetles and grasshoppers as prey for birds: Wolda 1990).

Analyses

I used generalized linear mixed modeling (PROC NLMIXED in SAS 9.3) (SAS 2011) and maximum likelihood methods (Burnham and Anderson 2002) to assess the size and importance of effects of vegetation management along transmission lines and land uses surrounding transmission lines. Response variables of interest included plant and animal species richness and abundances of individual species along urban transmission lines. Independent variables were land uses within 100 m of 48 transmission lines (built-up urban lands, wooded lands, total grassland) (Chapters 2-4), mowing frequency and presence of haying (Chapters 2-4), arthropod prey and vegetation habitat metrics for arthropod prey (Chapter 3), and resource plants for butterflies (Chapter 4) (Table 1.2).

Organization of Thesis

The PhD thesis is organized as a sandwich thesis of seven chapters, with the Introduction as Chapter 1.

Chapter 2 ("Experimentally Disentangling the Effects of Urbanization from Mowing on Prairie Wildlife Along Urban Transmission Lines") is formatted for submission to the journal *Ecological Applications*.

Chapter 3 ("Urbanization and Arthropod Food Availability for Grassland Birds: Do Grassland Birds Prefer Settling in Food-Rich Grassland Fragments?") is formatted for submission to the journal *Ecological Applications*.

Chapter 4 ("Managing vegetation along urban transmission lines to increase food plants and shelter habitat for butterflies") is formatted for submission to the journal *Biological Conservation*.

Chapter 5 ("Ecological and Economic Arguments for Converting Urban Transmission Lines into Prairie Wildlife Habitats") is formatted for submission to the journal *BioScience*.

Chapter 6 ("Conclusions").

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Table 1.1. Names of all 56 study sites, their Manitoba Hydro line designations, UTM locations (northing, easting) of the transect starting point at each site, and mowing regime (M.R.): unmowed = U; hayed once a year = H; 1x, 2x = mowed 1- 2 times a year.

Site Name	Line Name	Northing	Easting	M.R.	Site Name	Line Name	Northing	Easting	M.R.
206 East	GT1/ST2;WT34;ST5/ST6	5535390	225732	U	Marchand A	D602F; R49R	5481961	262976	U
206 South	R49R	5528889	223675	H	Marchand B	D602F; R49R	5481851	264318	U
206 West	GT1/ST2;WT34;ST5/ST6	5535559	222503	U	Mc Gillivary	XS49/YH33;VH1/VH2	5528961	200524	2x
207 South	R49R	5529352	217160	H	MC18	P1 / P2	5544152	220521	1x
Anola	GT1/ST2;WT34;ST5/ST6	5535055	238760	U	Oak Hammock	n/a: remnant prairie	5563778	204455	U
BGrandin D	VH1/VH2;YV5/XV39	5529008	207240	2x	Oakbank	GT1/ST2;WT34;ST5/ST6	5535559	222503	U
BGrandin E	VH1/VH2;YV5/XV39	5528036	204026	U	Pleasant	D602F;S1/S2	5528750	241778	U
BGrandin I	VH1/VH2;YV5/XV39	5526583	200463	2x	Plessis Station	SV24;TV1; TV2	5532007	210898	2x
BGrandin J	VH1/VH2;YV5/XV39	5526583	200463	2x	Portage A	D54C	5562802	139915	H
Bradley	north of Regent Park	5532007	210898	2x	Portage B	D54C	5562962	137540	H
Brady	VH1/VH2;YV5/XV39	5526583	200463	H	Portage D	D54C	5563131	134939	H
Bud	VH1/VH2;YV5/XV39	5528036	204026	2x	Prime Meridian Trail	n/a: remnant prairie	5555897	181577	U
Cooks creek	GT1/ST2;WT34;ST5/ST6	5535178	229192	U	Rotary Prairie	n/a: remnant prairie	5534859	210239	U
Dakota	VH1/VH2;YV5/XV39	5526583	200463	2x	Sapton	SV24 ; TS44	5547765	225347	U
Dogpark	XS49/YH33;VH1/VH2	5530810	201092	U	Scurfield	YX48	5526848	197065	2x
Eastdale	GT1/ST2;WT34;ST5/ST6	5536944	240663	U	Shorehill	VH1/VH2;YV5/XV39	5526583	200463	2x
Fairview	P1/P2	5542525	216321	1x	Southside	VJ50;VT63	5522707	210251	U
Garven B	P1/P2	5543188	218330	1x	Spruce	P1/ P2	5546861	226393	1x
Garven D	P1/P2	5542525	216321	1x	St. Mary	VH1/VH2;YV5/XV39	5528036	204026	U
Garven F	SV24;TS44	5542854	225080	U	Stoneridge	D602F;S1/S2	5529252	236932	U
Gros Isle	RP16	5555102	181648	1x	Sugar Factory	XS49/YH33;VH1/VH2	5527635	201082	2x
Heatherdale	R49R	5529166	220434	H	W2W	CN9	5562020	177986	1x
Lagimodiere	SV24;TV1; TV2	5528741	210475	U	W3E	CN9	5561530	186178	1x
Leila	sw of Leila & McPhillips	5541883	202083	2x	W5W	CN9	5561342	189460	1x
Living Prairie	n/a: remnant prairie	5534924	193182	U	Whyte Ridge	YX48	5526848	197065	2x
Mailhot	VJ50;VT63	5526183	209465	1x	Wilkes	Old Portage line	5529683	190209	U
Manitoba Hydro	XS49/YH33;VH1/VH2	5530810	201092	2x	Willowdale	P1/P2	5529683	190209	1x
Maple Grove	Roadside right-of-way	5517261	635615	U	Zora	SV24 ; TS44	5546071	225261	U

Table 1.2.Proportions of different land uses within 100 m of the 56 study sites. Italics = sites not used in analyses in Chapters 2-4. Remnant prairie sites in italics. Bold = control and treatment sites from the mowing experimental study (Chapter 4).

Site Name	% Urban	% Wooded	% Grass-land	Site Name	% Urban	% Wooded	% Grass-land
206 East (mowed twice in 2008-9)	2.95	9.15	22.79	*Marchand A*	0.00	79.72	18.18
206 South	11.57	1.47	48.94	*Marchand B*	0.00	85.71	14.29
206 West (control)	1.84	22.79	11.59	**Mc Gillivary (control)**	19.05	9.76	11.94
207 South	12.73	0.00	80.56	MC18	0.00	55.88	44.12
Anola	8.59	59.72	31.70	*Oak Hammock*	0.00	2.19	13.45
Bishop Grandin D (control)	38.34	19.40	42.26	**Oakbank (mowed twice in 2008-9)**	3.47	20.96	30.11
Bishop Grandin E	39.71	5.32	54.97	Pleasant	4.27	52.87	42.87
Bishop Grandin I (unmowed in 2008-9)	24.76	0.00	74.55	**Plessis Station (control)**	25.59	12.63	54.64
Bishop Grandin J (unmowed in 2008-9)	25.61	20.59	53.42	Portage A	7.32	15.75	73.88
Bradley	64.54	0.00	35.46	Portage B	10.22	36.42	53.36
Brady	0.00	21.68	19.36	Portage D	7.89	41.49	50.62
Bud	55.21	8.54	34.52	*Prime Meridian Trail*	9.40	12.02	48.75
Cooks creek (mowed twice in 2008-9)	2.79	6.94	29.87	*Rotary Prairie*	31.60	7.97	60.43
Dakota (unmowed in 2008-9)	42.05	6.76	44.01	Sapton	8.88	77.76	13.37
Dogpark (control)	0.00	17.11	82.89	Scurfield	42.78	0.00	57.22
Eastdale	5.03	56.18	35.67	**Shorehill (unmowed in 2008-9)**	19.87	21.46	58.67
Fairview	8.77	80.60	10.63	**Southside (control)**	10.02	0.00	78.64
Garven B	4.60	81.06	14.30	Spruce	1.63	39.29	57.82
Garven D	6.80	63.27	29.89	**St. Mary (control)**	34.63	5.15	60.22
Garven F (control)	9.04	39.82	47.83	Stoneridge	2.24	53.14	11.78
Gros Isle	35.10	4.57	10.08	**SugarFactory(unmowed in 2008-9)**	18.14	6.33	75.53
Heatherdale	14.79	3.63	24.61	W2W	11.80	1.29	18.56
Lagimodiere (control)	1.15	3.91	36.69	W3E	15.24	0.00	13.76
Leila	55.70	0.00	44.30	W5E	11.25	1.80	15.03
Living Prairie Museum	11.66	3.70	83.82	Whyte Ridge	42.74	10.28	38.48
Mailhiot	5.37	51.33	41.81	**Wilkes (control)**	8.77	14.26	76.97
Manitoba Hydro headquarters	23.28	0.00	76.72	Willowdale	8.77	14.26	76.97
Maple Grove (control)	29.98	3.02	66.96	**Zora (control)**	4.64	29.99	65.37

Chapter 2. Experimentally Disentangling the Effects of Urbanization from Mowing on Prairie Wildlife Along Urban Transmission Lines

Abstract

To maximize biodiversity conservation within cities, transmission lines and other underused urban grassy spaces could be restored and managed as critically endangered ecosystems such as tall-grass prairies. However, it is unclear whether conserving these ecosystems requires a reduction in mowing and spraying to control weeds, because mowing and spraying reduce numbers and cover of many plant species and resources for animals. Further, it is unknown whether urban sites can be restored as self-sustaining tall-grass prairies, as surrounding urban lands might prevent or deter plants and animals from settling along and benefiting from new wildlife habitats along transmission lines. Since urban transmission lines are frequently mowed and sprayed to control weeds, the separate effects of mowing, spraying, and degree of surrounding urbanization on biodiversity along transmission lines might be confounded with each other in purely observational studies. Experimental habitat manipulation can be used to decouple effects of mowing and surrounding urban land on biodiversity, but is rare in urban ecology studies. I compared effects of mowing and surrounding urban lands upon plants and animals along 48 transmission lines in Winnipeg, Manitoba (2007 – 2009). Surveys at 20 of these 48 lines were conducted before and after an experimental one-year adjustment to the mowing regime at eight of the sites. Increases in urban land within 100 m (20 and 40 %) were associated with 20 % and 35 % fewer plant species, 34 % and 56 % less arthropods in pitfall traps, 26 to 75 % fewer territories of grass-nesting birds, and lower numbers per species per visit of some butterflies. Frequent mowing and spraying reduced numbers of other numbers per visit of other butterfly species, arthropod biomass, and plant resources for arthropods and birds. A one-year change in mowing had little effect on plants or animals, suggesting that mowing effects on wildlife occur over longer periods. However, lepidopterans responded strongly to a change in mowing, increasing by 78 % with a halt in mowing and declining by 38 % with an increase in mowing. Lines that have less urban land nearby should be prioritized for management as prairie wildlife habitats, because they will attract more prairie birds and some butterflies. Mowing and spraying can be reduced along these lines to increase butterfly resource plants, other butterflies, and other arthropods.

Keywords*: experiment; birds; butterflies; habitat manipulation; mixed modeling; plants; tall-grass prairie; species richness; urbanization.*

Introduction

Transmission lines and other underused urban grassy spaces could be restored and managed as low-growing, endangered ecosystems such as tall-grass prairie, which is underrepresented in existing refuges and is less than 1 % of its former extent in Manitoba (Samson and Knopf 1994, Hoekstra *et al*. 2005). Restoring prairie along even narrow roadsides in Iowa has benefited prairie butterflies (Ries et al. 2001), suggesting that similar restorations along transmission lines would benefit wildlife. However, before investing in expensive restorations along transmission lines, ecologists need to understand how and where to manage such transmission lines to benefit the most species of prairie plants, butterflies, other arthropods, and prairie birds.

To attract animals and plants to wildlife habitats along urban transmission lines, mowing and herbicidal spraying may have to be reduced within these new habitats. Although mowing urban vegetation can make it more nutritious for herbivorous arthropods (Seastedt 1985) and create space for more species of forbs and butterfly resource plants among taller, faster-growing plants (Parr and Way 1988, Munguira and Thomas 1992), mowing eliminates taller plant species (e.g. Fenner and Palmer 1988, Schippers and Joenje 2002, Hovd and Skogen 2005) and removes shelter habitat for butterflies and other arthropods (Swengel 2001, Kruess and Tscharntke 2002). Spraying reduces the diversity of broadleaf plants (Parr and Way 1988), which could reduce species richness of butterflies (e.g. Munguira and Thomas 1992, Valtonen *et al*. 2007, Öckinger *et al*. 2009). By reducing arthropod habitat, frequent mowing and spraying may reduce food supplies for ground-foraging insectivorous birds (e.g. Lancaster and Rees 1979, Morneau *et al*. 1999, Rottenborn 1999). Mowing also destroys nests when it is conducted during the breeding season (Kershner and Bollinger 1996).

Even if mowing and spraying are reduced, surrounding urban land might prevent or deter plant and animal species from settling in and benefiting from restored habitats along transmission lines. Urban lands may be sources of pollution, predators, or invasive exotic competing species that can lower habitat quality for native plants (Bolsinger and Fluckiger 1988, Speight *et al*. 1998), arthropods (Gibb and Hochuli 2002), and birds (Soulé *et al*. 1988). As urban lands increase in the landscape, wildlife habitat areas usually decrease in size and distance between habitats increases (Fahrig 2003). Built-up lands such as roads may then serve as barriers or sources of mortality for dispersing plants and animals (Forman and Alexander 1998), preventing species from moving between and repopulating isolated habitats where populations of those species are declining (Levins 1969, Bolger *et al*. 2000).

Given that urban green spaces such as transmission lines are frequently mowed and sprayed (Byrne 2005), experimental studies are required to decouple mowing and spraying effects from effects of surrounding urban land on wildlife. Unlike observational studies of urban effects on wildlife (e.g. McKinney 2002, Forman and Alexander 1998), experimental studies are rare due to the expense and time required for habitat manipulation (Hurlbert 1984, Stewart-Oaten *et al*. 1986, Cook *et al*. 2004). However, identifying the separate effects of mowing and spraying from urban lands is needed to justify reductions in mowing and spraying, because such reductions may conflict with public by-laws mandating tidy, weed-free urban green spaces (Byrne 2005). Furthermore, prairie restoration along urban transmission lines is expensive (Egan 1994, Harrington 1994, Morgan and Collicut 1994), meaning that advocates of restoration must know how and where restoration along transmission lines will attract and benefit the most species. If mowing and spraying affect biodiversity along transmission lines more strongly than surrounding urban land, then more lines might be managed for conservation by reducing mowing and spraying. However, if surrounding urban lands reduce the numbers of organisms that reach or settle along transmission lines, then prairie restorations should be restricted to lines outside of urban areas.

To compare effects of mowing and surrounding urban lands upon plants and animals along transmission lines, I conducted plant and animal surveys along 48 transmission lines that varied in mowing frequency (including whether they were hayed or not) and the amount of nearby urban land. I predicted that species richness and numbers of plants and animals would generally decline as either mowing frequency or the amount of built-up urban lands within 100 m of transmission lines increased.

To decouple mowing frequency from the amount of urban land near twenty sites, I altered the regular mowing regime along eight of these transmission lines for the final year of a three-year study (2007-2009). For urban sites, all of which were frequently mowed before the adjustment, I predicted that species richness and organism abundances would increase on treated sites that were left unmowed in 2009, relative to mowed control sites. For rural sites, all of which were unmowed before the adjustment, I predicted that species richness and organism numbers would decline on treated sites that were mowed in 2009, relative to unmowed control sites.

Methods

Study Area

Surveys occurred over three years (2007 – 2009) along 48 power transmission line sections with grassy rights-of-way that were at least 30 m wide and 500 m long. All sites were within 200 km of Winnipeg, Manitoba (49.90˚ N, 97.14˚ W). Lines were at least 500 m apart to minimize the likelihood that individual prairie birds had territories spanning study sites.

Common grassland birds at my study sites were Savannah Sparrows (*Passerculus sandwichensis*), Clay-coloured Sparrows (*Spizella pallida*), Western Meadowlarks (*Sturnella pallida*), Le Conte’s Sparrows (*Ammodramus lecontei*), and Vesper Sparrows (*Pöocetes gramineus*). For this study, I defined grassland birds as those species that will forage and nest in grassland environments, either on the ground or in very small shrubs (< 1 m tall) in grassland-dominated landscapes, as opposed to nesting in forests or wetlands. Grassland birds in my study may use grasslands dominated by native or exotic plants and may use other habitats besides grasslands.

Common butterflies at sites were European Skipper (*Thymelicus lineola* Ochsenheimer), Common Sulfur (*Colias philodice* Godart), Cabbage White (*Artogeia rapae* Linnaeus), Common Wood-nymph (*Cercyonis pegala* Fabricius), Northern Pearl (*Phyciodes morpheus* Fabricius) and Pearl Crescents (*Ph. Tharos* Drury), Great-spangled Fritillary (*Speyeria cybele* Fabricius), Silver-bordered Fritillary (*Boloria selene* Dennis and Schiffermüller), Meadow Fritillary (*B. bellona* Fabricius), and Variegated Fritillaries (*Euptoieta claudiae* Cramer), Monarch (*Danaus plexippus* Linnaeus), Ringlet (*Coenonympha tullia* Müller), and Silvery Blue (*Glaucopsyche lygdanus* Doubleday).

Land Cover Classes Around Sites

To measure amounts of urban land and other land uses near transmission lines, I imported GPS waypoints for each 500-m transect into ArcGIS 8.3 (ESRI 2002) along with overhead digital orthophotos of land use surrounding each transect (Manitoba Conservation 2006). I digitized the boundaries of different land uses within 100 m of each transect and classified the resulting polygons by those land uses. Lands within 100 m of my study sites were predominantly built-up urban lands (buildings, roads, concrete), tilled croplands, wooded lands (forests, shrublands) or grasslands (frequently mowed grasslands like sports fields, lawns, and rights-of-way; hayed forage croplands; unhayed grasslands that were mowed once a year; pastures; and unmanaged grasslands such as fallow fields and unmowed transmission lines). I checked the accuracy of these classifications against Google Earth maps, LANDSAT data (Manitoba Conservation 2006), and on-site observations. I generated 100-m buffers around each transect and used those buffers to clip shape-files of polygons. Proportions of different land uses within 100 m represent amount of potential habitat (grassland) or non-habitat (urban land, wooded land) for plants and animals along transmission lines. All grasslands regardless of type (mowed, hayed, pastured, fallow) within 100 m of transects were generally treated as potential habitats for grassland species.

Long-Term Mowing Regime Along Transmission Lines

Manitoba Hydro mows and sprays its transmission lines with a broadleaf herbicide (2, 4-D) in Winnipeg at least twice a year in the spring and fall to control weeds like Canada thistle (*Cirsium arvense*) and dandelion (*Taraxacum officinale*). Exurban lines may be mowed once a year or not at all except to remove trees under transmission line cables. Mowing is done as time allows on a circuit rather than specific calendar dates. Some lines are left unmowed while the ground is still swampy or until there are complaints about weeds or tall vegetation. For efficiency, mowing and spraying involve a 15-foot-wide mower and a complete tank system on a truck. Smaller mowers and spot-spraying with backpack sprayers are used next to private property. Cut vegetation is left as mulch along transmission lines except along hayed transmission lines (Spence Heyman, *personal communication*).

The management regime along the 48 transmission lines in 2007 – 2008 consisted of four categories: frequent mowing and spraying twice a year without haying (n = 13), infrequent mowing and spraying once a year without haying (n = 9), haying once a year without spraying (n = 7), and no mowing or spraying except for tree removal (n = 19). Mowing frequency was strongly correlated with the proportion of urban land within 100 m of transects along these lines in 2007 - 2008 (ρ =0.61, p< 0.0001), which potentially confounds mowing and urban land effects in analyses of plant and animal abundances along lines. Urban land within 100 m of transects was also negatively correlated with wooded land within 100 m of transects (ρ =-0.58, p< 0.0001).

Another caveat for this study was that effects of mowing and spraying were confounded with each other since they co-occurred at frequently mowed and sprayed sites and infrequently mowed, unhayed sites. Spraying did not occur at hayed or unmowed sites. Therefore, when effects of mowing and spraying were noted on wildlife, I could not identify a distinct effect of mowing or lack of mowing separate from spraying in this study.

Short-term Mowing Experiment Along Transmission Lines

To disentangle mowing effects on plants and animals from effects of surrounding urbanization, I used two groups of mowing control and treatment sites from my 48 transmission lines. The first group of nine sites (four control, five treated) occurred within the City of Winnipeg's Perimeter Highway, where urban lands occupied ≥ 18 % of land within 100 m. Urban control and treatment sites were frequently mowed and sprayed in 2007 – 2008, but the five treated sites were left unmowed and unsprayed by Manitoba Hydro for one year (late August, 2008 – late August 2009). The other 11 sites (eight control, three treated) occurred outside of Winnipeg's Perimeter Highway, where urban lands occupied ≤ 8 % of land within 100 m. Rural control and treatment sites were unmowed and unsprayed prior to late August, 2008. To decouple effects of mowing and urbanization, the three (previously unmowed) treated sites were mowed twice by a private contractor between late August, 2008 and mid-June, 2009. Urban land within 100 m of transects was strongly correlated with mowing frequency at the 20 sites (ρ =0.64, $p<$ 0.0001) before the mowing adjustment, but not afterwards (ρ =0.07, p = 0.77). Only three unmowed rural sites were dry enough to be mowed easily by hired farm equipment, but I selected treatment and control sites to minimize variation in factors other than mowing regime and proportion of urban land within 100 m of transmission lines.

Mowing and spraying were partially confounded with each other in the mowing experiment, in that urban treatment sites experienced a halt in both mowing and spraying simultaneously. Thus, a positive or negative effect of the treatment cannot be attributed to mowing separately from spraying. However, the rural treatment sites were mowed twice between the 2008 and 2009 field seasons without being sprayed. So the response of organisms to the rural treatment was solely a response to mowing.

Vegetation Surveys

From mid-July to the end of August in either 2007 or 2008, I conducted vegetation surveys (2 plots per site, spaced 300 m apart) at 48 sites to determine plant species richness and abundance at each site. Most sites were first visited and surveyed in 2007, and due to time and labour constraints, the only vegetation surveys conducted in 2008 were at sites that were visited for the first time in 2008. As individual plots usually took one hour per plot for 2-3 people to complete, sample sizes for vegetation surveys were smaller than for animal surveys in this study, which took less time per survey and could be done by one field worker. In 2009 after the mowing adjustment, I revisited the 20 treatment and control sites to repeat vegetation surveys, giving me 68 surveys from 48 sites over three years.

Each survey plot consisted of a 1000-m^2 Modified-Whittaker plot where I recorded presence of plant species. I measured cover of predominant plant species and ground cover types in ten 0.1-m^2 systematically spaced subplots (Kalkhan and Stohlgren 2000). Cover types of interest consisted of total forb cover (nectar plants for adult butterflies); larval host plant cover for Cabbage White (mustards), Common Sulfur and Silvery Blue (legumes), Common Wood-nymph (grasses), crescents as a group (asters), European Skipper (timothy and redtop), fritillaries as a group (violets), Monarch (milkweeds and dogbanes), native skippers as a group (grasses), and Ringlet (grasses) (Klassen *et al*. 1989); total grass cover; total woody plant stem cover; litter cover; and bare ground cover. I assigned plant species and ground covers in each quadrat to cover classes (0%, trace = > 0-0.5%; 1 = 0.5-1%; 2 = 1-3%; 3 = 3-10%; 4 = 10-25%; 5 = 25-50%; 6 = 50-75%; 7 = 75-90%; 8 = 90-100%; 100%) instead of estimating percentage cover directly. I used this scale because it produces more consistent estimates of plant cover by different field technicians (Daubenmire 1959). For analyses, I converted this ranking to the mid-range values for each number range.

In addition to cover types, I measured average vegetation height-density among all twenty quadrats per site with a Robel pole as a metric of the amount of habitat available for arthropods or nesting birds (Robel *et al*. 1970). I also measured cumulative plant species richness among both plots per site.

Butterfly Surveys

I counted butterflies and moths within 5 m of a 500-m transect at each site between 10:30 and 1:30, on days without strong wind ($\geq$ 15 kmhr^{-1}) or precipitation, when temperatures were at least 13 ° Celsius (Pollard 1977). There were 2-4 visits per site from mid-June to mid-August in each year, giving me 415 surveys from 48 sites over three years. I identified individual butterflies and skippers to species wherever possible. Unknown butterflies and skippers were briefly captured and identified in the hand prior to release, or collected and stored as voucher specimens in the J. B. Wallis/R. E. Roughley Museum of Entomology, University of Manitoba Department of Entomology.

Other Arthropod Surveys

I surveyed for other arthropods with sweep-nets at 47 sites and pitfall traps at 48 sites in 2007 through 2009 to assess mowing and urban land effects on different types of arthropods (Cooper and Whitmore 1990). There were ten pitfall traps per site in two groups of five traps each, with the two groups spaced 300 m apart. I opened traps for 1-3 one-week collection periods from mid-June to late August. This gave me 212 pitfall trap collections from 48 sites over three years. While open, pitfall traps were filled with a solution of salt and soapy water to kill any arthropods that fell in before predatory arthropods consumed other arthropods in the traps. This solution was chosen for its non-toxicity, in case children or pets encountered traps, especially at urban sites. To keep rainwater from flooding the traps, the lid of the traps was used as a roof held off the open traps by a 1-inch mesh frame. A circular, second 1-inch mesh frame was used as a false floor halfway down in each trap to minimize the number of frogs, mice and shrews that fell into the traps, while allowing arthropods to fall through the mesh into the traps' solution. After collection, I brought samples back to the lab to preserve them in 70% ethanol until processing.

There were two 20-m sweep-net transects per site spaced 300 m apart, with 2-3 collection periods per site between mid-June and late August, 2008 – 2009. This gave me 244 sweep net collections from 47 sites over two years. I conducted sweep net collections under the same conditions as for butterfly transects (Pollard 1977). As soon as possible after capture, I froze net collections for at least 48 hours before processing.

During processing, I separated, identified, and counted taxa in each sample by length and width (mm), class (millipedes, isopods, nonarthropod classes like gastropods), order (arachnids, insects), and where possible to family and species (adult grasshoppers and carabid beetles). After this, the taxa were dried for at least 48 hours in an oven at 50˚ Celsius before measuring biomass pooled by size-class and taxon in an electronic balance (Mettler AE166 Delta Range ± 0.0001 g). I identified species of ground beetles based on Lindroth (1961, 1963, 1966, 1968, 1969) and adult grasshoppers based on Vickery and Kevan (1985). Voucher specimens for these taxa were deposited in the J. B. Wallis/R. E. Roughley Museum of Entomology, University of Manitoba Department of Entomology.

Bird Surveys

I used the spot-mapping protocol of Bibby *et al*. (1992) to determine territory densities of prairie birds within a 50,000-m^2 area (50 m to either side of the 500-m transect line). Territory densities of individual species were based upon three rounds of avian transects per site (May 25 – June 30) with at least 10 days between visits to the same site. Surveys were conducted between dawn and 1000 hours, on days without strong wind or precipitation (Bibby *et al*. 1992). This gave me 126 bird surveys from 48 sites over three years.

Analyses

1. *Effects of Mowing, Spraying and Landscape on Plants, Arthropods, and Birds Along Transmission Lines*

From graphs, some dependent variables were nonlinearly related to independent variables of interest (e.g. Julian date, mowing frequency). In such cases, I modeled those dependent variables as a quadratic or cubic function of Julian date and as a quadratic function of mowing frequency, in which case dependent variables reached maximum values at intermediate values of the independent variables.

I determined which data distribution best described the residuals associated with dependent variable. According to quantile-quantile plots, continuously distributed dependent variables (ground cover percentages, arthropod biomasses in sweep-nets and pitfall traps) were best modeled as normally distributed after log-transformation. I modeled other dependent variables that consisted of counts (plant and butterfly species richness, numbers per butterfly species per transect, bird territory densities) as Poisson or negative binomial distributions, which I selected based on which distribution resulted in a lower model deviance.

I calculated Pearson correlation coefficients to identify redundant independent variables that were strongly correlated with each other ($|r| > 0.6$). In such cases, the variable in the pair considered to be less biologically relevant was excluded from models for predicting each dependent variable of interest.

I used ordinary least-squares regression to identify sites or survey visits that were statistical outliers for each dependent variable. One study site ("Zora") was distinct from the others in having greater native prairie plant cover and bare ground cover, instead of exotic grasses and forbs, and greater pitfall trap biomasses relative to other sites. Similarly, there were a few extremely high counts for each individual butterfly species on butterfly transects. To evaluate the relative impacts of these outliers on my results, I compared model results for pitfall traps with and without Zora's pitfall trap surveys, and for individual butterfly species with and without the visits with unusually high counts.

I used generalized linear mixed modeling (PROC NLMIXED in SAS 9.2) (SAS 2011) to assess effects of mowing regime and surrounding land use on vegetation, arthropods, and birds after accounting for time effects of each visit and repeated measurements at the same sites (Bolker et al. 2008). Mixed modeling enabled me to account for repeated sampling of sites among years. I used generalized linear models (PROC GENMOD in SAS 9.2) (SAS 2011) to generate starting parameter estimates of time, mowing, and land use parameters for mixed models.

I included year as a time effect in all models except the null model because I predicted that annual differences in weather would have effects on vegetation, arthropods, and prairie birds. I included Julian date (the number of days since January 1) in models of arthropod abundance because I predicted that arthropods would increase in abundance and/or activity as temperatures increased (Taylor 1963). Julian date of pitfall trap surveys was strongly, positively correlated ($r > 0.60$) with weather data for the Winnipeg region during the 2007-2009 field seasons (mean and minimum weekly temperatures during 7-day periods that pitfall traps were open to collect arthropods), suggesting that Julian date was a reasonable index for several different weather variables.

I used an information theoretic approach to rank the best model predicting each dependent variable (Burnham and Anderson 2002). The best (most parsimonious) model was the model with the smallest value of Akaike's Information Criterion modified for small sample size (AIC_c) in the set of *a priori* models for each response variable (Burnham and Anderson 2002). Models in which AIC_c values differ from the best model's by two units or less ($\Delta\ AIC_c \leq 2$) are considered to be more or less equivalent (Burnham and Anderson 2002), in which case the model with the fewest parameters is considered to be the most parsimonious (Arnold 2010). To determine if no mowing or land use effects strongly predicted a particular dependent variable, I tested a null model with no time, mowing, or land use effects for all dependent variables. I also tested a model with time effects but no mowing or land use effects. I calculated model weights (ω) to express the relative likelihood that a given model best predicted each dependent variable (Burnham and Anderson 2002).

To determine how mowing regime along transmission lines and proportions of different land uses (urban lands, total potential grassland habitat) within 100 m of lines affected vegetation that may be resources for butterflies, other arthropods, and birds, I compared the following models:

1) *year* + *mowing frequency* + *mowing frequency*^{2} + *hayed* (yes = 1, no = 0)(full management model)

2) *year* + *urban 100 m* + *grassland 100 m* (land use model)

3) *year* + *mowing frequency* + *mowing frequency*^{2} + *hayed* + *urban 100 m* + *grassland 100 m* (global model).

4) year (time effects model)

5) null model

6) *year* + *mowing frequency* (simplified mowing model, only for vegetation density)

7) *year* + *hayed* (simplified haying model, only for forb and bare ground cover)

For vegetation structure, dependent variables consisted of mean vegetation height-density (cm), which might be positively correlated (Kruess and Tscharntke 2002) or negatively correlated with different arthropods (Seastedt 1985, Morris and Rispin 1988, Onsanger 1996); mean per cent forb cover, mean per cent woody plant cover, and mean per cent grass cover which serve as food sources for different arthropods (Vickery and Kevan 1985, Klassen *et al*. 1989); 5) mean per cent cover of bare ground as sunbathing or egg-laying sites for grasshoppers (Onsanger 2000) and as a measure of how easily arthropods can move across ground to encounter pitfall traps (Greenslade 1964); 6) mean litter cover as a potential habitat for terrestrial arthropods (Usher and Smart 1988, Gardner and Usher 1989); 7) cumulative plant species richness from the two vegetation plots per site, because the presence of more plant species may support a wider range of different species of arthropods, and thus a more diverse food resource base (Munguira and Thomas 1992); 8) larval host-plant cover for common species or species-groups of butterflies (*see below*) (Table 2.1).

In addition to the full management model, I also examined two simpler management models for a small number of dependent variables. I examined a linear function of mowing frequency without haying when predicting vegetation height-density, because I predicted that vegetation height-density would decline linearly with mowing frequency. Similarly, I also included a simpler haying model (yes = 1, no = 0) without mowing frequency when predicting total forb cover and bare ground cover. I had *a priori* reasons to predict that hayed transmission lines would have more forb cover because there was visibly greater forb cover on hayed sites during surveys, due to exotic legumes being intentionally cultivated there. I also had an *a priori* reason to predict that hayed transmission lines would have more bare ground cover because hayed transmission lines were the only lines where cut vegetation was removed. I did not run these simpler management models for other dependent vegetation variables, because I did not have *a priori* reasons to predict that other vegetation variables would decrease linearly with mowing frequency or increase with haying.

Models for butterflies and other arthropods were similar to vegetation models but included Julian day as another independent variable:

1) *year + Julian day + mowing frequency + mowing frequency*^{2} + *hayed* (full management model)

2) *year + Julian day + urban 100 m + grassland 100 m* (land use model)

3) *year + Julian day + mowing frequency + mowing frequency*^{2} + *hayed + urban 100 m + grassland 100 m* (global model).

4) *year + Julian day* (time effects model)

5) null model

6) *year + Julian day + hayed* (simplified haying model, only for Common Sulfurs and Silvery Blues)

Dependent variables for butterfly models consisted of 1) number of adult butterflies and moths per 500-m transect per visit; 2) butterfly species richness per 500-m transect per visit; and 3) number of individuals per common butterfly species (Cabbage White, Common Sulfur, Common Wood-nymph, European Skipper, Monarch, Ringlet, Silvery Blue) or species-group (crescents, fritillaries, native skippers) per 500-m transect per visit. Dependent variables for sweep-net and pitfall trap models consisted of 4) total biomass per sweep-net collection; 5) lepidopteran biomass per sweep-net collection; 6) orthopteran biomass per sweep-net collection; 7) total biomass per pitfall-trap collection; 8) lepidopteran biomass per pitfall-trap collection; 9) orthopteran biomass per pitfall-trap collection; 10) carabid biomass per pitfall-trap collection. I ran butterfly models twice, once for all visits and once excluding outliers. I ran pitfall-trap models twice, once with all 48 sites and once without the outlier site Zora (47 sites).

In addition to the full management model, I also included a simplified haying model (hayed, yes = 1, no = 0) when predicting numbers of Common Sulfurs and Silvery Blues per visit. I included this model for analyses of those species, because legumes and total forb cover were visibly greater at hayed sites during surveys. This gave me an *a priori* reason to predict that Common Sulfurs, Silvery Blues, and their larval host-plants (legumes) would be most abundant along hayed transmission lines. I did not run this simpler haying model for other dependent arthropod variables, because I did not have *a priori* reasons to predict that other arthropods would increase with haying.

Models for prairie birds were similar to vegetation models but included the amount of wooded land within 100 m of transmission lines as another independent variable:

1) *year* + *mowing frequency* + *mowing frequency*^{2} + *hayed* (full management model)

2) *year* + *urban 100 m* + *grassland 100 m* + *wooded 100 m* (land use model)

3) *year* + *mowing frequency* + *mowing frequency*^{2} + *hayed* + *urban 100 m* + *grassland 100 m* + *wooded 100 m* (global model).

4) *year* + *Julian day* (time effects model)

5) null model

Dependent variables for these prairie bird density models consisted of individual species of birds that were common enough for analysis (present at > 10 % of study sites). Wooded land was an independent variable in these models, because many prairie bird species avoid settling in landscapes with more wooded lands (Bakker *et al*. 2002, Grant *et al*. 2004).

2. ***Effects of Experimental Mowing on Plants, Arthropods, and Birds Along Transmission Lines***

I used generalized nonlinear mixed models (SAS 2011) to calculate the effects of a change in mowing upon the same set of response variables that was analyzed at 48 sites (Table 2.1). I ran the following models separately for the nine urban sites and the 11 rural sites:

1) *year* (all models) + *Julian day* (for arthropod models only) + *mowed* (yes = 1, no = 0)
2) *year* (all models) + *Julian day* (for arthropod models only) (time effects model)
3) null model

I compared the AIC_c value of each dependent variable's models, and I concluded that a short-term mowing effect existed if the mowing model's AIC_c value was at least two AIC_c units smaller or more negative than the AIC_c values for both time and null models (Burnham and Anderson 2002).

Results

Effects of Mowing, Spraying and Landscape on Plants, Arthropods, and Birds Along Transmission Lines

Long-term mowing and spraying either partially or best predicted many aspects of a site's vegetation, with different ground covers declining along frequently mowed and sprayed transmission lines (Figure 2.1, Tables 2.2-2.4). Models predicted that hayed transmission lines had three times more forb cover for adult butterflies, six times more legume cover (larval host-plants for Common Sulfurs and Silvery Blues), 39 % less grass cover (host-plants for Common

Wood-nymphs, Ringlets, and native skippers), and six times more timothy and redtop cover (host-plants for European Skippers) than unhayed transmission lines in this study. The mowing model predicted that vegetation height-density decreased by 9.6 cm with an increase from no mowing to once per year, but changed by much smaller amounts either with further increases in mowing frequency or with haying of cut vegetation (Figure 2.1, Tables 2.2-2.4).

Although plant species richness was lower along frequently mowed and sprayed lines (Table 2.3), surrounding land use either partially or best predicted total plant species richness, woody stem cover, and abundances of violets (host-plants for fritillaries) and legumes (host-plants for Common Sulfurs and Silvery Blues) (Figures 2.2-2.3, Table 2.4). There were 177 species of forbs along transmission lines, including 130 species of butterfly nectar-plants and larval host-plants, 47 species of grasses, rushes, and sedges, and 42 species of woody shrubs and trees (Appendices II-IV). Models predicted that increases of 20 % and 40 % in the amount of land within 100 m that was urban (which varied from 0 – 65 %) were associated with 20 % and 35 % fewer plant species than along lines with no urban land within 100 m. Similarly, increases of 20 % and 40 % in the amount of land within 100 m that was grassland (which varied from 10 – 85 %) were associated with 13 % and 24 % fewer species of plants than along lines where 10 % of land within 100 m was grassland (Figure 2.2, Table 2.4). Cover by woody plants declined with increasing urban land within 100 m, whereas legume and violet cover changed to no meaningful extent along transmission lines with more urban land within 100 m (Figures 2.2-2.3, Table 2.4).

Either the null model or a model with only year effects best predicted litter cover and abundance of host-plants for Cabbage Whites (i.e. mustards), crescents (i.e. asters) and Monarchs (i.e. milkweeds and dogbanes) (Table 2.4). However, coverage of milkweeds and mustards was negligible along most transmission lines in the study and litter was only removed from hayed sites (Tables 2.2-2.3).

Year and Julian date were important predictors of butterfly species richness (44 species, Appendix I) and abundance per visit, which generally declined from 2007 to 2009 and increased with increasing Julian day. In contrast, Cabbage Whites and Ringlets increased from 2007 to 2009 and Silvery Blues declined with increasing Julian day. A model with only time effects and no mowing or land use effects was the most parsimonious model predicting butterfly species richness and numbers per visit of Cabbage Whites, Common Wood-nymphs, and Monarchs.

Some butterfly species or species-groups (European Skippers, native skippers, total butterflies and moths per transect) were most abundant along unmowed or infrequently mowed transmission lines. Counts of total adult lepidopterans per visit declined with mowing and spraying frequency, and unmowed and unhayed, infrequently mowed lines had nearly twice as many adult lepidopterans as frequently mowed lines (Figure 2.4, Tables 2.5-2.7). The global model predicted that hayed transmission lines would have twice as many Common Sulfurs and over four times as many Silvery Blues as unhayed transmission lines. Unhayed, infrequently mowed transmission lines had over twice as many Ringlets, native skippers, and European Skippers as transmission lines under other management (Figure 2.5-2.7, Tables 2.5-2.7).

Surrounding urban land within 100 m of transmission lines was negatively associated with some butterfly species (crescents, fritillaries), but was positively associated with other species (Common Sulfurs, Ringlets, Silvery Blues) (Figures 2.4, 2.8-2.9, Tables 2.6-2.7). Increases of 20 % and 40 % in the amount of urban land were respectively associated with 67 % and 89 % fewer crescents, 72 % and 92 % fewer fritillaries, and two and four times more Ringlets than along lines with no urban land within 100 m (Figures 2.4, 2.10-2.11, Tables 2.6-2.7). With removal of outliers, Common Sulfurs and Silvery Blues were best predicted by management alone, increasing along hayed lines (Table 2.7).

Arthropods in sweep nets and pitfall traps, including 70 species of carabid beetles and 28 species of short-horned grasshoppers (Appendix I), generally declined from 2007 to 2009 and increased with Julian day. However, carabid biomass in pitfall traps increased from 2007 to 2009 and varied little with Julian day. Neither mowing regime nor surrounding urbanization had strong effects on dry arthropod (except lepidopteran) biomass in sweep nets or dry carabid biomass in pitfall traps, in that a model with only time effects was the most parsimonious model for predicting these biomasses.

Some arthropods in sweep nets and pitfall traps were best predicted by long-term mowing regime, reaching greatest abundance along unmowed or infrequently mowed transmission lines. Unmowed and unhayed, infrequently mowed lines had over two times more dry lepidopteran biomass per sweep net collection than along frequently mowed lines (Figure 2.12, Tables 2.8, 2.9). Orthopteran biomass per pitfall-trap collection was at least three times greater along infrequently mowed lines (with or without haying) than along unmowed or frequently mowed lines (Figure 2.13, Tables 2.8-2.9).

Other arthropods in pitfall traps were best predicted by the global model, declining with urbanization and peaking along infrequently mowed transmission lines. Infrequently mowed transmission lines, with or without haying, had two times more total dry arthropod biomass and three times more dry lepidopteran biomass per pitfall trap collection than along other lines (Figures 2.14-2.15, Tables 2.8-2.9). Increases of 20 % and 40 % in the amount of urban land within 100 m were associated with 34 % and 56 % less total dry arthropod biomass per pitfall trap collection than along lines with no urban land within 100 m. Increases of 20 % and 40 % in the amount of grassland within 100 m were associated with 18 % and 33 % less total dry arthropod biomass per pitfall trap collection than along lines where 10 % of land within 100 m was grassland (Figures 2.14-2.15, Tables 2.8-2.9).

When the outlier site ("Zora") was excluded from analysis, adult lepidopterans counted on transects and orthopteran biomasses per pitfall-trap collection were no longer better predicted by management or surrounding land use than by time effects alone. However, total dry arthropod biomass and biomass for each bird species per collection were still best predicted by the global model (Table 2.10).

Eight species of prairie birds held breeding territories along transmission lines in 2007 – 2009 (Appendix I), increased in abundance from 2007 to 2009, and were generally predicted by land use within 100 m of transmission lines rather than by mowing (Figures 2.16 – 2.18, Tables 2.5, 2.11). In the best model for each species, increases of 20 % and 40 % in the amount of urban land within 100 m were associated with 26 % and 45 % fewer Clay-coloured Sparrow territories, 89 % and 99 % fewer Le Conte's Sparrow territories, 50 % and 75 % fewer Savannah Sparrow territories, 74 % and 93 % fewer Vesper Sparrow territories, and 28 % and 48 % fewer Western Meadowlark territories than along lines with no urban land within 100 m. Increases of 20 % and 40 % in the amount of grassland within 100 m were associated with three and ten times more Le Conte's Sparrow territories and two and three times more Western Meadowlark territories than along lines where 10 % of land within 100 m was grassland. Increases of 20 % and 40 % in the amount of wooded lands within 100 m were associated with 59 % and 83 % fewer Western Meadowlark or Savannah Sparrow territories, and 37 % and 61 % fewer Vesper Sparrow territories than along lines with no wooded lands within 100 m. Clay-coloured and Vesper

Sparrows also tended to increase along infrequently mowed transmission lines in this study (Figures 2.16 – 2.18, Tables 2.5, 2.11).

Effects of Experimental Mowing on Plants, Arthropods, and Birds Along Transmission Lines

The experimental, short-term change in mowing at the eight treatment sites had few effects on dependent variables in this study. A model containing only time effects was the most parsimonious model predicting changes in most plants and animals at urban and rural treatment sites relative to controls. Mowing twice a year at rural treatment sites was predicted to reduce vegetation height-density by 38 % (13 cm) from rural control sites (Table 2.12). Lepidopterans in general were negatively affected by the mowing treatment. Halting mowing for one year at urban sites resulted in twice as many butterflies and moths counted on transects, twice as many European Skippers per transect, and 38 % more lepidopteran biomass per urban sweep net collection (Table 2.12). The rural mowing treatment reduced lepidopteran biomass per pitfall trap collection by 78 % (Table 2.12). However, the rural mowing treatment was also associated with three times more Monarchs per transect and nearly three times more Savannah Sparrow territories than before mowing (Table 2.12).

Discussion

Effects of Mowing, Spraying and Landscape on Plants, Arthropods, and Birds Along Transmission Lines

Strong effects of year and Julian date on abundance of butterflies and other arthropods in general are consistent with positive correlations between temperature and Julian date and between temperature and activity of insects (Taylor 1963). Birds showed the opposite response to year from insects, increasing from 2007 to 2009 while arthropods decline. Birds may have been responding to different environmental changes associated with year from insects, such as factors during migration or on the birds' wintering grounds.

Plant species richness declined with frequent mowing and spraying and peaked with infrequent mowing as in previous studies (Parr and Way 1988, Munguira and Thomas 1992). Lower forb cover and vegetation height-density along frequently mowed transmission lines were also consistent with past studies in which mowing and spraying eliminated forbs and taller grassland plants (Fenner and Palmer 1988, Schippers and Joenje 2002, Hovd and Skogen 2005). Hayed transmission lines probably had greater legume cover and total forb cover because they were deliberately seeded with legumes such as alfalfa, sweet clover, alsike clover, and red clover. Alternatively, haying removed litter from cut vegetation, which can replenish soil nutrients that are used by taller or faster-growing plants to outcompete forbs (Schippers and Joenje 2002, Hovd and Skogen 2005). Hayed transmission lines probably had greater bare ground cover and less grass cover because cut vegetation was removed from these lines, but not from other mowed lines. Given these results, reductions in mowing and spraying will be necessary to improve habitat for butterflies, other arthropods, and birds that use dense, taller vegetation and forb cover as resources. Furthermore, since mowing and haying increased some kinds of vegetation while decreasing others, a patchwork of unmowed and hayed areas might create more types of resources for more animals than a single mowing regime along transmission lines.

Despite negative effects of mowing and spraying, plant species richness, woody plant cover, and resource plant cover for some butterflies were better predicted by and declined with increasing urban land, consistent with some but not all previous studies (McKinney 2002, Williams *et al*. 2005). Urban grasslands might be hostile habitats for many plant species due to urban pollution, soil changes, insect pests or invasive exotic plants, in addition to frequent mowing and spraying (Bolsinger and Fluckiger 1988, Speight *et al*. 1998). Surrounding urban lands may also have hindered or prevented plant seeds from recolonizing lines and replenishing their species (Levins 1969). Although animals and vehicles may facilitate the spread of exotic plants in cities (Von der Lippe and Kowarik 2006), seed rain from invasive species can have low dispersal distances and produce little germinated seed (Otfinowski *et al*. 2008). Therefore, even transmission lines that are not isolated by large distances may still be functionally isolated for prairie plants, and changes in mowing regime alone will not lead to increased plant diversity along transmission lines unless plant species are reintroduced.

Butterflies may have responded as they did in this study to mowing or land use, because their resource plants responded in a similar manner to mowing and land use. First, butterflies with grass-eating caterpillars (e.g. Common Wood-nymphs, Ringlets, most skippers) and total adult lepidopterans on transects were most abundant along infrequently mowed transmission lines, perhaps because such lines produced more freshly cut, nutritious regrowing grass (Seastedt 1985). Haying of these lines reduced skipper numbers, perhaps because cut vegetation that was removed contained skipper eggs, reducing future skipper numbers on-site (Layberry *et al*. 1998). However, hayed lines had more forb cover (particularly legumes) for caterpillars of Common Sulfurs and Silvery Blues. Second, resource plants of butterfly species with grass-eating or legume-eating larvae did not strongly change with increasing urban land, which may explain why these butterfly species did not decline along urban transmission lines. Third, both fritillaries and their host-plants (violets) declined as amount of grassland increased within 100 m of transmission lines. These results suggest that specific larval host-plants need to be reintroduced or augmented along urban transmission lines to increase numbers of particular butterfly species along urban transmission lines. Managing urban transmission lines as haylands might increase numbers of butterflies with forb-feeding caterpillars, but infrequent mowing without haying might create better habitat for butterflies with grass-eating caterpillars.

Urban land amount could have been negatively associated with butterfly diversity in other studies (Clark *et al*. 2007, Bergerot *et al*. 2010), because urban lands inhibited movements of smaller, less vagile butterflies (Stasek *et al*. 2008). While urban lands might have hindered movements of smaller, less vagile butterflies such as crescents in my study (Stasek *et al*. 2008), most butterfly species in my study were strong fliers (Stasek *et al*. 2008, Burke *et al*. 2011). Furthermore, transmission lines were probably less isolated as habitats for butterflies than for plants, because most grassland habitats along lines in this study were separated from similar habitats along the same lines at most by single roads or highways at most. Thus, if appropriate resource plants are increased along transmission lines, surrounding urban lands should not prevent most butterflies from settling along and benefiting from these resources.

Sweep nets and pitfall traps caught higher biomass of some arthropods along infrequently mowed transmission lines, perhaps because such lines supported more resources, such as forbs, that were important as resources for herbivorous insects in the samples (Vickery and Kevan 1983) and freshly cut, regrowing grass (Seastedt 1985). Other arthropods in samples were predators or scavengers such as spiders, ground beetles, and carrion beetles. By increasing resources for larger numbers of herbivorous insects, infrequent mowing might foster larger populations of predatory arthropods that prey on those herbivores, as has been observed for some but not all grazing studies in grasslands (Chen and Wise 1999). Carrion beetles might also have been draw into traps by the smell of large numbers of dead animals in traps. Greater bare ground cover along hayed transmission lines might have provided egg-laying and sunbathing sites for insects as well (Onsanger 2000). Thus, reduction but not elimination of mowing along transmission lines may increase habitat not only for butterflies, but arthropods in general, as those changes in mowing seem to increase resources for forb-eating and grass-eating arthropods.

Like butterflies in this study, arthropods in sweep nets and pitfall traps were generally not strongly affected by the amount of urban land surrounding transmission lines. Again, urban lands might not have strongly isolated grassland habitats along transmission lines in my study, unlike previous urban studies of arthropods that occurred in isolated remnant habitats (Bolger *et al*. 2000). The only arthropod metric that declined with increasing urbanization around my study sites was total dry arthropod biomass in pitfall traps. This measure of biomass included terrestrial, flightless arthropods that might have difficulty crossing roads between grassy habitats along transmission lines (Vandergast *et al*. 2009). With the exception of these flightless species, arthropods besides butterflies will probably also be able to reach and benefit from new wildlife habitats created along transmission lines.

It is surprising that few birds responded to mowing in my study, because different species have previously been reported to prefer mowed or unmowed habitats for nesting (Murray and Best 2003, Roth *et al* 2005). Vesper Sparrows might have increased along infrequently mowed transmission lines because such transmission lines in my study had more potential arthropod prey. Grassland birds other than Vesper Sparrows might not have been strongly affected by mowing, because they either do not depend on one type of grassland for nesting, e.g. Savannah Sparrow (Wheelwright and Rising 2008), or they found sufficient nesting habitat off but within 100 m of mowed or hayed transmission lines, e.g. Clay-coloured Sparrows nesting in woody shrubs (Knapton 1994) and Le Conte’s Sparrows nesting in taller grass (Lowther 2005). While I suggest that mowing and spraying regime does not affect abundance of urban grassland birds, previous studies suggest that mowing should be delayed along transmission lines until after the breeding season to avoid destroying nests (Kershner and Bollinger 1996). Having a patchwork of hayed and unmowed sections within transmission line wildlife habitats might also provide nesting habitat for more prairie bird species (Murray and Best 2003, Roth *et al* 2005).

Grassland birds declined in urban landscapes, consistent with results of previous studies (e.g. Engle *et al*. 1999, Bock *et al*. 1999, Haire *et al*. 2001), and some species increased in landscapes with more grassland (also see Ribic and Sample 2001, Bakker *et al*. 2002, Cunningham and Johnson 2006). Larger organisms such as birds would have greater resource and territorial requirements than smaller organisms such as arthropods (McNab 1963), and fewer resources for prairie birds in urban landscapes may explain why birds were more affected than arthropods by urbanization in my study. Although there were negligible mowing effects on prairie birds in this study, shorter vegetation along frequently mowed urban transmission lines would be less attractive as nesting habitat for prairie birds like Le Conte's Sparrows (Lowther 2005). Urban transmission lines might also be less hospitable habitats for prairie birds due to the presence of cats and other predators (Soulé *et al*. 1988). Results from my study and previous studies suggest that if restoration advocates want to attract prairie birds along transmission line sections, those sections should have as few wooded or built-up urban lands and as much grassland habitat as possible within 100 m of lines.

Experimental Mowing Effects on Plants, Arthropods, and Birds Along Transmission Lines

A one-year change in mowing regime produced few changes in plants and animals along transmission lines, perhaps because mowing effects on animals take more than a year to be manifested (Petersen and Best 1999). Mowing reduced taller vegetation as in other studies (e.g. Fenner and Palmer 1988, Schippers and Joenje 2002, Hovd and Skogen 2005). Taller vegetation serves as shelter habitat for arthropods (Swengel 2001, Kruess and Tscharntke 2002), which may explain why lepidopterans declined with the rural mowing treatment and increased where mowing was suspended at urban sites. Mowing and spraying occurred at smaller spatial scales within transmission lines. Arthropods respond to disturbances at finer spatial scales than birds (Carignan and Villard 2002), which may explain why most organism responses to the short-term mowing experiment came from arthropods and not birds.

However, individual butterfly species and other arthropods either declined (e.g. Monarch) or did not increase with increases in dense vegetation, perhaps because they responded to plant species richness or abundance of resource plants instead (Morris and Rispin 1988, Munguira and Thomas 1992). Such habitat features may not have changed after one year of mowing due to short dispersal distances and slow colonization rates of seed rain from plants (Otfinowski *et al*. 2008). Thus, if only mowing frequency is reduced and plant species are not actively reintroduced to transmission lines, then plants and arthropods will require years to resettle restored prairies along transmission lines without assistance from people.

The resources that drew Savannah Sparrows to newly mowed rural sites are unknown, but Savannah Sparrows are generalists that use many different grassland habitats (Wheelwright and Rising 2008). Arthropod food was probably not what drew Savannah Sparrows to settle, since mowing was not associated with increases in arthropod prey. The reduction in vegetation density at rural treatment sites might have created nesting habitat for Savannah Sparrows, since some prairie birds prefer shorter vegetation for nest sites (Murray and Best 2003). However, surprisingly, other species that prefer taller vegetation (e.g. Le Conte’s Sparrows (Lowther 2005);

Clay-coloured Sparrow (Knapton 1994)) were not affected by the mowing treatment. Mowing may not have affected these other species, either because preferred resources did not change along treated sites over one year, or because those resources were sufficiently abundant within 100 m of sites, regardless of treatment.

One year was probably not enough time to detect effects of a change in mowing on prairie birds. Prairie birds responded to short-term changes in mowing in a study of switch-grass fields, but the treatment in that study involved removing cut vegetation (Murray and Best 2003), which did not occur in my mowing treatment. Over five years of grassland habitat manipulation (i.e. burning) in another study were required for effects of manipulation on birds to be detected (Petersen and Best 1999). Changes in mowing frequency along transmission lines will not produce short-term changes in prairie bird abundance for at least a year after the change, although more drastic habitat manipulation like haying might.

The rural mowing treatment differed from long-term urban mowing in that rural mowing did not include spraying for weeds at rural treatment sites. If the rural mowing treatment sites had also been sprayed with the same herbicide (2,4-D) that Manitoba Hydro uses along urban transmission lines, then plant species richness, forbs and woody plants might have declined at rural treatment sites. More arthropods might have then declined if spraying had both been conducted and also eliminated their resource plants (Morris and Rispin 1988, Munguira and Thomas 1992).

Conclusion

Habitat restoration along urban transmission lines can be expensive in the short term due to material costs such as native plant seed (Egan 1994, Harrington 1994, Morgan and Collicut

1994), and can be controversial due to public concerns about reductions in urban mowing and spraying that are perceived to allow weeds to proliferate (Byrne 2005). This means that public concerns about vegetation management and the cost of restoration may put limits on the number of transmission line sections or other urban green spaces that are restored as wildlife habitats, even if those habitats have benefits for conservation. Therefore, advocates of restoration need criteria for selecting those transmission lines that will benefit the most species.

For example, if transmission lines are restored as tall-grass prairie, higher priority should be given to lines in less urbanized landscapes to attract prairie birds, but mowing and spraying can be adjusted along most transmission lines in urban landscapes to benefit butterflies and other arthropods. Given the expense of prairie restorations, this strategy for selecting restoration sites would result in more species of plants and animals being able to settle along and benefit from these restored habitats. Restoring tall-grass prairies along transmission lines would not only contribute to prairie conservation, but also provide an excellent opportunity to study the effects of habitat manipulation on urban wildlife. This study is the first one I know of in which urban grasslands were manipulated at a large spatial scale to distinguish the combined effects of mowing and spraying from the separate effects of surrounding urban land on wildlife. Prairie restorations along transmission lines could be used to study effects of mowing over longer periods of time, distinguish effects of mowing from those of spraying, and to evaluate the potential benefits of a patchwork mowing regime on plants and animals. Such experiments would contribute to both conservation and expand urban ecological knowledge.

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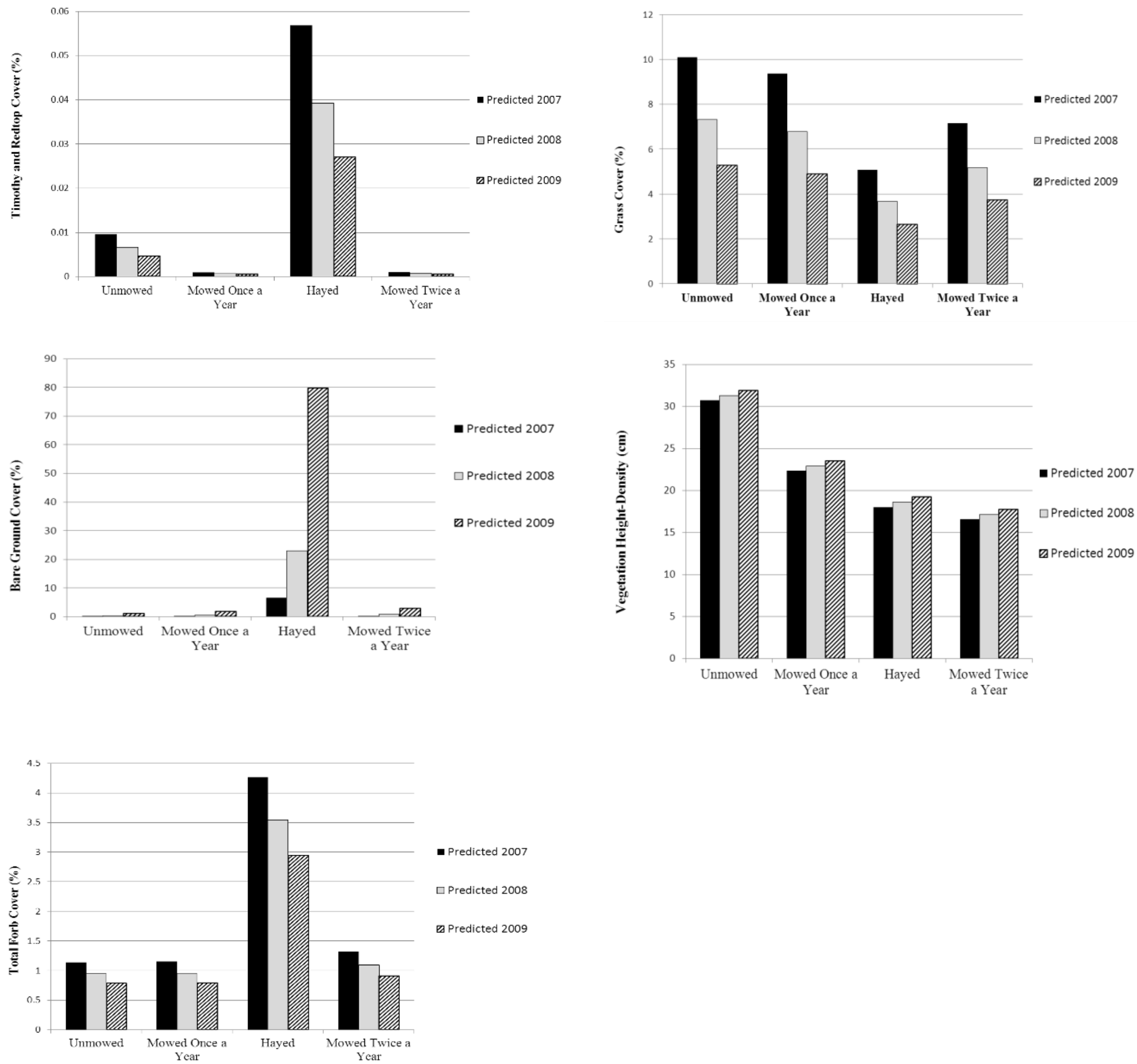


Figure 2.1. Differences in vegetation structure under different mowing regimes along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009. Columns in each bar graph = predicted mean of each type of vegetation structure in different years under each type of mowing regime in the study, based on effect sizes of mowing frequency and haying (yes or no) in the management model.

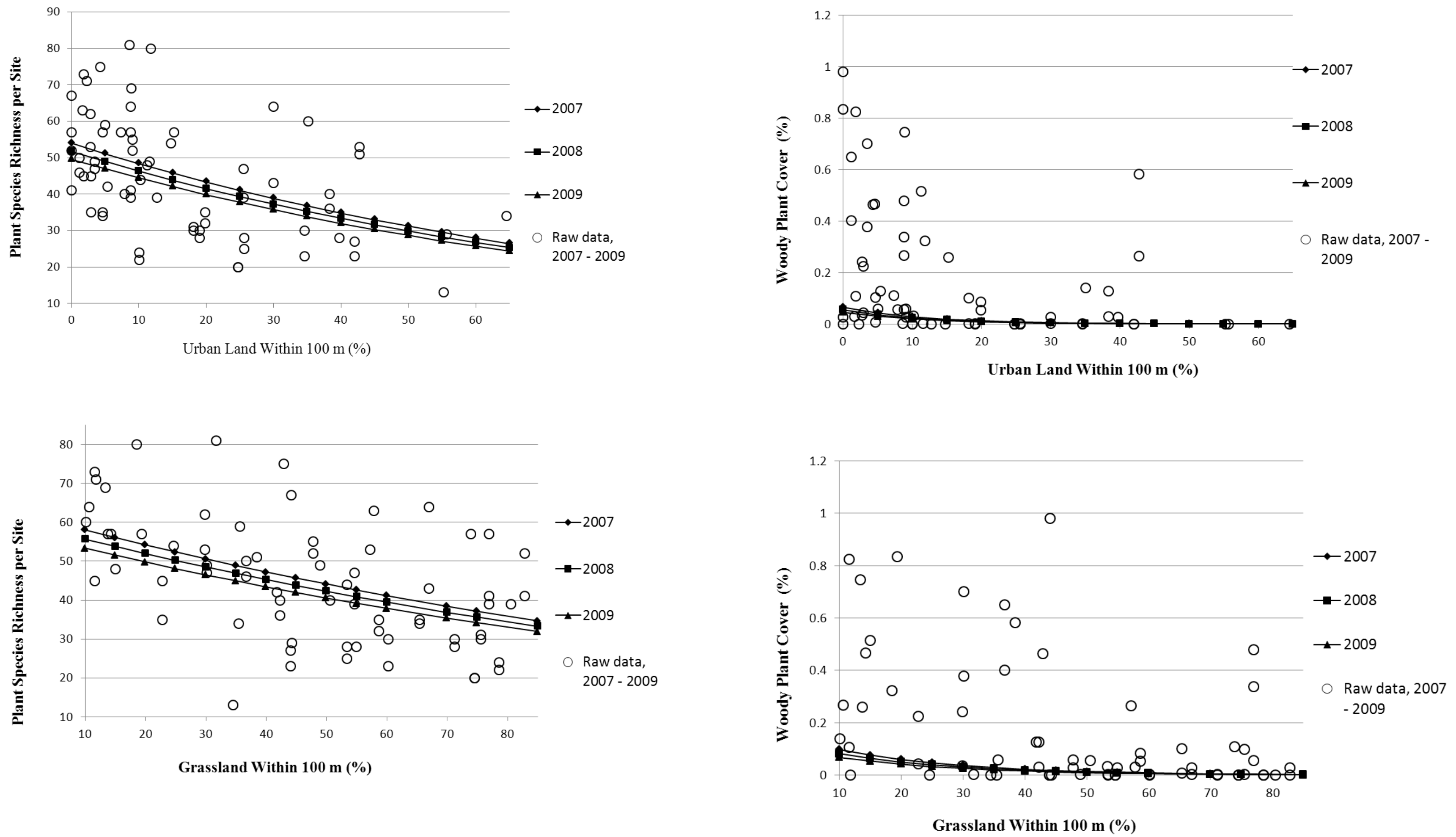


Figure 2.2. Changes in plant species richness and woody plant cover with year and each independent land use variable from the land use model for plant surveys along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009 (*n* = 68 site-year measurements).

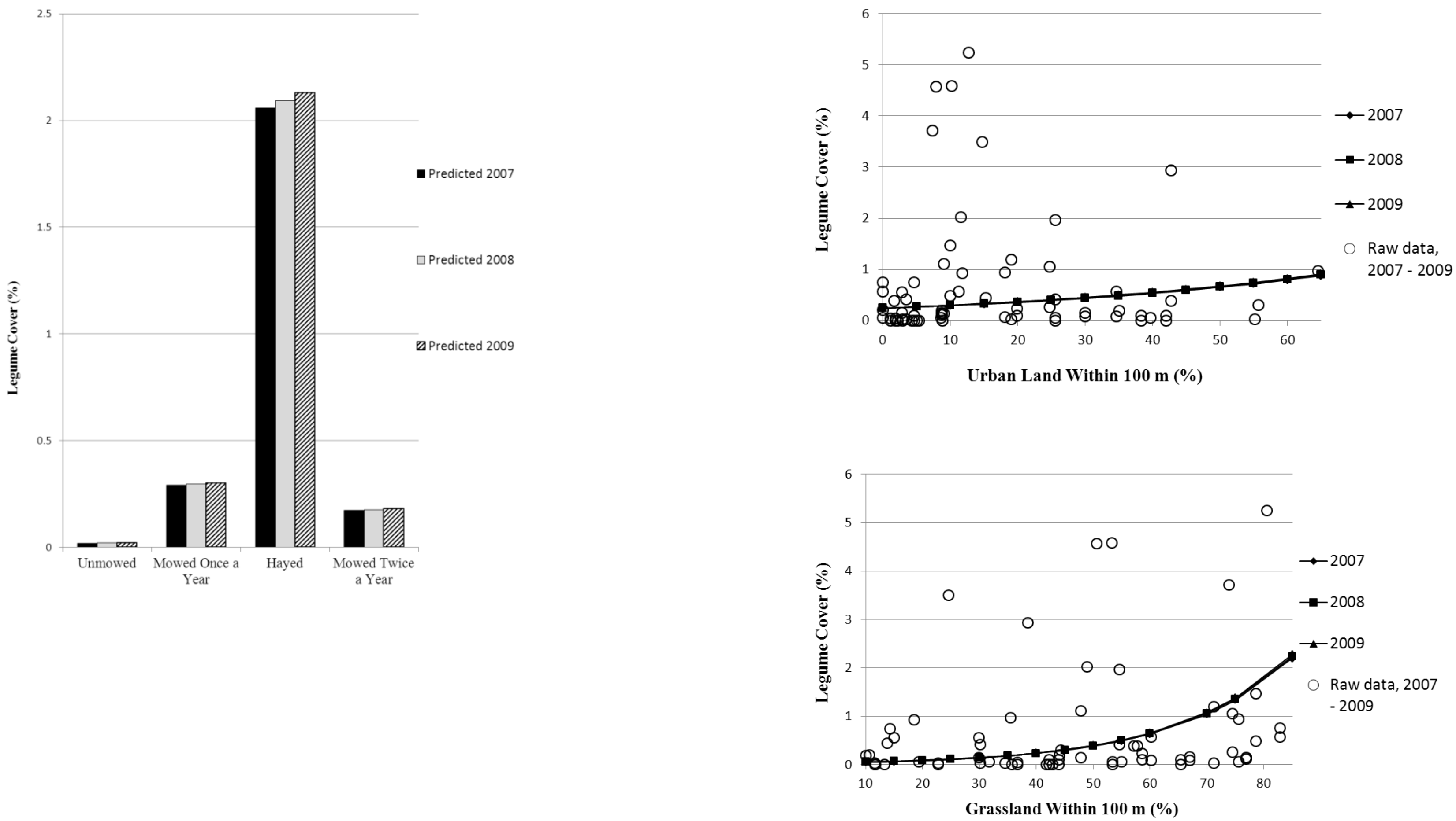
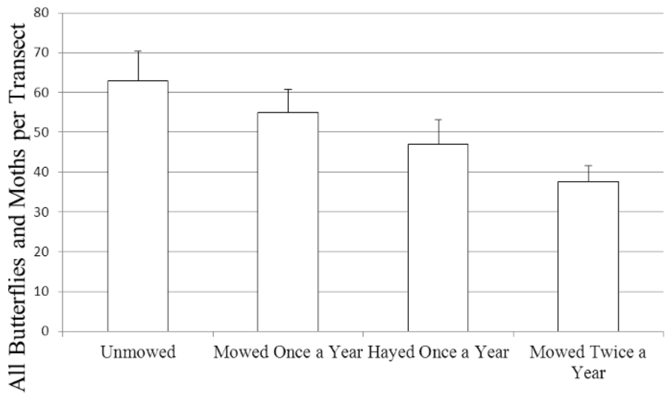


Figure 2.3. Changes in legume cover with mowing and land use effects from the global model predicting legume cover along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009. Columns in bar graph = mean actual legume cover from 48 transmission lines in 2007-2008 before the mowing regime adjustment at eight sites. Error bars for raw data = 1 standard error. Other columns in bar graph = predicted mean legume cover under each type of management in different years.



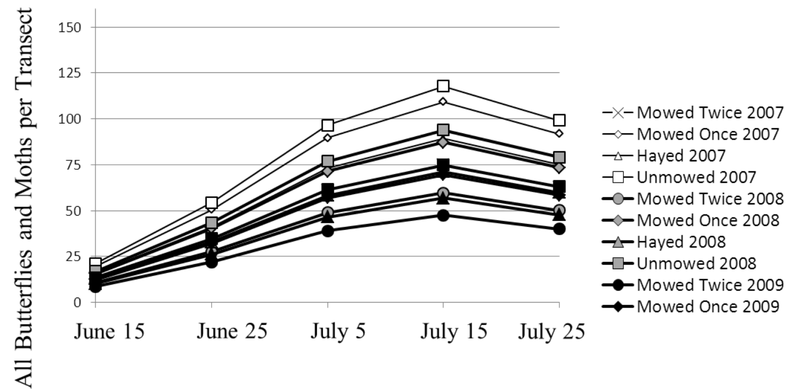


Figure 2.4. Changes in actual and predicted total numbers of butterflies and moths (regardless of species) per butterfly transect (*n* = 415) with changes in mowing effects from the management model predicting total butterflies and moths along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual lepidopteran numbers varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graph = changes in predicted total numbers of butterflies and moths per transect (regardless of species) with changes in year, time of season and mowing regime.

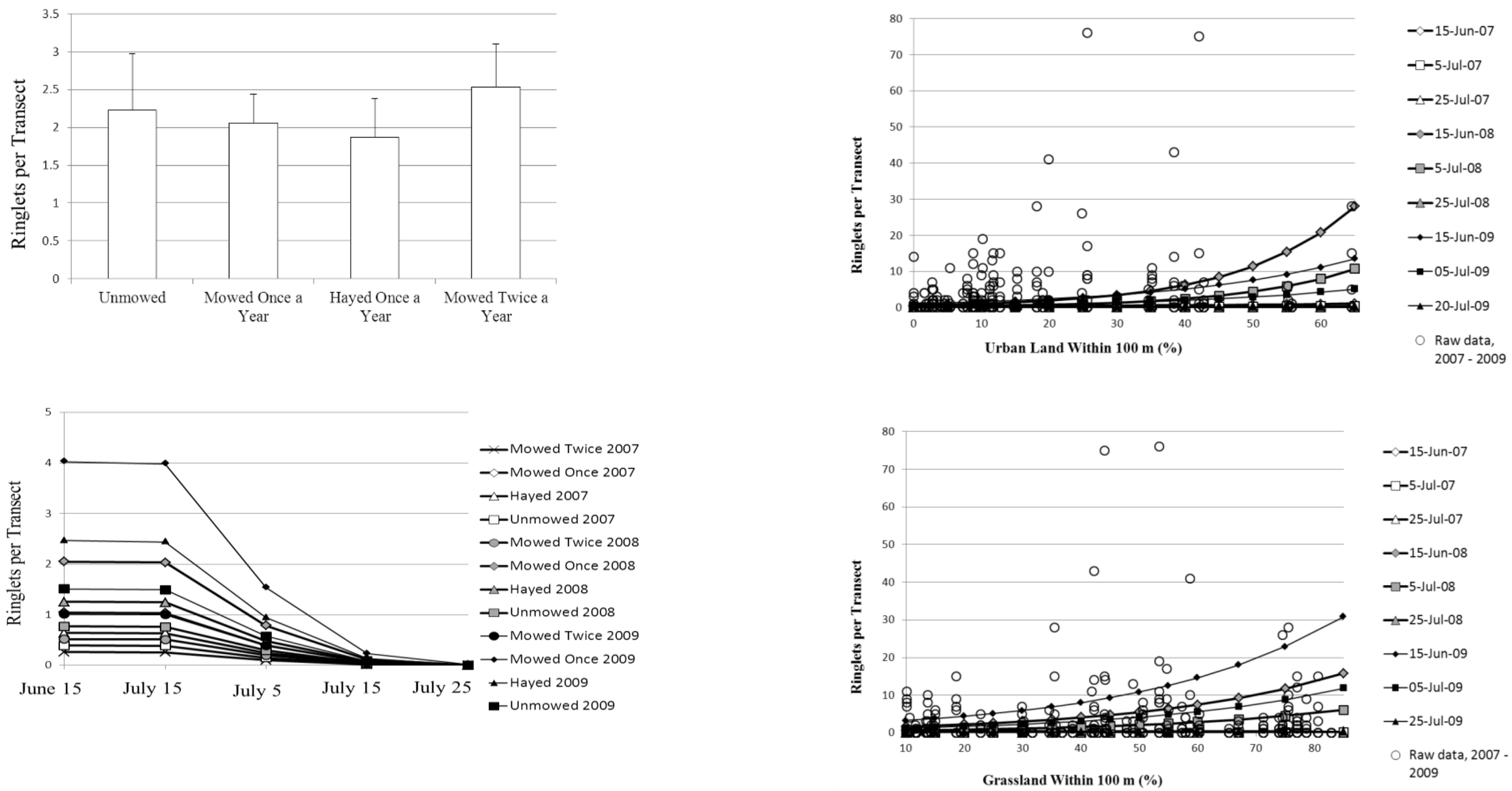


Figure 2.5. Changes in actual and predicted Ringlets per butterfly transect (*n* = 415) with changes in mowing and land use effects from the global model for predicting Ringlets along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual Ringlet numbers varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graphs = predicted Ringlet numbers with changes in year, time of season, and mowing regime, % urban land within 100 m of transmission lines, and % grassland within 100 m of transmission lines.

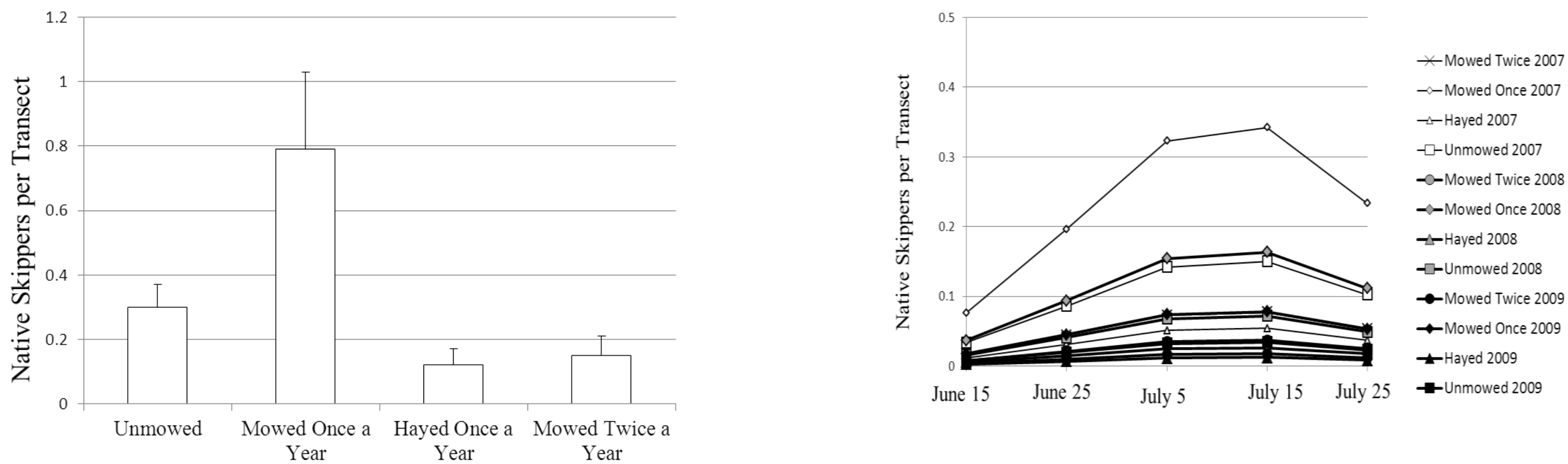


Figure 2.6. Changes in actual and predicted native skippers per butterfly transect (*n* = 415) with changes in mowing effects from the management model predicting native skippers along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual native skipper numbers varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graph = changes in predicted native skipper numbers per transect with changes in year, time of season and mowing regime.

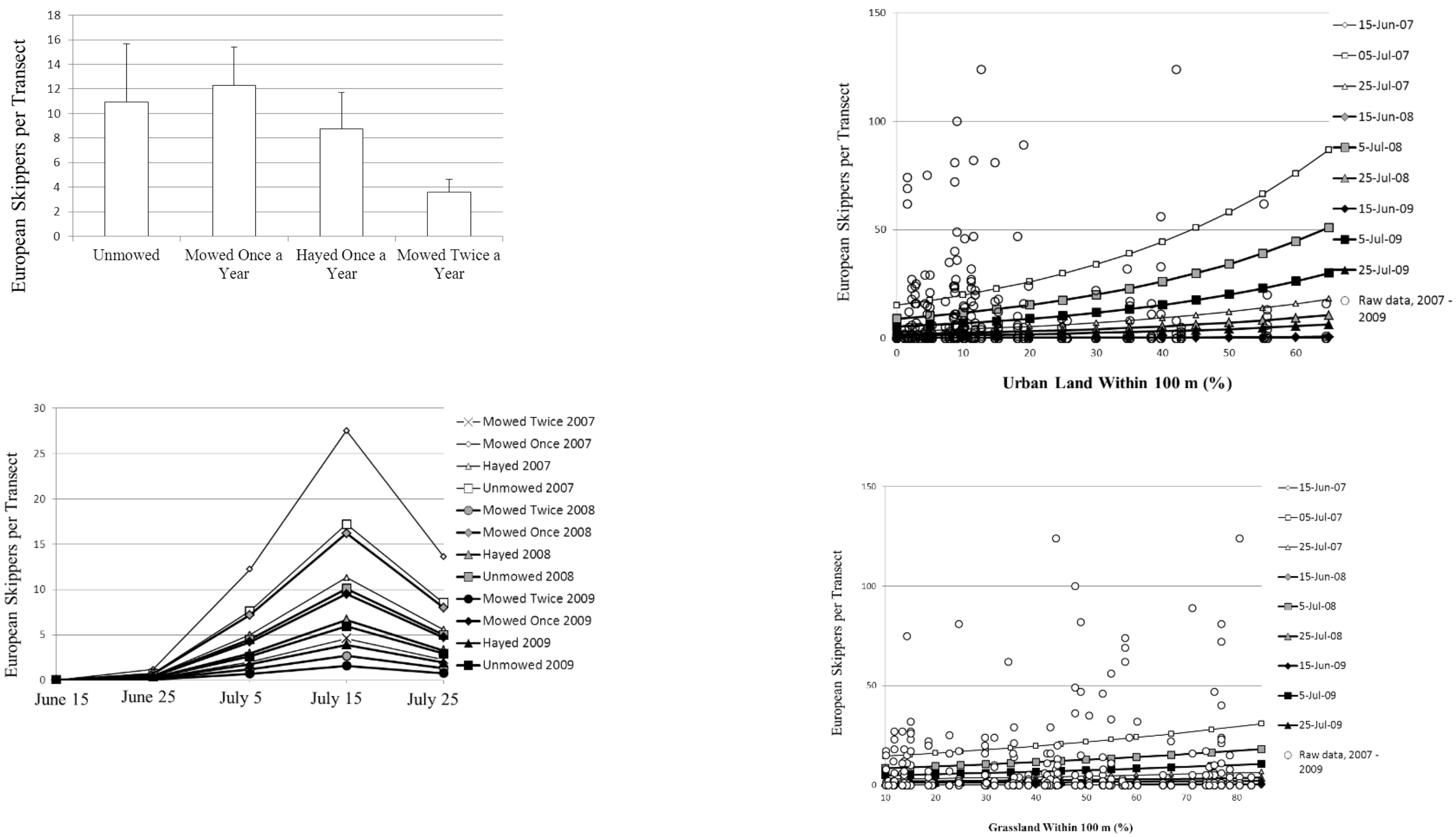


Figure 2.7. Changes in actual and predicted European Skippers per butterfly transect (*n* = 415) with changes in mowing and land use effects from the global model predicting European Skippers along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual European Skipper numbers varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graph = changes in predicted European Skipper numbers per transect with changes in year, time of season, mowing regime, and land uses within 100 m.

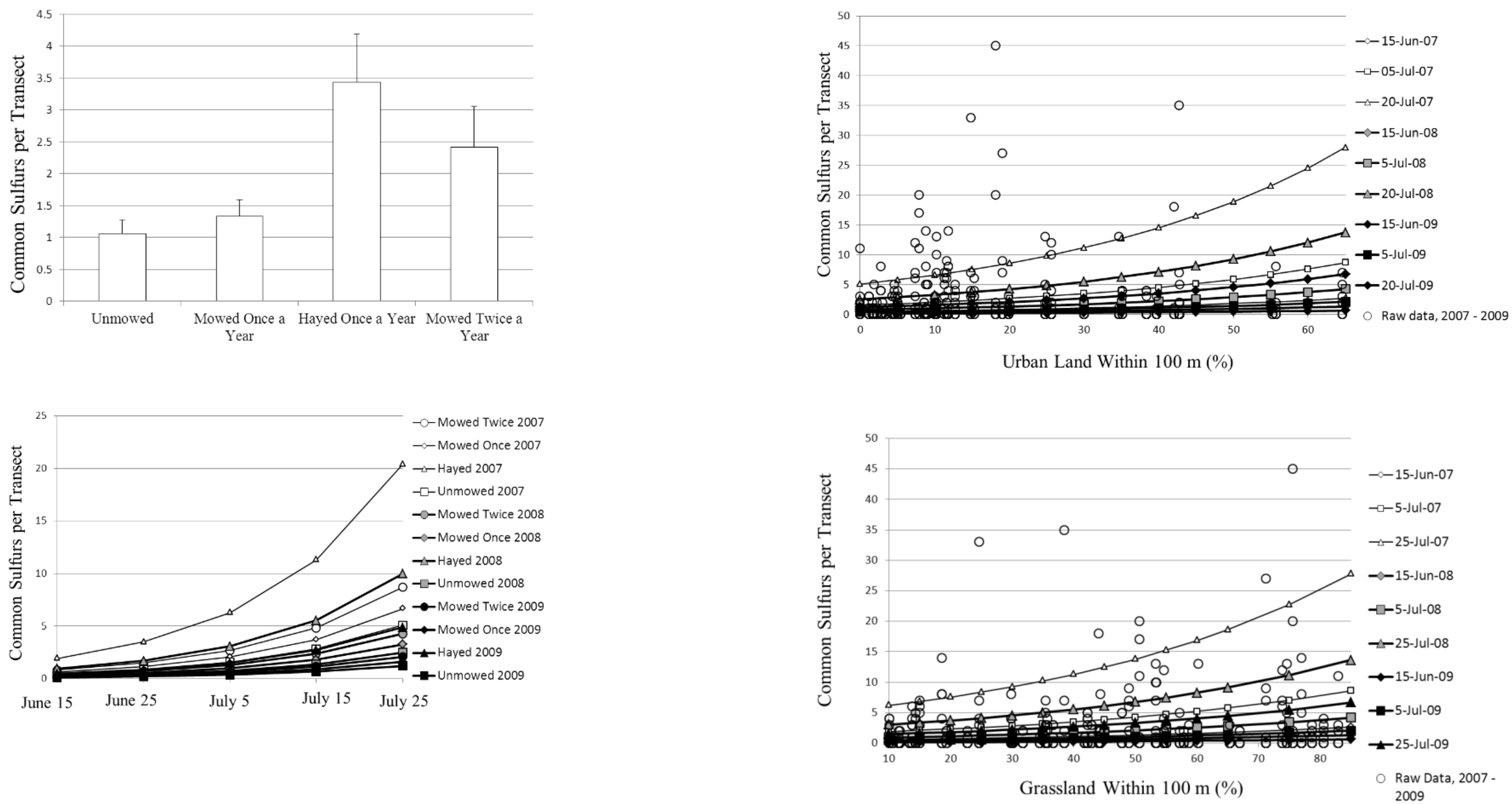


Figure 2.8. Changes in actual and predicted Common Sulfurs per butterfly transect (n = 415) with changes in mowing and land use effects from the global model predicting Common Sulfurs along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual Common Sulfur numbers varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graph = changes in predicted Common Sulfur numbers per transect with changes in year, time of season, mowing regime, and land uses within 100 m.

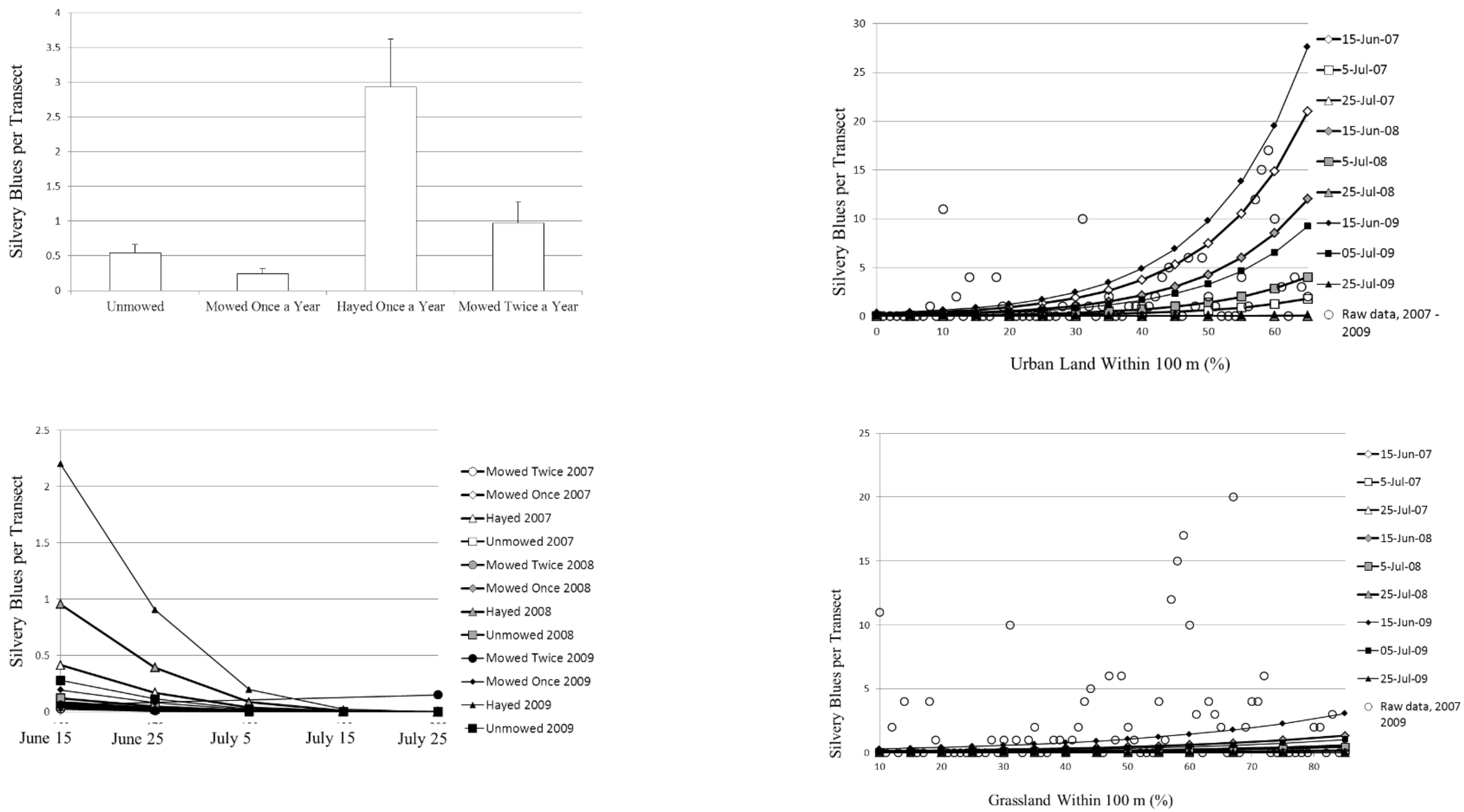


Figure 2.9. Changes in actual and predicted Silvery Blues per butterfly transect (*n* = 415) with changes in mowing and land use effects from the global model predicting Silvery Blues along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual Silvery Blue numbers varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graphs = changes in predicted Silvery Blue numbers per transect with changes in year, time of season, mowing regime, and land uses within 100 m.

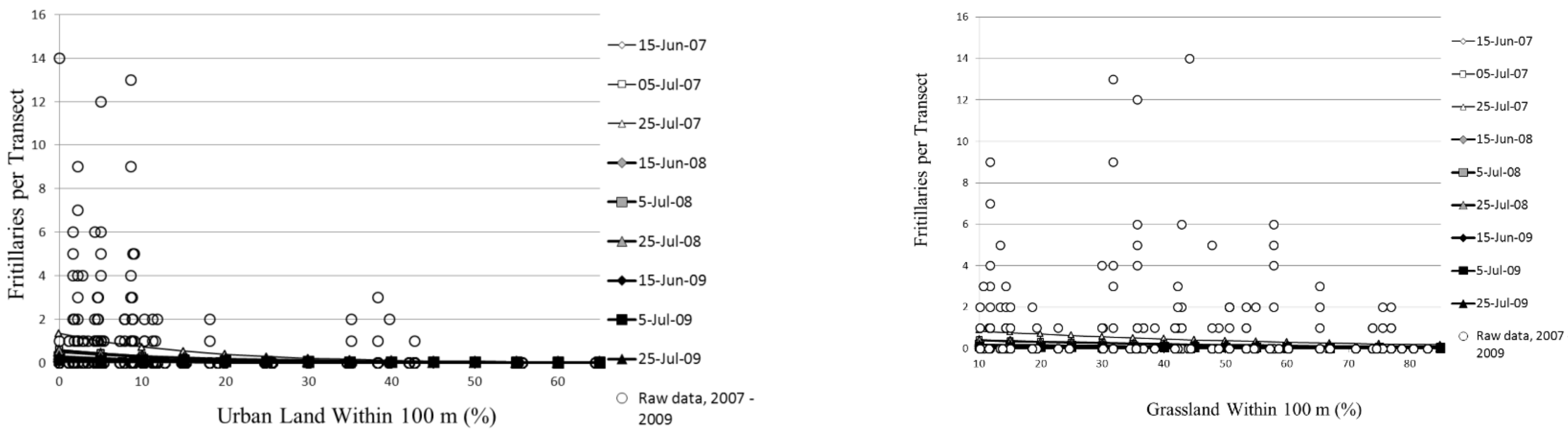


Figure 2.10. Changes in actual and predicted number of fritillaries per butterfly transect (n = 415) with changes in year and each land use variable from the the land use model predicting fritillaries along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009.

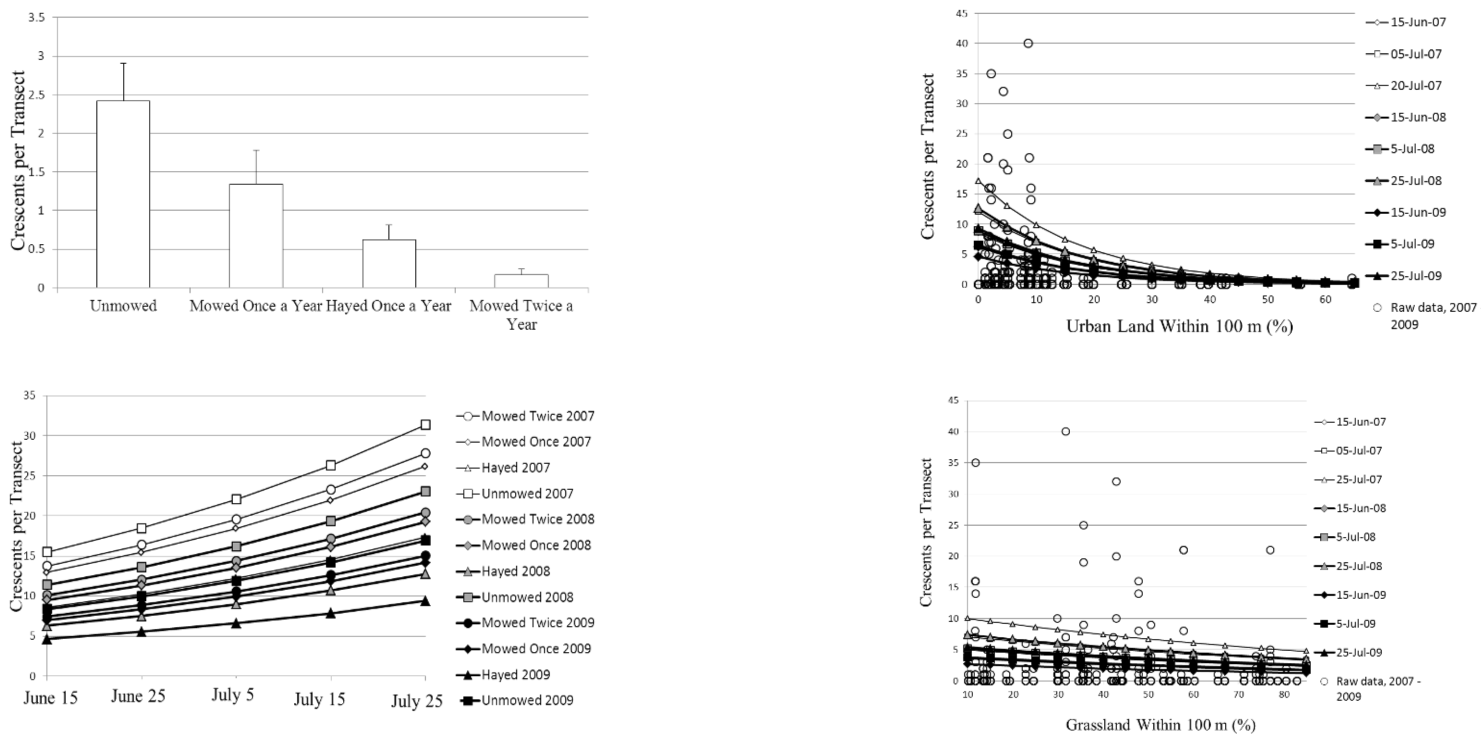
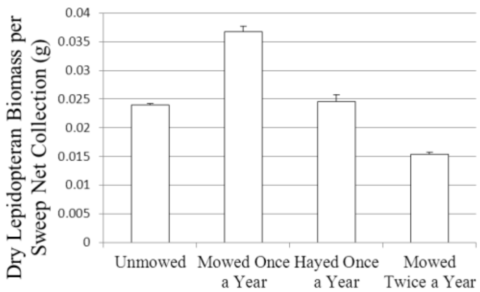


Figure 2.11. Changes in actual and predicted crescents per butterfly transect (*n* = 415) with changes in mowing and land use effects from the global model predicting crescents along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual crescent numbers varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graphs = changes in predicted crescent numbers per transect with changes in year, time of season, mowing regime, and land uses within 100 m.



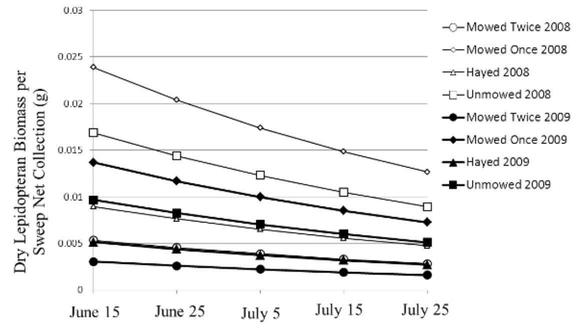


Figure 2.12. Changes in actual and predicted dry lepidopteran biomass per sweep net collection (*n* = 244) with changes in mowing effects from the management model predicting lepidopteran biomass along 47 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual dry lepidopteran biomass varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graph = changes in predicted dry lepidopteran biomass with changes in year, time of season and mowing regime.

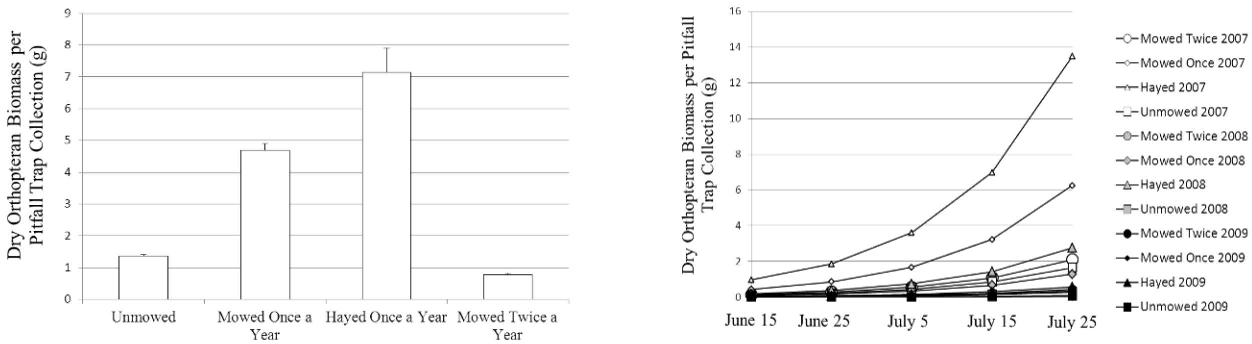


Figure 2.13. Changes in actual and predicted dry orthopteran biomass per pitfall trap collection (*n* = 212) with changes in mowing effects from the management model predicting orthopteran biomass along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual dry orthopteran biomass varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graph = changes in predicted dry orthopteran biomass with changes in year, time of season and mowing regime.

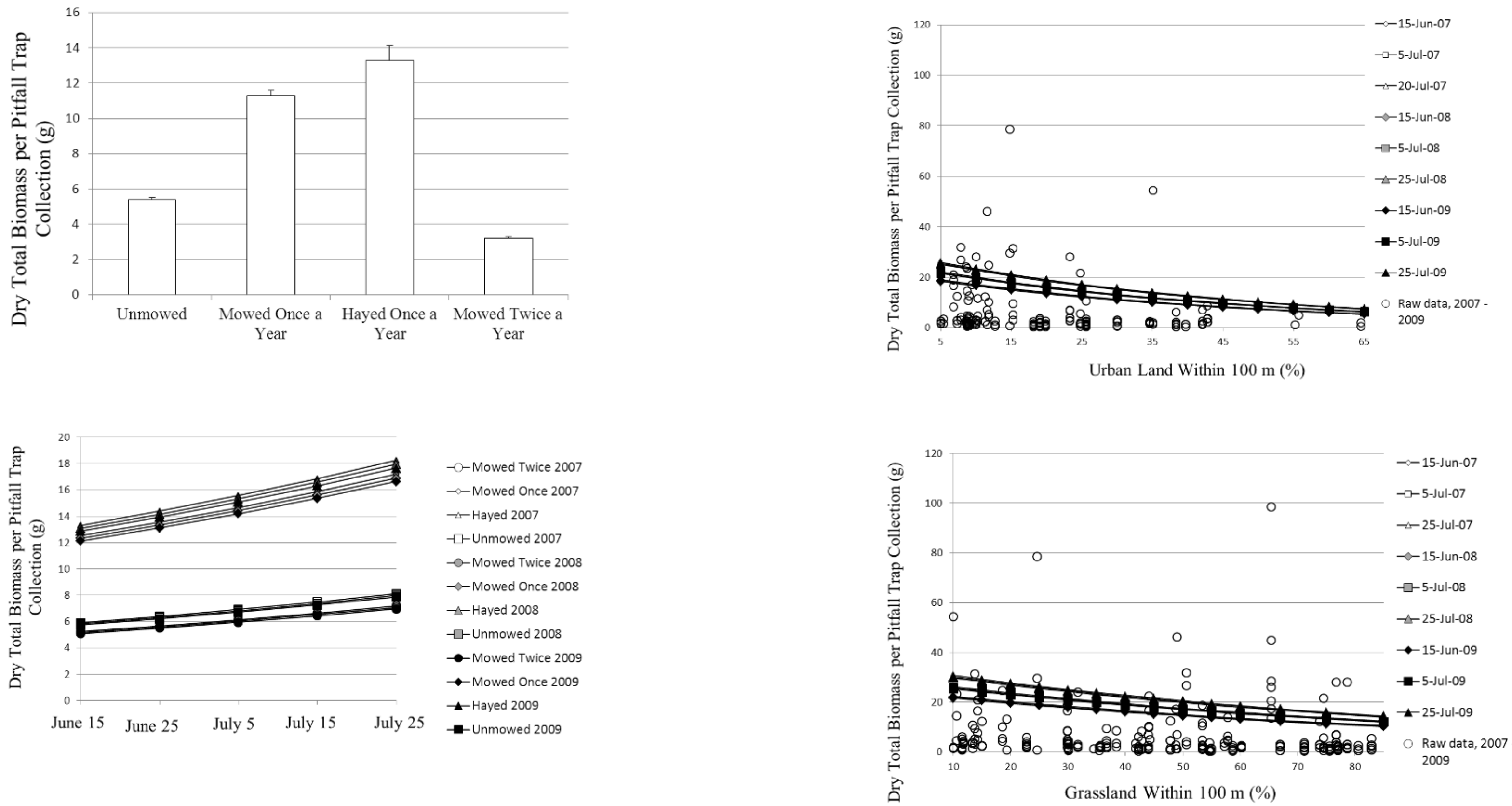


Figure 2.14. Changes in actual and predicted dry total biomass per pitfall trap collection (*n* = 212) with changes in mowing and land use effects from the global model predicting total biomass along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual dry total biomass varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graphs = changes in predicted dry total biomass with changes in year, time of season, mowing regime, and land use.

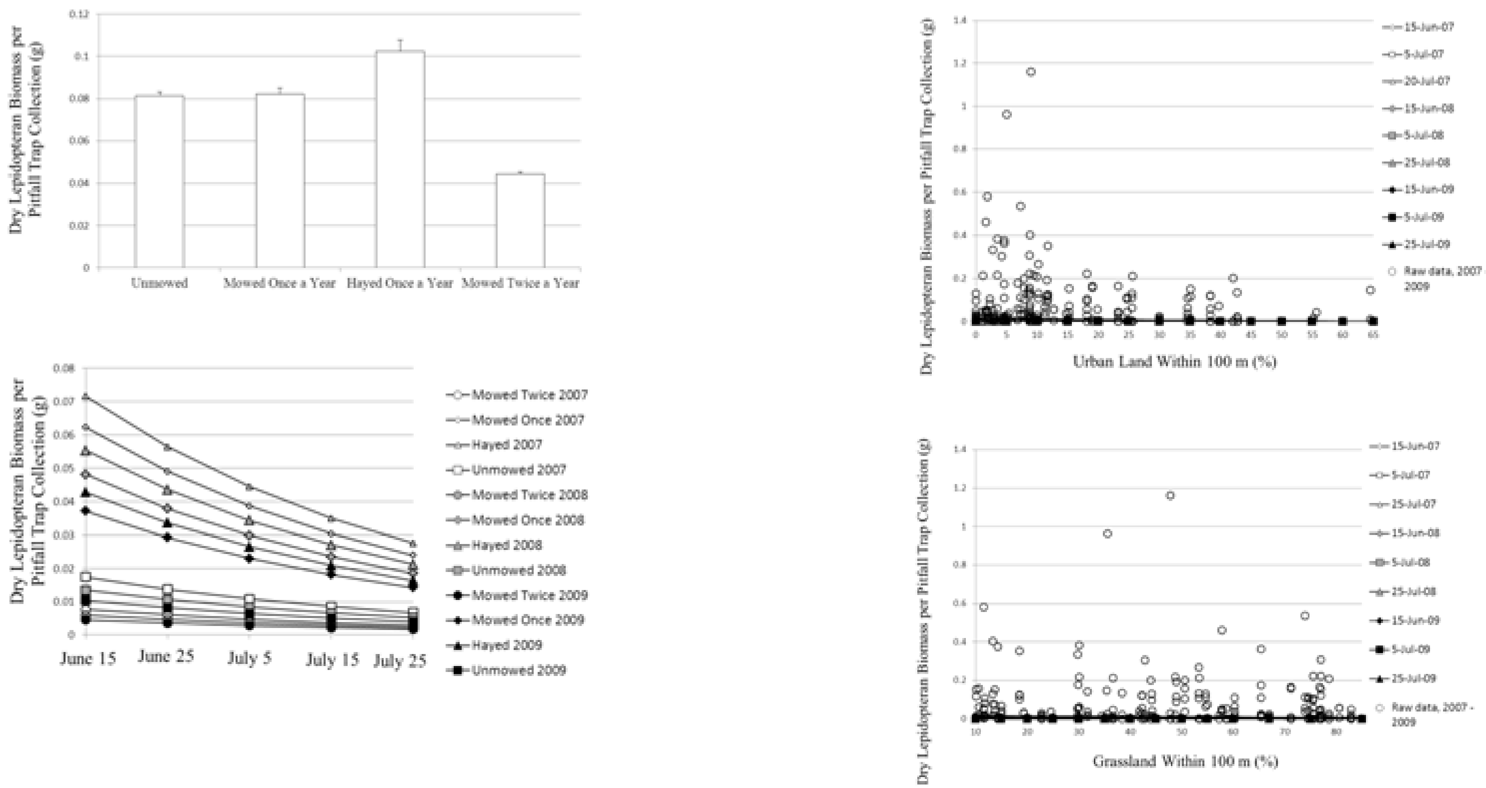


Figure 2.15. Changes in actual and predicted dry lepidopteran biomass per pitfall trap collection (n = 212) with changes in mowing and land use effects from the global model predicting lepidopteran biomass along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Columns in bar graph = mean actual dry lepidopteran biomass varying by mowing regime along transmission lines (raw data). Error bars for raw data = 1 standard error. Line graphs = changes in predicted dry lepidopteran biomass with changes in year, time of season, mowing regime, and land use.

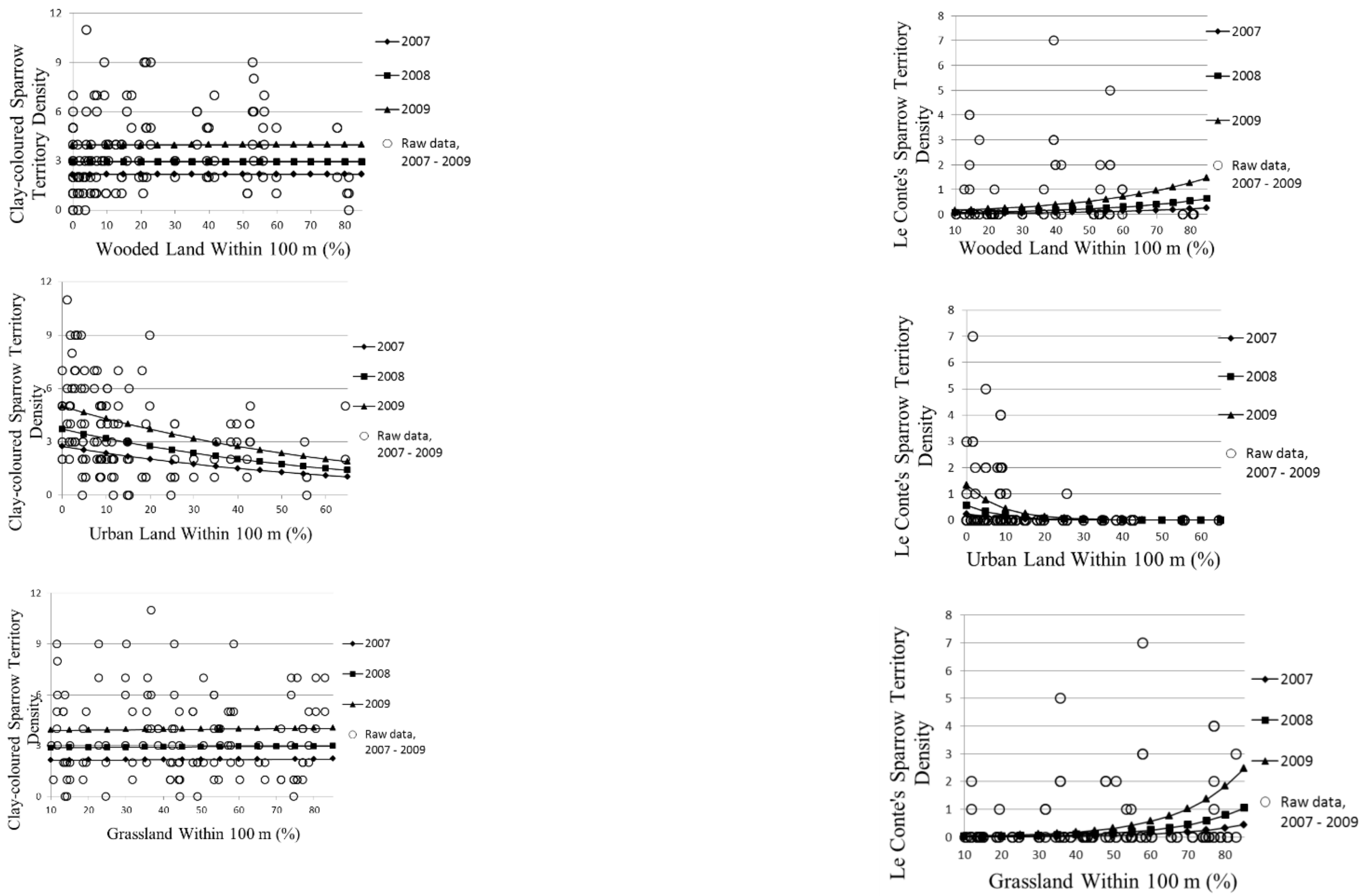


Figure 2.16. Changes in Clay-coloured and Le Conte's Sparrow territory densities with changes in year and each land use variable from the land use model predicting these species along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009 (n = 126 site-year density measurements).

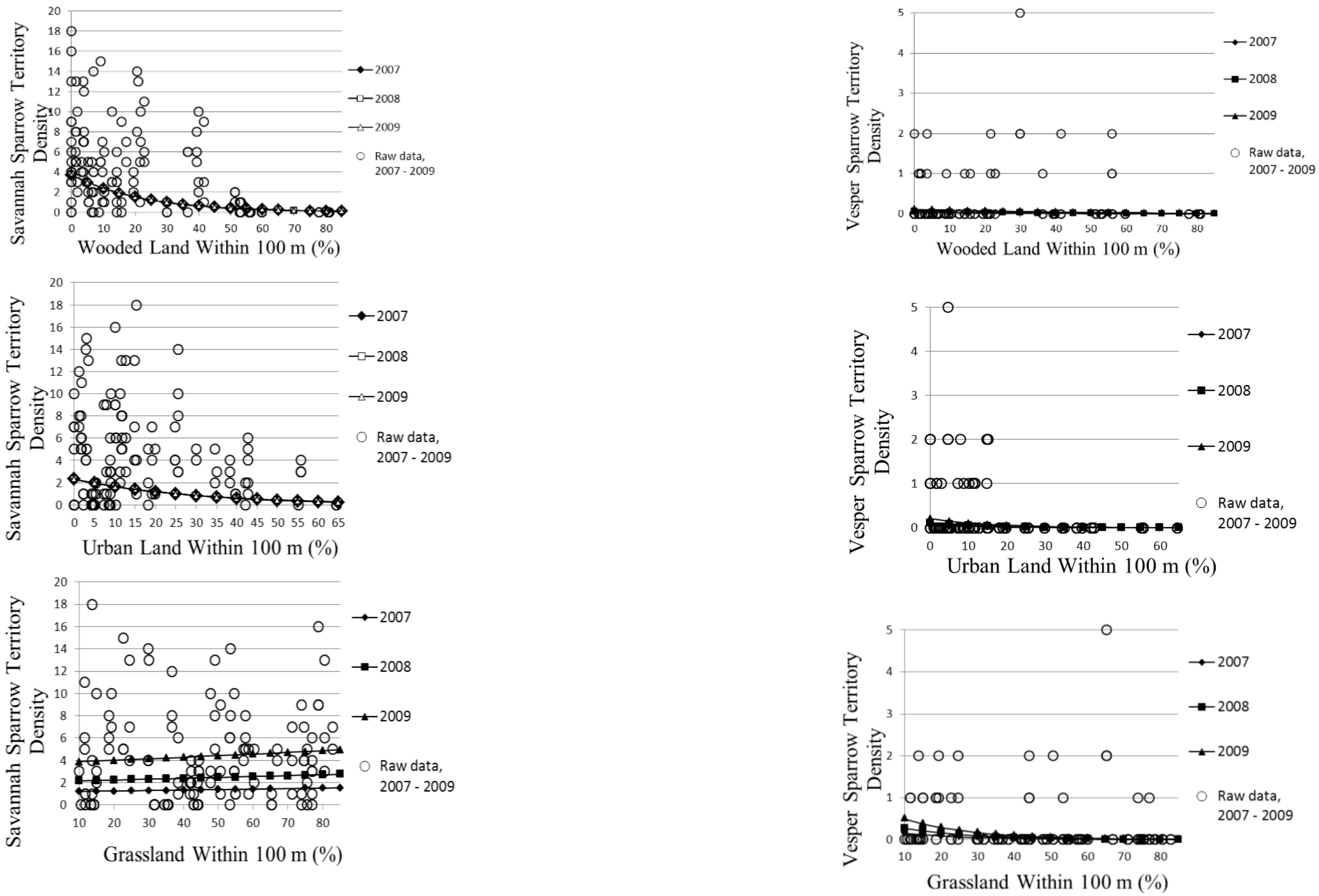


Figure 2.17. Changes in Savannah and Vesper Sparrow territory densities with changes in year and each land use variable from the land use model predicting these species along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009 (*n* = 126 site-year density measurements).

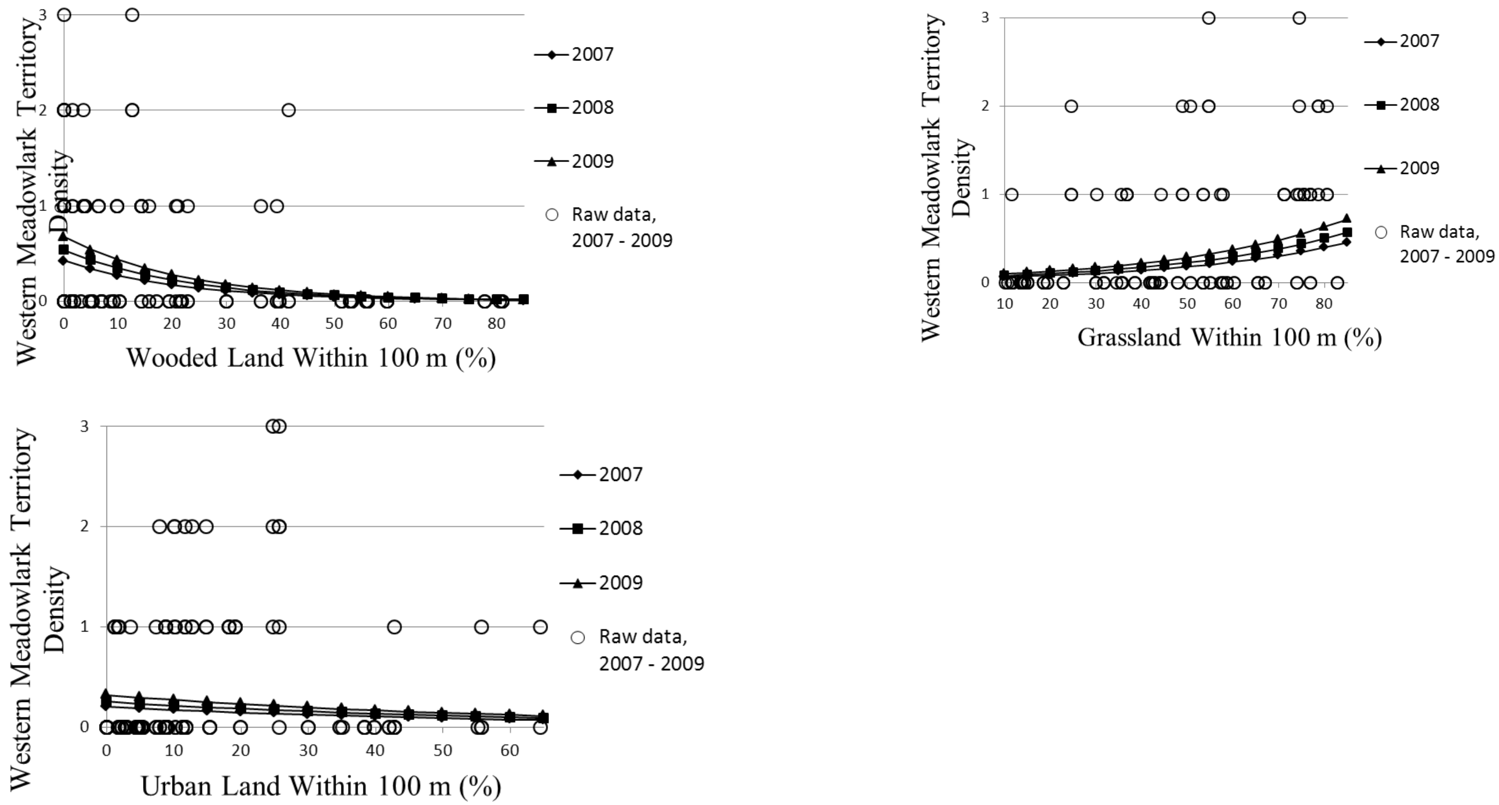


Figure 2.18. Changes in Western Meadowlark territory densities with changes in year and each land use variable from the land use model predicting Western Meadowlarks along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009 (*n* = 126 site-year density measurements).

Table 2.1. Models used to predict dependent variables (vegetation structure, abundance of arthropod food for prairie birds, and prairie bird territory densities) along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007-2009. The same dependent variables were used in the short-term mowing experiment in this study.

Dependent Variable (Vegetation Structure)	**Independent Variables in Models Used for Each Dependent Variable**
Woody cover (%)	Management: year + mowing + mowing^2 + hayed
Litter cover (%)	Land use: year + urban100 + habitat100 (= all grasslands)
Bare ground cover (%)	Global: year + mowing + mowing^2 + hayed + urban100 + habitat100
Vegetation height-density (cm)	Time effects only: year
Plant species richness (# across both vegetation plots per site)	Null: no year, management, or landscape variables
Grass cover (%) = larval host-plant cover for grass-eating caterpillars of certain butterflies	
Larval host-plant cover (%) for individual species of butterflies	
Forb cover (%) = adult nectar plant cover for butterflies	

Dependent Variable (Arthropod surveys)	**Independent Variables in Models Used for Each Dependent Variable**
Lepidopteran counts (#/transect)	Management: year + Julian day + mowing + mowing^2 + hayed
Total biomass in pitfall traps (g), orthopteran biomass in pitfall traps (g)	Land use: year + Julian day + urban100 + habitat100 (= all grasslands)
Lepidopteran biomass in pitfall traps (g), carabid biomass in pitfall traps (g)	Global: year + Julian day + mowing + mowing^2 + hayed + urban100 + habitat100
Butterfly species richness, abundance of each common species or species-group of butterfly (#/transect)	Time effects only: year + Julian day Null: no time, management, or landscape variables
Total biomass in sweep nets (g), orthopteran biomass in sweep nets (g), lepidopteran biomass in sweep nets (g)	

Dependent Variable (Bird surveys)	**Independent Variables in Models Used for Each Dependent Variable**
Clay-coloured Sparrow, Le Conte's Sparrow. Savannah Sparrow, Vesper Sparrow, Western Meadowlark (# territories/survey area)	Management: year + mowing + mowing^2 + hayed Land use: year + urban100 + habitat100 (= all grasslands) + wooded100
	Global: year + mowing + mowing^2 + hayed + urban100 + habitat100 + woodland100
	Time effects only: year
	Null: no year, management, or landscape variables

Table 2.2. Summary statistics (mean, standard error of mean (SE), minimum, maximum) for dependent and independent variable values along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009.

Variable	Mean	SE	Min	Max
Dependent Variables (Local Vegetation)				
% Bare ground cover	6.04	1.15	0	43.85
% Forb cover	1.79	0.19	0.01	7.5
% Grass cover	7.77	0.58	1.82	27.65
% Larval host-plant cover				
for Blues, Sulfurs (legumes) (units)	0.67	0.14	0	5.24
for Cabbage White (mustards)	0	0	0	0
for Crescents (asters)	0.09	0.02	0	0.76
for European Skipper (redtop, timothy)	0.24	0.10	0	3.64
for Fritillaries (violets)	0	0	0	0.05
for Monarch (milkweeds, dogbanes)	0.01	0.01	0	0.33
for Native skippers, Ringlets, Wood-nymphs (grasses)	7.77	0.58	1.82	27.65
% Litter cover	72.9	1.90	31.18	95
Plant species richness (# / both plots per site)	44.84	1.92	13	81
Vegetation height-density (cm)	24.2	1.50	4	61
% Woody stem cover	0.17	0.03	0	0.98
Independent Variables (Landscape)				
% Urban land within 100 m of transects	16.8	1.91	0	64.54
% Total grassland within 100 m of transects	47.4	2.66	10.08	82.89
% Wooded land within 100 m of transects	19.33	2.52	0	81.06

Table 2.3. Summary statistics (mean, standard error of mean (SE), minimum, maximum) for dependent and independent variable values along 48 transmission lines in Winnipeg, Manitoba, 2007 - 2009, separated by management regime along the lines.

Independent Variables (Management):	Mowed twice a year			Mowed once a year, unhayed			Hayed once a year			Unmowed		
Other Variables	Mean	SE	Min - Max	Mean	SE	Min - Max	Mean	SE	Min – Max	Mean	SE	Min - Max
Dependent Variables (Local Vegetation)												
% Bare ground cover	3.65	1.16	0-18.90	8.40	4.17	0-41.75	9.76	2.34	0-18.38	5.90	1.87	0-43.85
% Forb cover	1.94	0.40	0-7.21	1.28	0.23	0-2.73	4.61	0.73	0-7.50	1.25	0.15	0-3.16
% Grass cover	6.32	0.80	1.82-12.14	10.59	2.25	0-27.65	4.98	0.45	0-6.77	8.35	0.82	0-19.56
% Larval host plant cover												
for Blues, Sulfurs (legumes)	0.57	0.18	0-2.94	0.39	0.09	0.12-0.93	3.38	0.68	0-5.24	0.23	0.07	0-1.46
for Cabbage White (mustards)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
for Crescents (asters)	0.05	0.02	0-0.22	0.06	0.03	0-0.36	0.17	0.08	0-0.54	0.11	0.04	0-0.76
for European Skipper (redtop, timothy)	0.02	0.01	0-0.19	0.14	0.10	0-0.87	0.21	0.09	0-0.71	0.41	0.16	0-3.64
for Fritillaries (violets)	0.00	0.00	0-0.03	0.00	0.00	0-0.05	0.00	0.00	0-0.03	0.00	0.00	0-0.05
for Monarch (milkweeds, dogbanes)	0.04	0.02	0-0.33	0.01	0.01	0-0.08	0.01	0.01	0-0.06	0.00	0.00	0-0.03
for Native skippers, Ringlets, Wood-nymphs (all grasses)	6.32	0.80	1.82-12.14	10.59	2.25	0-27.65	4.98	0.45	0-6.77	8.35	0.82	0-19.56
% Litter cover	75.04	3.98	38-95	76.17	4.74	49.63-94.38	77.20	2.04	68-83.20	69.67	2.88	31.18-89.10
Plant species richness (#/both plots)	35.32	2.61	13-53	59.20	3.46	39-80	48.57	2.92	39-57	45.19	3.05	20-81
Vegetation height-density (cm)	16.18	1.96	7-40.50	21.67	3.45	4-37	18.11	3.86	6.25-32.50	31.09	2.06	8.25-61.00
% Woody stem cover	0.11	0.05	0-0.70	0.34	0.09	0-0.98	0.15	0.12	0-0.84	0.15	0.04	0-0.83
Other Independent Variables (Landscape)												
% Urban land within 100 m	29.82	4.13	2.79-64.54	10.59	3.10	0-35.10	9.22	1.83	0-14.79	12.66	2.28	0-42.05
% Total grassland within 100 m	49.22	3.68	22.79-75.53	33.82	8.74	10.08-76.97	50.19	8.59	19.36-80.56	49.95	3.95	11.59-82.89
% Wooded land within 100 m	10.24	1.70	0-21.46	29.30	10.32	0-81.06	17.21	6.38	0-41.49	22.07	3.74	0-77.76

Table 2.4. Best landscape and management predictors of vegetation structure, larval host plant cover, and total plant species richness along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009 (*n* = 68 visits). Response variables were log-transformed prior to modeling as normal distributions, except for plant species richness (negative binomial distribution).

Dependent Variable	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Aster cover	Full management	0.30	Mowing: 3.34 (-0.69 -- 7.37) Mowing ^{2}: -1.58 (-3.62 -- 0.46) Hayed (yes/no): 2.06 (-0.84 -- 4.96)
	Global	0.28	
	Landscape	0.23	Urban: -0.06 (-0.11 -- -0.01) Grassland: -0.02 (-0.06 -- -0.02)
	Time effects only	0.11	
Bare ground	Haying	0.71	Hayed (yes/no): 3.89 (1.02 -- 6.76)
	Full management	0.09	Mowing: 0.37 (-4.64 – 5.38) Mowing ^{2}: 0.04 (-2.47 – 2.56) Hayed (yes/no): 3.83 (0.39 – 7.27)
Legume cover	Global	0.99	Mowing: 5.93 (2.61 -- 9.24) Mowing ^{2}: -2.52 (-4.76 -- -0.28) Hayed (yes/no): 1.16 (1.12 -- 1.20) Urban: 0.02 (-0.01 -- 0.05) Grassland: 0.05 (-0.33 -- 0.43)
Litter cover	Null	0.65	
Milkweed cover	Time effects only	0.82	
Mustard cover	Time effects only	0.99	
Plant species richness	Landscape	0.90	Urban: -0.01 (-0.015 -- -0.005) Grassland: -0.01 (-0.010 -- -0.004)
Timothy and redtop cover	Full management	0.50	Mowing: -3.52 (-8.17 -- 1.13) Mowing ^{2}: 1.22 (-1.13 -- 3.57) Hayed (yes/no): 4.08 (0.81 -- 7.35)
Total forb cover	Haying	0.82	Hayed (yes/no): 1.28 (0.52 -- 2.04)
	Full management	0.09	Mowing: -0.06 (-1.36 – 1.25) Mowing ^{2}: 0.06 (-0.59 -- 0.72) Hayed (yes/no): 1.31 (0.41 – 2.22)
Total grass cover	Full management	0.84	Mowing: 0.03 (-0.64 -- 0.68) Mowing ^{2}: -0.10 (-0.34 -- 0.32) Hayed (yes/no): -0.61 (-1.07 -- -0.15)
Vegetation density	Mowing frequency	0.80	Mowing: - 7.19 (-9.66 -- - 4.72)
Violet cover	Landscape	0.91	Urban: -0.00 (0.00 -- 0.00) Grassland: -0.02 (-0.03 -- -0.01)
Woody plant cover	Landscape	0.81	Urban: -0.08 (-0.13 -- -0.03) Grassland: -0.05 (-0.08 -- -0.02)

Table 2.5. Summary statistics (mean, standard error of mean (SE), minimum, maximum) for butterfly numbers per visit per site (367 visits, with *n* visits per type of mowed and sprayed line) and yearly bird abundances (126 territory measurements, with *n* measurements per type of mowed and sprayed line) along 48 transmission line sites within 200 km of Winnipeg, Manitoba, 2007 - 2009, separated by management regime along the lines.

Independent Variable (Management):	Mowed 2x/year			Mowed 1x/year, unhayed			Hayed 1x/year			Unmowed		
Dependent Variable	Mean	SE	Min - Max	Mean	SE	Min - Max	Mean	SE	Min - Max	Mean	SE	Min - Max
Butterfly numbers	*n*=106			*n*=86			*n*=60			*n*=163		
Butterfly species richness	**2.68**	0.15	0-8	**3.69**	0.23	0-9	**3.53**	0.30	1 - 12	**3.24**	0.18	0-13
All adult lepidopterans	**37.61**	3.97	2-254	**54.90**	5.94	0-269	**47.05**	6.09	1-228	**63**	7.25	0-827
Cabbage White	**0.49**	0.14	0-13	**0.81**	0.28	0-22	**0.50**	0.31	0-18	**0.42**	0.10	0-13
Common Sulfur	**2.41**	0.64	0-45	**1.33**	0.26	0-14	**3.43**	0.76	0-33	**1.06**	0.21	0-18
Common Wood-nymph	**1.49**	0.41	0-37	**2.06**	0.59	0-32	**2.28**	0.69	0-31	**1.92**	0.50	0-66
Crescent spp.	**0.17**	0.07	0-6	**1.34**	0.44	0-21	**0.62**	0.19	0-9	**2.42**	0.49	0-40
European Skipper	**3.58**	1.08	0-89	**12.28**	3.13	0-211	**8.77**	2.95	0-124	**10.95**	4.70	0-746
Fritillary spp.	**0.08**	0.04	0-3	**0.62**	0.20	0-14	**0.25**	0.07	0-2	**0.82**	0.16	0-13
Monarch	**0.34**	0.09	0-5	**0.84**	0.23	0-10	**0.65**	0.21	0-9	**0.49**	0.10	0-9
Native skipper spp.	**0.15**	0.06	0-5	**0.79**	0.24	0-14	**0.12**	0.05	0-2	**0.30**	0.07	0-6
Ringlet	**2.53**	0.57	0-43	**2.06**	0.38	0-15	**1.87**	0.51	0-19	**2.23**	0.74	0-76
Silvery Blue	**0.97**	0.30	0-20	**0.24**	0.07	0-3	**2.93**	0.69	0-22	**0.54**	0.12	0-10
Bird territory densities	*n*=36			*n*=17			*n*=20			*n*=53		
Bobolink	**0.00**	0.00	0	**0.18**	0.13	0-2	**0.00**	0.00	0	**0.02**	0.02	0-1
Clay-coloured Sparrow	**3.18**	0.39	0-9	**2.47**	0.36	0-5	**3.80**	0.50	0-7	**3.89**	0.34	0-11
Killdeer	**0.30**	0.11	0-3	**0.00**	0.00	0	**0.35**	0.13	0-2	**0.11**	0.04	0-1
Le Conte's Sparrow	**0.12**	0.09	0-3	**1.35**	0.51	0-7	**0.20**	0.12	0-2	**0.34**	0.12	0-5
Savannah Sparrow	**4.28**	0.69	0-15	**2.24**	0.64	0-8	**6.20**	0.93	0-13	**4.16**	0.59	0-18
Sedge Wren	**0.03**	0.03	0-1	**0.41**	0.17	0-2	**0.00**	0.00	0	**0.07**	0.05	0-2
Vesper Sparrow	**0.03**	0.03	0-1	**0.24**	0.14	0-2	**0.50**	0.17	0-2	**0.32**	0.11	0-5
Western Meadowlark	**0.61**	0.14	0-3	**0.29**	0.11	0-1	**0.80**	0.17	0-2	**0.23**	0.08	0-3

Table 2.6. Best landscape and management predictors of butterfly species richness (#/visit) and abundances of common butterflies and species-groups (#/visit) along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009 (*n* = 415 visits). Response variables were modeled with negative binomial distributions except for butterfly species richness (Poisson).

Response Variable	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Species richness	Land use	0.51	Urban: -0.01 (-0.01 -- -0.00) Grassland: -0.00 (-0.01 -- -0.00)
	Time effects only	0.28	
All lepidopterans	Management	0.60	Mowing: 0.08 (-0.57 -- 0.73) Mowing^2: -0.15 (-0.48 -- 0.17) Hayed: -0.20 (-0.65 -- 0.24)
Cabbage White	Land use	0.33	Urban: 0.01 (-0.01 -- 0.03) Grassland: 0.01 (-0.01 -- 0.02)
	Time effects only	0.33	
Common Sulfur	Global	0.84	Mowing: 0.27 (-0.83 -- 1.37) Mowing^2: -0.00 (-0.57 -- 0.57) Hayed: 1.12 (0.40 -- 1.84) Urban: 0.02 (0.00 -- 0.04) Grassland: 0.02 (0.00 -- 0.03)
Common Wood-nymph	Time effects only	0.68	
Crescents	Global	0.99	Mowing: -0.30 (-2.48 -- 1.88) Mowing^2: 0.12 (-1.27 -- 1.03) Hayed: -0.41 (-1.87 -- 1.05) Urban: -0.09 (-0.13 -- -0.05) Grassland: -0.01 (-0.03 -- 0.01)
European Skipper	Global	0.57	Mowing: 1.60 (-0.12 -- 3.33) Mowing^2: -1.13 (-2.02 -- -0.24) Hayed: -0.89 (-2.05 -- 0.27) Urban: 0.03 (0.00 -- 0.05) Grassland: 0.01 (-0.01 -- 0.02)
	Management	0.30	Mowing: 0.92 (-0.79 -- 2.63) Mowing^2: -0.69 (-1.55 -- 0.17) Hayed: -0.64 (-1.82 -- 0.54)
Fritillaries	Land use	0.90	Urban: -0.06 (-0.10 -- -0.03) Grassland: -0.02 (-0.04 -- -0.00)
Monarch	Land use	0.61	Urban: -0.01 (-0.03 -- -0.01) Grassland: 0.01 (-0.00 -- 0.02)
	Time effects only	0.25	
Native Skippers	Management	0.70	Mowing: 2.20 (0.50 -- 3.90) Mowing^2: -1.25 (-2.11 -- -0.39) Hayed: -1.91 (-3.23 -- -0.59)
Ringlet	Global	0.67	Mowing: 2.16 (0.44 -- 3.88) Mowing^2: -1.17 (-2.04 -- -0.30) Hayed: -0.49 (-1.60 -- 0.62) Urban: 0.04 (0.02 -- 0.06) Grassland: 0.01 (-0.01 -- 0.03)
Silvery Blue	Global	0.99	Mowing: -0.41 (-2.47 -- 1.65) Mowing^2: 0.05 (-1.00 -- 1.10) Hayed: 2.42 (1.17 -- 3.67) Urban: 0.07 (0.04 -- 0.10) Grassland: 0.03 (0.01 -- 0.05)

Table 2.7. Best landscape and management predictors of abundances of common butterflies and species-groups (#/visit) along 48 transmission lines within 200 km of Winnipeg, Manitoba, after removing unusually large counts (i.e. statistical outliers) for each species from analysis. Response variables were modeled with negative binomial distributions. Subscript = number of visits analyzed per species.

Response Variable (# visits)	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Cabbage White$_{411}$	Time effects only	0.22	
Common Sulfur$_{396}$	Hayed	0.59	Hayed: 0.81 (0.22 -- 1.40)
Common Wood-nymph$_{398}$	Time effects only	0.47	
Crescents$_{397}$	Land use	0.94	Urban: -0.09 (-0.12 -- -0.05) Grassland: -0.02 (-0.03 -- -0.00)
European Skipper$_{395}$	Management	0.45	Mowing: 1.22 (-0.33 -- 2.77) Mowing^2: -0.80 (-1.57 -- -0.02) Hayed: -0.68 (-1.73 -- 0.38)
	Time effects only	0.23	
Fritillaries$_{397}$	Land use	0.9	Urban: -0.04 (-0.06 -- -0.01) Grassland: -0.02 (-0.03 -- -0.00)
Monarch$_{397}$	Time effects only	0.57	
Native Skippers$_{407}$	Management	0.57	Mowing: 1.53 (0.16 -- 2.90) Mowing^2: -0.94 (-1.65 -- -0.24) Hayed: -1.28 (-2.35 -- -0.21)
Ringlet$_{397}$	Global	0.61	Mowing: 2.51 (1.09 -- 3.94) Mowing^2: -1.17 (-1.89 -- -0.44) Hayed: -0.56 (-1.49 -- 0.36) Urban: 0.03 (0.00 -- 0.05) Grassland: 0.01 (-0.01 -- 0.02)
Silvery Blue$_{396}$	Global	0.49	Mowing: -0.15 (-2.18 -- 1.89) Mowing^2: 0.09 (-0.93 -- 1.11) Hayed: 1.87 (0.56 -- 3.18) Urban: 0.04 (0.01 -- 0.06) Grassland: -0.00 (-0.02 -- 0.02)
	Hayed	0.34	Hayed: 1.49 (0.42 -- 2.56)

Table 2.8. Summary statistics (mean, standard error of mean (SE), minimum, maximum) for arthropod biomasses (grams dry biomass) per pitfall trap collection (*n*= 212) and per sweep-net collection (*n*= 244) along 48 transmission lines within 200 km of Winnipeg, Manitoba, separated by management regime along the lines.

Independent Variable (Management):	Mowed 2x/year			Mowed 1x/year, unhayed			Hayed 1x/year			Un-mowed		
Dependent Variable	Mean	SE	Min - Max	Mean	SE	Min -Max	Mean	SE	Min -Max	Mean	SE	Min -Max
<u>Per ten pitfall traps</u>	*n*=57			*n*=36			*n*=23			*n*=96		
Total biomass	**2.64**	0.44	0.29-21.70	**10.75**	1.87	0.61-54.33	**13.28**	3.93	0.66-78.55	**5.42**	1.20	0.36-98.51
Carabidae	**0.78**	0.17	0-8.50	**0.77**	0.14	0-3.41	**1.28**	0.35	0.04-5.78	**0.69**	0.09	0-6.45
Lepidoptera	**0.05**	0.01	0-0.38	**0.08**	0.02	0-0.46	**0.10**	0.02	0-0.54	**0.08**	0.02	0-1.16
Orthoptera	**0.64**	0.25	0-9.67	**4.47**	1.49	0-47.35	**7.15**	3.49	0-71.51	**1.33**	0.71	0-23.14
For Clay-coloured or Le Conte’s Sparrow	**1.22**	0.22	0.05-9.01	**6.02**	1.06	0.24-25.68	**4.45**	1.25	0.28-27.47	**2.81**	0.85	0.25-77.36
For Savannah Sparrow adult	**1.74**	0.39	0.16-19.67	**8.27**	1.64	0.31-48.35	**9.64**	3.64	0.44-77.75	**3.85**	1.02	0.28-84.61
For Savannah Sparrow nestling	**2.27**	0.42	0.25-20.75	**10.16**	1.83	0.55-53.80	**12.96**	3.92	0.59-78.04	**4.93**	1.14	0.31-91.91
For Vesper Sparrow	**2.37**	0.41	0.23-20.58	**9.46**	1.77	0.61-53.01	**11.31**	3.78	0.48-78.41	**4.57**	1.05	0.34-86.23
For Western Meadowlark	**2.47**	0.42	0.28-20.83	**9.86**	1.80	0.61-53.80	**12.10**	3.82	0.66-78.55	**4.77**	1.05	0.34-86.44
<u>Per two sweep-net transects</u>	*n*=71			*n*=45			*n*=34			*n*=94		
Total biomass	**0.28**	0.03	0.02-1.79	**0.40**	0.05	0.01-1.21	**0.41**	0.09	0.02-2.43	**0.34**	0.04	0.01-2.88
Lepidoptera	**0.01**	0.00	0-0.17	**0.04**	0.01	0-0.16	**0.02**	0.01	0-0.16	**0.02**	0.00	0-0.16
Orthoptera	**0.13**	0.03	0-1.52	**0.09**	0.02	0-0.49	**0.23**	0.07	0-2.05	**0.08**	0.01	0-0.57
For Clay-coloured or Le Conte’s Sparrow	**0.26**	0.03	0.01-1.55	**0.37**	0.04	0.01-1.21	**0.36**	0.07	0.02-1.99	**0.31**	0.04	0.01-2.88
For Savannah Sparrow adult	**0.27**	0.03	0.01-1.79	**0.39**	0.04	0.01-1.21	**0.39**	0.08	0.02-2.39	**0.33**	0.04	0.01-2.88
For Savannah Sparrow nestling	**0.27**	0.03	0.01-1.79	**0.39**	0.05	0.01-1.21	**0.41**	0.08	0.02-2.41	**0.34**	0.04	0.01-2.88

Table 2.9. Best management and land use predictors of arthropod biomass (grams dry biomass) per sweep-net collection at 47 sites (n = 244 sweep-net collections) and per pitfall-trap collection along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009 (*n* = 212 pitfall-trap collections). All response variables were log-transformed before being modeled with the normal distribution.

Response Variable	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Orthopteran biomass in nets	Time effects only	0.63	
Lepidopteran biomass in nets	Management	0.79	Mowing: 1.27 (-0.27 -- 2.81) Mowing^2: -0.92 (-1.68 -- -0.16) Hayed: -0.98 (-2.00 -- 0.04)
Total biomass in nets	Time effects only	0.59	
Carabid biomass in traps	Time effects only	0.46	
Lepidopteran biomass in traps	Global	0.99	Mowing: 2.95 (0.67 -- 5.23) Mowing^2: -1.68 (-2.85 -- -0.52) Hayed: 0.14 (-1.40 -- 1.67) Urban: -0.01 (-0.04 -- 0.02) Grassland: -0.01 (-0.03 -- 0.01)
Orthopteran biomass in traps	Management	0.77	Mowing: 2.54 (0.29 -- 4.80) Mowing^2: -1.21 (-2.34 -- -0.08) Hayed: 0.77 (-0.77 -- 2.30)
Total biomass in traps	Global	0.62	Mowing: 1.56 (0.55 -- 2.57) Mowing^2: -0.81 (-1.33 -- -0.30) Hayed: 0.06 (-0.61 -- 0.74) Urban: -0.01 (-0.02 -- 0.01) Grassland: -0.01 (-0.02 -- -0.00)
	Management	0.36	Mowing: 1.94 (0.95 -- 2.94) Mowing^2: -0.81 (-1.53 -- -0.53) Hayed: 0.06 (-0.79 -- 0.58)

Table 2.10. Best management and land use predictors of arthropod biomass (grams dry biomass) per pitfall-trap collection along 47 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009 (*n* = 205 pitfall-trap collections), after excluding a statistical outlier site ("Zora") from analysis. All response variables were log-transformed before being modeled with the normal distribution.

Response Variable	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Carabid biomass in traps	Time effects only	0.46	
Lepidopteran biomass in traps	Time effects only	0.30	
Orthopteran biomass in traps	Time effects only	0.28	
Total biomass in traps	Global	0.94	Mowing: 1.73 (0.93 -- 2.54) Mowing^2: -0.89 (-1.30 -- -0.48) Hayed: 0.08 (-0.45 -- 0.62) Urban: -0.00 (-0.02 -- 0.01) Grassland: -0.01 (-0.02 -- -0.00)

Table 2.11. Best predictive models of territory densities of prairie songbirds along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009 (*n* = 126 measurements over 3 years). Response variables were modeled with Poisson distributions.

Response Variable	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Clay-coloured Sparrow	Land use	0.31	Urban: -0.02 (-0.03 -- -0.01) Grassland: -0.00 (-0.01 -- 0.01) Woodland: -0.00 (-0.01 -- 0.01)
	Global	0.60	Mowing: -1.28 (-2.13 -- -0.43) $Mowing^2$: 0.68 (0.24 -- 1.11) Hayed: 0.56 (0.07 -- 1.05) Urban: -0.02 (-0.03 -- -0.01) Grassland: 0.00 (-0.01 -- 0.01) Woodland: 0.00 (-0.00 -- 0.01)
Le Conte's Sparrow	Land use	0.96	Urban: -0.11 (-0.23 -- 0.01) Grassland: 0.06 (0.02 -- 0.10) Woodland: 0.03 (-0.00 -- 0.06)
Savannah Sparrow	Land use	0.79	Urban: -0.03 (-0.05 -- -0.02) Grassland: 0 (-0.01 -- 0.01) Woodland: -0.04 (-0.06 -- -0.03)
Vesper Sparrow	Global	0.88	Mowing: 0.48 (-3.41 -- 4.36) $Mowing^2$: -0.80 (-2.65 -- 1.04) Hayed: -0.59 (-2.70 -- 1.52) Urban: 0.01 (-0.13 -- 0.16) Grassland: 0.11 (-0.01 -- 0.23) Woodland: 0.08 (-0.05 -- 0.20)
Western Meadowlark	Land use	0.99	Urban: -0.02 (-0.04 -- 0.01) Grassland: 0.03 (0.01 -- 0.04) Woodland: -0.04 (-0.08 -- -0.01)

Table 2.12. Changes in dependent variables with a one-year change in mowing treatment along 11 urban transmission lines (six control, five treatment) in and nine rural transmission lines within 200 km of Winnipeg, Manitoba, 2007-2009.

Response Variable	Model Weight	Data set	Treatment direction	*n*	Mowing Effect Size (no = 0, yes = 1) and 95 % Confidence Interval
Vegetation height-density (cm)	0.92	rural	unmowed to mowed	18	-24.39 (-34.60 -- -14.19)
Lepidopteran counts (#/transect)	0.98	urban	mowed to unmowed	97	-1.06 (-1.70 -- -0.43)
European Skippers (#/transect)	0.81	urban	mowed to unmowed	97	-2.25 (-4.37 -- -0.13)
Monarchs (#/transect)	0.99	rural	unmowed to mowed	90	2.92 (1.17 -- 4.67)
Lepidopteran biomass in nets (g)	0.95	urban	mowed to unmowed	54	-2.24 (-3.10 -- -1.37)
Lepidopteran biomass in traps (g)	0.95	rural	unmowed to mowed	59	-2.49 (-4.40 -- -0.57)
Savannah Sparrow densities	0.82	rural	unmowed to mowed	23	0.69 (0.14 -- 1.24)

Chapter 3. Urbanization and Arthropod Food Availability for Grassland Birds: Do Grassland Birds Prefer Settling in Food-Rich Grassland Fragments?

Abstract

Insectivorous birds generally decline in abundance in cities, but it is unknown if these declines result primarily from reductions in arthropod prey. Prairie songbirds along urban transmission lines provide an opportunity to test this hypothesis, because their prey may decline with frequent mowing and spraying of urban line vegetation and with built-up lands surrounding lines. In 2007 – 2009, I determined how mowing frequency and surrounding built-up lands affected vegetation, arthropod and prairie bird abundance along 48 transmission line sections in Winnipeg, Manitoba. Arthropod abundance on transects and in sweep nets and pitfall traps responded differently mowing and spraying through changes to vegetation. Dense vegetation 20 and 40 cm high had 61 and 89 % fewer grasshoppers than vegetation 5 cm high, while lepidopterans peaked when vegetation was at least 35 cm high (transect counts) or 50 cm high (biomass in sweep-nets). Most arthropods did not decline along transmission lines with more built-up lands, because line habitats were not isolated from other grasslands by more than single roads. However, total arthropod biomass in pitfall traps declined by 34 and 67 % with increases of urban land (20 and 40 %) within 100 m of lines. Although this measure of potential food and prairie birds declined with urbanization, except for Vesper Sparrows, prairie birds within 5-ha survey grids were not more abundant at sites with more arthropods. Although frequently mowed urban grasslands have fewer resources for arthropod food, I concluded that prairie birds do not generally settle in larger numbers in grasslands with more arthropod prey.

Keywords: *grassland birds; arthropod; food availability; mixed modeling; mowing; resources; vegetation management; biomass; urbanization.*

Introduction

Insectivorous birds generally decline in urban landscapes (Lancaster and Rees 1979, Morneau *et al*. 1999, Rottenborn 1999), but no one has investigated if those declines result from lower abundance of arthropods which serve as food in cities. The challenges of such studies include using multiple types of arthropod surveys, both to sample the full range of potential foraging habitats and arthropod prey for birds, and to counter the sampling biases of any one technique (Cooper and Whitmore 1990). Furthermore, not all arthropods within samples are available as food for birds, since arthropods vary by species in their detection, capture, and acceptability as food items by foraging birds (Hutto 1990, Wolda 1990). Furthermore, the primary mechanisms underlying declines in urban arthropod prey for birds are unknown.

For several reasons, prairie birds along urban transmission lines provide an opportunity to evaluate if arthropod declines in cities have caused declines of some insectivorous birds. First, availability of arthropod food is generally important throughout life cycles of birds (Martin 1987), including those prairie birds that are seed-eaters (e.g. Knapton 1994, Lowther 2005, Wheelwright and Rising 2008). Second, in contrast to forest birds that forage high in trees, the terrestrial foraging habitats of prairie birds are easily sampled by sweep nets and pitfall traps (Cooper and Whitmore 1990). Third, stomach samples and foraging observations indicate that prairie birds may be opportunistic foragers (Orians and Horn 1969, Wiens and Rotenberry 1979), so most arthropods within samples can be treated as potential food. Fourth, although insectivorous birds in prairie-dominated landscapes are not thought to be limited by food (Wiens 1974, Wiens and Innis 1974, Wiens 1977), correlations between grassland bird and arthropod numbers occur outside of prairie-dominated landscapes (Bock *et al*. 1986, Flanders *et al*. 2006, Nocera *et al*. 2007). Fifth, there are fewer grassland birds in croplands than the native grasslands that croplands have replaced (Herkert 1994, Peterjohn and Sauer 1999), and croplands have less arthropod food for breeding birds (Brickle *et al*. 2000, Boatman *et al*. 2004, Britschgi *et al*. 2006). Finally, urban grasslands have fewer prairie birds (Sodhi 1992, Haire *et al*. 2001, Bock *et al*. 2002) and arthropods (Bolger *et al*. 2000, Niemela *et al*. 2002, Clark *et al*. 2007). Thus, food availability in the breeding season might be an important habitat cue for prairie birds in urban landscapes.

Frequent mowing and spraying to remove weeds along urban transmission lines (Byrne 2005) might reduce resource plants needed by arthropods eaten by birds. Frequent mowing and spraying together reduce plant species richness (Parr and Way 1988), and eliminates arthropods that depend on those plants (Morris and Rispin 1988, Munguira and Thomas 1992, Erhardt 1995). Mowing also reduces dense vegetation that is shelter habitat for butterflies and other arthropods (Dover 1996, Kruess and Tscharntke 2002). However, infrequent mowing may enable more plant species to occur at sites by reducing competitive species (Parr and Way 1988), and freshly cut vegetation may be more nutritious for herbivorous insects such as grasshoppers (Seastedt 1985, Morris and Rispin 1988, Onsanger 1996).

Urban landscapes surrounding remnant habitats may reduce abundance of arthropods eaten by birds within those habitats through several mechanisms. Although pests and introduced species may increase in cities (Frankie and Ehler 1974, McIntyre *et al*. 2001), urban landscapes usually have fewer native insects, e.g. ants (Suarez *et al*. 1998, Bolger *et al*. 2000, Heterick *et al*. 2000), butterflies (Kitahara *et al*. 2000, Hogsden and Hutchinson 2004, Clark *et al*. 2007), and carabid beetles (Niemela *et al*. 2002). Remnant habitats converted to urban lands are usually isolated by greater distances from other habitats (Fahrig 2003); however, physical isolation may be no more than single roads separating arthropod habitats along transmission line sections. Arthropod abundance declined in smaller remnant habitats (Krauss *et al*. 2003), more physically isolated habitats (Steffan-Dewenter and Tscharntke 2002), and in smaller, older remnant habitats that were isolated for longer periods (Bolger *et al*. 2000); however, isolated habitats may offer refuges to herbivorous insects from predators and parasites (Denys and Schmidt 1998). Edge effects from surrounding urbanization (e.g. changes in temperature, humidity) might reduce arthropod prey of birds (Burke and Nol 1998); however, herbivorous insects may increase on vulnerable plants that are stressed by edge effects as well (Bolsinger and Fluckiger 1988, Hanks and Denno 1993, Speight *et al*. 1998). Thus, arthropods that are food for birds could increase or decrease as urban land increases near transmission lines.

To determine if and how urbanization reduced arthropod prey of prairie birds and to assess arthropod prey as a habitat cue for birds, I conducted arthropod and bird surveys along transmission lines that varied in mowing regime, plant resources for arthropods, and the amount of nearby urban land within 100 m of lines. I predicted that: 1) arthropod prey of birds would decline along transmission lines where mowing regime reduced plant resources and shelter for arthropods; 2) transmission lines surrounded by more urban land would support less arthropod food for birds; 3) prairie birds would be more abundant along transmission lines with more arthropod prey.

Methods

Study Area

Surveys occurred over three years (2007 – 2009) along 48 power transmission line sections with grassy rights-of-way that were at least 30 m wide and 500 m long, within 200 km of Winnipeg, Manitoba (49.90˚ N, 97.14˚ W). Sections were at least 500 m apart to reduce the likelihood birds had territories spanning study sites, and to minimize spatial autocorrelation among sites. For this latter reason, I did not analyze landscape effects at spatial extents greater than 100 m from sites, as larger buffers around sites would overlap and lack independence. Sections varied in mowing and spraying frequency, whether or not they were hayed, proportions of different land uses within 100 m, and vegetation that served as habitat for both grassland birds and their arthropod food.

Mowing Regime Along Transmission Lines

Transmission lines in and near Winnipeg are usually mowed and sprayed with a broadleaf herbicide (2, 4-D) to kill weeds such as dandelion (*Taraxacum officinale*) and Canada thistle (*Cirsium arvense*), and incidentally other broadleaf, non-target plants. Mowing and spraying occur once or twice annually, without removing cut vegetation afterwards. In contrast, rural transmission lines in Manitoba are cropped, hayed (mowed once annually, with cut vegetation baled and removed), or left unmanaged except for tree removal. My study sites consisted of line sections that in 2007 – 2008 were mowed and sprayed twice per year without haying (*n* = 13), mowed and sprayed once a year without haying (*n* = 9), mowed once a year and hayed (*n* = 7), and unmowed except for tree removal (*n* = 19). Effects of mowing and spraying were confounded with each other since they co-occurred at frequently mowed and sprayed sites and infrequently mowed, unhayed sites. Spraying did not occur at hayed or unmowed sites. Therefore, when effects of mowing and spraying were noted on wildlife, I could not identify a distinct effect of mowing or lack of mowing separate from spraying in this study.

Habitat for Arthropods and Birds Along Transmission Lines

I used vegetation surveys from another study along the same 48 transmission lines (Leston 2013) to identify four vegetation metrics affected by mowing and spraying, which represent resources such as food and shelter for arthropods and birds. First, vegetation height-density (cm) (Robel *et al*. 1970) declined with mowing frequency (Leston 2013), and either might indicate the volume of habitat for arthropods (Kruess and Tscharntke 2002) or be negatively correlated with freshly cut, nutritious grass for herbivorous arthropods (Seastedt 1985, Morris and Rispin 1988, Onsanger 1996). Second, forb cover (%) increased along hayed transmission lines (Leston 2013), and indicates food sources for grasshoppers (Vickery and Kevan 1985) and butterflies (Klassen *et al*. 1989). Third, bare ground cover (%) increased along hayed transmission lines (Leston 2013), and could indicate sunbathing or egg-laying sites for grasshoppers (Onsanger 2000), or how easily arthropods can move across ground to encounter pitfall traps (Greenslade 1964). Fourth, grass cover (%) declined along hayed transmission lines (Leston 2013), and serves as food sources for grasshoppers (Vickery and Kevan 1985) and larval butterflies (Klassen *et al*. 1989). Other metrics of arthropod habitats in previous studies, e.g. litter cover (Usher and Smart 1988, Gardner and Usher 1989) and plant species richness

(Munguira and Thomas 1992) were not used in this study, because those metrics were better predicted by factors other than mowing and spraying along transmission lines.

Sites where I conducted bird and arthropod surveys in 2007 also had vegetation surveys done in 2007, while sites with bird and arthropod surveys that began in 2008 also had vegetation surveys in 2008. In 2009, after a mowing adjustment at eight sites (Leston 2012), I revisited the 20 treatment and control sites to repeat vegetation surveys. I assumed that vegetation on sites in 2007 did not significantly change in 2008, and I used vegetation measurements from 2007 as independent variables for bird and arthropod models at the same sites in 2008. However, because some management regimes were changed in 2009, I only analyzed 2009 arthropod and bird data from sites that had vegetation surveys in 2009.

Land Use Around Study Sites

To measure amounts of habitat and non-habitat within 100 m of my study sites for arthropods and birds, I imported GPS waypoints for a 500-m transect at each study site and land cover data for southern Manitoba into ArcGIS 8.3 (ESRI 2002). Land cover data consisted of digital orthophotos and LANDSAT data (Manitoba Conservation 2006). In combination with ground-truthing on-site and overhead maps in Google Earth, I used land cover data to create shape-files of polygons representing different land uses within a 100-m buffer around each study site transect. Most polygons were classified as grassland (mowed, hayed, fallow, or pastured, including forage crops), cropland (tilled crops), built-up urban land (roads, concrete, buildings), or wooded land (forests, shrublands). Water bodies, marshes, and quarries occupied negligible amounts of land. I calculated the cumulative proportions of grasslands, croplands, built-up urban lands, and wooded lands within 100 m of each transect as measures of habitat and non-habitat area (McIntyre and Barrett 1992). I used the total proportion of land within 100 m that consisted of any grassland as the measure of habitat for arthropods and most grassland bird species that I analyzed (Table 1). However, I calculated Vesper Sparrow habitat as the combined total proportion of grasslands and tilled croplands, because that species will nest within tilled fields (Rodenhouse and Best 1995) (Table 3.1). Similarly, habitat for Le Conte's Sparrows consisted of the proportion of unmowed grasslands (fallow or pastured) but not mowed or hayed grasslands within 100 m, due to that species' preference for taller vegetation (Lowther 2005) (Table 3.1).

Urban sites were located within the City of Winnipeg's Perimeter Highway, where urban lands occupied ≥ 18 % of land within 100 m. Rural sites occurred outside of Winnipeg's Perimeter Highway, where urban lands occupied ≤ 8 % of land within 100 m.

Arthropod Prey for Prairie Birds Along Transmission Lines

I used four types of surveys to ensure I sampled potential arthropod food in all foraging habitats for grassland birds, and to account for sampling biases which were unique to each survey (Cooper and Whitmore 1990). First, I counted the total number of adult lepidopterans (butterflies and moths regardless of species) within 5 m of the observer along a 500-m transect, 2-4 times per site per season between 14 June and 30 July, 2007, 4 June 4 and 18 August, 2008, and between 15 June and 18 August, 2009 (Pollard 1977). Secondly, I counted the total number of grasshoppers flushed by a 2-m horizontal bar dragged along two 50-m transects that were 300 m apart, 1-2 times per site per season between 3-30 July, 2007 and between 10-21 July, 2008. Third, I conducted 2-3 sweep-net collections per site per season to catch foliage-dwelling arthropods between 6 June and 18 August, 2008 and between 15 June and 18 August, 2009 (Cooper and Whitmore 1990). A sweep-net collection consisted of two 20-m transects 300 m apart at each site where a technician conducted 20 sweeps in a 1-m arc to the left and then to the right in each transect. Net contents were then stored in plastic bags and frozen for 48 hours before processing. Butterfly, grasshopper, and sweep-net transects occurred from 1000 - 1300 hours on warm days (>13 ° Celsius), with winds ≤ 15 $kmhr^{-1}$ and without precipitation (Pollard 1977). Finally, I used pitfall traps (2-L plastic yogurt buckets) to capture terrestrial surface-dwelling arthropods such as spiders, ground-beetles, grasshoppers and crickets (Cooper and Whitmore 1990). Each pitfall trap collection consisted of ten traps (five each at two locations 300 m apart along each study site's 500-m transect) that were opened for 7-day periods for one round in 2007 (3 – 18 July), two or three rounds in 2008 (28 May to 20 August), and for three rounds in 2009 (3 June to 13 August). Soapy saltwater in the open traps killed arthropods that fell in. This solution was chosen for its non-toxicity, in case children or pets encountered traps, especially at urban sites. To keep rainwater from flooding the traps, the lid of the traps was used as a roof held off the open traps by a 1-inch mesh frame. A circular, second 1-inch mesh frame was used as a false floor halfway down in each trap to minimize the number of frogs, mice and shrews that fell into the traps, while allowing arthropods to fall through the mesh into the traps' solution. After each collection period, I closed traps and preserved samples in 70% ethanol until processing.

To determine the proportion of invertebrates (mainly arthropods) in each sweep-net or pitfall-trap collection that was potentially available as food for each prairie bird species, I separated, identified, and counted invertebrates in each sample by class (snails, earthworms, millipedes, isopods, arachnids, insects), order (e.g. Orthoptera, Coleoptera), family (e.g. Acrididae, Carabidae) and where feasible, morphospecies (Wolda 1990). I recorded length and width (mm) of individuals from each invertebrate type. I identified species of ground beetles based on Lindroth (1961, 1963, 1966, 1968, 1969) and adult grasshoppers based on Vickery and Kevan (1985). Voucher specimens of these taxa were deposited at the J.B. Wallis/R.E. Roughley Museum of Entomology, Department of Entomology, University of Manitoba. Except for voucher specimens, I then dried arthropods for 48 hours in an oven at 50˚ Celsius before measuring dry biomasses of arthropods in an electronic balance (Mettler AE166 Delta Range ± 0.0001 g). Arthropods were measured by length, width, and taxon in each sample during weighing.

After drying and weighing the sorted arthropods, I identified and selectively removed from analyses any arthropods that were probably unpalatable or toxic to birds (Eisner *et al*. 1963, Heinrich 1979, Hasegawa and Taniguchi 1996, Yamaguchi and Hasegawa, Weller *et al*. 2008). Next, I removed arthropods that I thought individual species of birds would rarely encounter while foraging. For example, subterranean invertebrates such as earthworms or carrion beetle larvae would not normally be encountered by surface foragers such as Savannah Sparrows (*Passerculus sandwichensis*) (Wheelwright and Rising 2008), but would be available to Western Meadowlarks (*Sturnella neglecta*), which probe with their bills for subterranean arthropods (Davis and Lanyon 2008). Food items that are wider than the gape of a bird's bill require more time to dismember before consumption and would be less desirable prey (Wiens and Rotenberry 1980, Sherry and McDade 1982, Wheelwright 1985); thus, I used the width of each arthropod type in each sample to determine which arthropods were too wide to be easily eaten without further processing, i.e., > one bill width (Bañbura *et al*. 1999). I compared the width of arthropod types in the sample to mean gape widths of specimens of adult Clay-coloured Sparrows (*Spizella pallida*) (n = 18; x= 4.43 ± 0.36 mm), Killdeer (*Charadrius vociferus*) (n = 9; x = 6.00 ± 0.52 mm), Le Conte's Sparrows (*Ammodramus lecontei*) (n = 17; x = 4.75 ± 0.34 mm), Savannah

Sparrows (*n* = 28; *x* = 5.02 ± 0.38 mm), Sedge Wrens (*Cistothorus platensis*) (*n* = 12; *x* = 3.58 ± 0.30 mm), Vesper Sparrows (*Pöoecetes gramineus*) (*n* = 15; *x* = 6.80 ± 0.54 mm), and Western Meadowlarks (*n* = 18; *x* = 8.48 ± 0.58 mm) from the Manitoba Museum of Man and Nature. I selectively removed hard-bodied arthropods that were wider than these mean gape widths from the analysis of food for each species of prairie bird (Bañbura *et al*. 1999). Wider-bodied caterpillars were not removed because they could be easily squashed without dismembering before being swallowed by birds (Bañbura *et al*. 1999).

I also estimated arthropod food availability for prairie nestlings, because 1) adult prairie birds also eat plant seeds and might be less dependent on arthropod prey than nestlings (Wheelwright and Rising 2008, Davis and Lanyon 2008), and 2) arthropod biomass could influence nestling survival, in which case adult birds may settle in sites with more food for offspring (Martin 1987). Due to a lack of published data and museum specimens, I used an 8-day-old Savannah Sparrow as a model for nestlings of all prairie bird species in my study. I estimated gape width of an 8-day old nestling Savannah Sparrow (10.3 mm) by multiplying the mean gape width from the adult Savannah Sparrow specimens by the ratio of mean gape width for an 8-day-old nestling Chestnut-collared Longspur (*Calcarius ornatus*) (*n* = 4; *x* = 12.48 ± 0.21 mm: Jongsomjit *et al*. 2007) to mean gape width of an adult Chestnut-collared Longspur from Manitoba Museum of Man and Nature specimens (*n* = 13; *x* = 6.08 ± 0.40 mm):

$$\frac{\text{Gape width}_{\text{SAVSnestling}}}{\text{Gape width}_{\text{SAVSadult}}} = \frac{\text{Gape width}_{\text{CCLOnestling}}}{\text{Gape width}_{\text{CCLOadult}}}$$

Bird Densities Along Transmission Lines

I used a spot-mapping protocol (Bibby *et al*. 1992) to determine territory densities of prairie birds within a 50,000-m^2 area (50 m to either side of the 500-m transect line). Territory densities of individual species were based upon three visits per site per year (May 25 – June 30, 2007 - 2009) to record the locations of countersinging males and distinct individual birds, with 10 days between visits to the same site. Surveys occurred between dawn and 1000 hours, on days without strong wind or precipitation (Bibby *et al*. 1992).

Data Analysis

I conducted exploratory data analyses before modeling to determine how to model effects of vegetation and land use appropriately on dependent variables. First, from scatter plots and loess plots, some dependent variables were best modeled as quadratic or cubic functions of independent variables (e.g. Julian date, vegetation density). In such cases, I modeled those dependent variables as a quadratic or cubic function of Julian date and as a quadratic function of vegetation density, in which case, dependent variables reached maximum values at intermediate values of the independent variables. Using normality statistics and quantile-quantile plots, continuously distributed dependent variables (arthropod biomasses in sweep-nets and pitfall traps) were best modeled as normally distributed after log-transformation. Other dependent variables that consisted of counts (number of grasshoppers per transect, number of adult butterflies and moths per transect, bird territory densities) were modeled with generalized linear models as either Poisson or negative binomial distributions, with the preferred distribution having a lower model deviance. I calculated Pearson correlation coefficients to identify redundant variables or pairs of land use predictor variables that were very strongly correlated with each other (|r| > 0.6). In such cases, I excluded the variable in the pair I considered to be less biologically relevant from models for predicting each dependent variable of interest, to minimize issues within modeling.

One site in the study ("Zora") was distinct from the other 47 sites in being dominated by native prairie plants instead of exotic grasses and forbs, and in having greater bare ground cover (45 %) and greater pitfall trap biomasses relative to other sites. The biomass values at Zora had high leverage and statistical influence in a regression of bird densities on biomass, and made Zora an outlier site in models of pitfall trap biomasses. To evaluate the relative impact of this one site on my results, I ran and compared model results for pitfall traps and birds with (48 sites) and without Zora's pitfall trap and bird surveys (47 sites).

I used generalized linear mixed modeling (PROC NLMIXED, SAS 9.3) (SAS 2011) to assess effects of vegetation and surrounding land use on arthropods, and effects of vegetation, arthropod biomass, and surrounding land use on birds after accounting for time effects of each visit and repeated measurements at the same sites (Bolker *et al*. 2008). I used generalized linear models (PROC GENMOD, SAS 9.3) (SAS 2011) to generate starting parameter estimates of time, management, vegetation, and land use parameters for mixed modeling.

I included year as a time effect in all models except the null model because I predicted that annual differences in weather would have effects on vegetation, and in turn prairie birds and their arthropod foods. I also included Julian date (the number of days since January 1) in models of arthropod abundance because I predicted that arthropods would generally increase in abundance and/or activity as temperatures increased (Taylor 1963). Julian date of pitfall trap surveys was strongly, positively correlated (r > 0.60) with weather data for the Winnipeg region during the 2007-2009 field seasons (mean and minimum weekly temperatures during 7-day periods that pitfall traps were open to collect arthropods), suggesting that Julian date was a reasonable index for several different weather variables.

I used an information theoretic approach to rank the best model for predicting each dependent variable (Burnham and Anderson 2002). The best (most parsimonious) model was the model with the smallest value of Akaike's Information Criterion modified for small sample size (AIC_c) in the set of *a priori* models for each response variable (Burnham and Anderson 2002). Models whose AIC_c values differ from the best model's by two units or less ($\Delta AIC_c \leq 2$) are considered to be more or less equivalent (Burnham and Anderson 2002), in which case, the highest-ranking model with the fewest parameters is considered to be the most parsimonious (Arnold 2010). To determine if no vegetation, arthropod food, or land use effects strongly predicted a particular dependent variable, one *a priori* model I tested for all dependent variables was a null model with no fixed effects. Another *a priori* model that I tested for all dependent variables was a model with time effects but no vegetation, arthropod food, or land use effects. I calculated model weights (ω) to express the relative likelihood that a given model best predicts each dependent variable (Burnham and Anderson 2002).

I next determined if arthropod food for birds was affected more by the amount of land use within 100 m of transmission lines (which could either support arthropods as potential habitat (*grassland 100 m*) or prevent arthropods from replenishing their populations along transmission lines (*urban 100 m*)) or by mowing regime (through its effects on potential resources for arthropods). The following models were used (Table 3.1):

1) *year + Julian date + bare ground + vegetation density + forb cover + grass cover* (full vegetation model)

2) *year + Julian date + bare ground* 3) *year + Julian date + vegetation density*

4) *year + Julian date + forb cover* 5) *year + Julian date + grass cover*

6) *year + Julian date + urban 100 m + grassland 100 m* (land use model)

7) year + Julian date + *bare ground + vegetation density + forb cover + grass cover + urban 100 m + grassland 100 m* (global model)

8) *year + Julian date* (time effects model)

9) null model

Dependent variables for these arthropod food availability models were: 1) number of butterflies and moths per 500-m transect per visit; 2) number of grasshoppers from both 50-m transects per visit; 3) total biomass per sweep-net collection; 4) lepidopteran biomass per sweep-net collection; 5) orthopteran biomass per sweep-net collection; 6-10) biomass available to each species per sweep-net collection for adult Savannah Sparrows, nestling Savannah Sparrows, Clay-coloured Sparrow, Le Conte's Sparrow, and Sedge Wren; 11) total biomass per pitfall-trap collection; 12) lepidopteran biomass per pitfall-trap collection; 13) orthopteran biomass per pitfall-trap collection; 14) carabid biomass per pitfall-trap collection; and 15-22) biomass available to each species per pitfall-trap collection for adult Savannah Sparrows, nestling Savannah Sparrows, Clay-coloured Sparrow, Le Conte's Sparrow, Sedge Wren, Killdeer, Vesper Sparrow, and Western Meadowlark (Table 3.1). Biomass in sweep-net collections was not modeled for the latter three species because they are larger birds that forage on the ground instead of grassy foliage. Pitfall-trap models were run twice, once for all sites including the outlier site "Zora" and once without data from Zora.

I ran two sets of models to determine whether or not territory densities of prairie birds increased along transmission lines with more arthropod food earlier in the season (June), which birds might assess directly, or more arthropod food for nestlings and fledglings later in the field season (July). I had different sample sizes for sites with pitfall-trap collections in June, 2008 – 2009 (n = 65) and sites with pitfall-trap collections in July, 2007 - 2009 (n = 90), which provided the biomass estimates for modeling, and running two sets of models enabled me to make use of all of the data, since all models must have the same sample size to be compared to each other by AIC_c (Table 3.1). I used the following models for both the early-season and late-season data sets (Table 3.1):

1) *year + bare ground + vegetation density + forb cover + grass cover* (full vegetation model)

2) *year + biomass available to adults of each species of analyzed prairie bird* (biomass model 1)

3) *year + biomass available to prairie bird nestlings as represented by an 8-day-old Savannah Sparrow* (biomass model 2:)

4) *year + urban 100 m + habitat 100 m + wooded 100 m* (land use model)

5) year + *biomass available to an 8-day-old Savannah Sparrow + vegetation density + forb cover + grass cover + urban 100 m + habitat 100 m + wooded 100 m* (global model: biomass for adults and bare ground cover were excluded because they were strongly negatively correlated with biomass available to nestlings)

6) year + *biomass available to an 8-day-old Savannah Sparrow + vegetation density + forb cover + grass cover + urban 100 m + habitat 100 m* (Vesper Sparrow global model: wooded land was excluded from this model because it was strongly correlated with habitat for Vesper Sparrows (grassland + cropland within 100 m))

7) *year* (time effects model)

8) null model

I ran the early-season and late-season bird models twice, first for all 48 sites including "Zora", and then without this outlier. Dependent variables were densities of individual species of birds that were common enough for analysis (present at > 10 % of study sites) (Table 3.2). Land-use and global models included the proportion of land that was either forest or shrub-land (*wooded 100 m*) within 100 m of transmission lines because many prairie birds avoid settling in wooded landscapes (Bakker *et al*. 2002, Grant *et al*. 2004). Habitat within 100 m of lines (*habitat 100 m*) consisted of total grassland within 100 m for Clay-coloured and Savannah Sparrows and Western Meadowlarks, total grassland within 100 m+ cropland within 100 m for Vesper Sparrows, and total grassland within 100 m – mowed grassland within 100 m for Le Conte's Sparrows.

Results

Effects of Vegetation and Land Use on Arthropod Prey for Prairie Birds Along Transmission Lines

Potential arthropod prey for grassland birds along transmission lines included 44 species of butterflies and skippers from butterfly transects, 28 species of grasshoppers (Acrididae) and hairless caterpillars (Geometridae, Noctuidae) in sweep-nets and pitfall-traps, and 70 species of ground-beetles (Carabidae) in pitfall-traps (Appendix I). Orthopterans included crickets (Gryllidae) in traps and common, nontoxic grasshoppers such as *Melanoplus bivittatus* and *M.*

sanguinipes in nets and traps. Beetles in traps were dominated in biomass and numbers by the nontoxic ground-beetles, *Pterostichus melanarius*, *Poecilus lucublandus*, and *Agonum cupreum*, and by carrion-beetles (Silphidae).

Year and time of season had strong effects on arthropod abundances, which generally declined from 2007 to 2009 (except for carabids) and increased with Julian day (Figures 3.1-3.7).

After accounting for time effects in their best models, grasshopper and butterfly numbers per transect responded in opposite ways to vegetation height-density (Figures 3.1-3.2, Table 3.3). Transmission lines with 20 and 40-cm-tall vegetation height-density had 61 % and 89 % fewer grasshoppers per transect than lines where vegetation height-density was 5 cm. Adult lepidopterans counted per visit varied as a quadratic function of vegetation density, peaking on average when dense vegetation was at least 35 cm high (Figures 3.1-3.2, Table 3.3).

Arthropod biomass per sweep net collection generally increased along transmission lines with more forb cover or dense vegetation (Figures 3.3-3.5, Table 3.3). Models with time effects and no other variables best predicted total dry arthropod biomass and dry biomass for Sedge Wrens per collection. However, models predicted that transmission lines with 3 % and 5 % total forb cover (which varied from 0 – 7.5 %) had 19 % and 34 % more total dry biomass available per collection for Clay-coloured, Le Conte’s, and Savannah Sparrows than lines with no forb cover (Figure 3.5, Table 3.3). Transmission lines with 20 and 40-cm-tall vegetation height-density (which varied from 5 – 65 cm) had 57 % and 86 % less dry grasshopper biomass per collection than lines where vegetation height-density was 5 cm (Figure 3.3, Table 3.3). Dry adult or larval lepidopteran biomass per collection varied as a quadratic function of vegetation height-density, peaking when dense vegetation was 50 cm high (Figure 3.4, Table 3.3).

Whether or not the outlier site was included in the analysis, total dry arthropod biomass per pitfall trap collection and biomass available to each species of prairie bird were best predicted by the global model (Figure 3.6, Tables 3.4-3.5). The global model predicted that sites with mean bare ground cover of 20 % and 40 % (which varied from 0 – 45 %) would have over two and three times more total dry biomass per collection than lines with no bare ground cover. Sites with 20 and 40-cm-tall vegetation height-density had 15 % and 36 % less total dry biomass per collection than lines where vegetation height-density was 5 cm (Figure 3.6, Tables 3.4-3.5). Sites with 3 % and 5 % total forb cover had 20 % and 34 % more total dry biomass available per collection than lines with no forb cover (Figure 3.6, Tables 3.4-3.5). Increases of 20 % and 40 % in the amount of urban land within 100 m of lines (which varied from 0 – 65 %) were associated with 34 % and 67 % less total dry arthropod biomass than along lines with no urban land within 100 m (Figure 3.6, Tables 3.4-3.5). Increases of 20 % and 40 % in the amount of land within 100 m that was grassland (which varied from 10 – 85 %) were associated with 18 % and 26 % less total dry arthropod biomass than along lines where 10 % of land within 100 m was grassland (Figure 3.6, Tables 3.4-3.5). Vegetation features and land uses had similar-sized effects upon the biomass available as food to each species of prairie bird (Tables 3.4-3.5).

When I modeled dry biomass of different arthropods per pitfall trap collection, carabid biomass per collection was best predicted by a model with only time effects. However, lepidopteran and orthopteran biomass in pitfall traps responded to vegetation height-density similarly to lepidopterans and grasshoppers from transects and sweep net collections (Figures 3.7-3.8, Tables 3.4-3.5). The global model best predicted adult or larval lepidopteran biomass per collection while the full vegetation model best predicted orthopteran biomass per collection. Models predicted that sites with 20 and 40-cm-tall vegetation height-density had 45 % and 75 %

less dry orthopteran biomass and 15 % and 31 % more dry lepidopteran biomass per collection than lines where vegetation height-density was 5 cm. Lepidopteran and orthopteran biomass also increased with increasing bare ground cover (Figures 3.7-3.8, Table 3.4). However, a model with only time effects best predicted lepidopteran and orthopteran biomass per collection after the outlier site was removed from analysis (Table 3.5).

Effects of Arthropod Prey and Land Use on Bird Densities Along Transmission Lines

There were strong year effects in the best early-season and late-season models predicting each species of bird. Territory densities of birds increased from 2007 to 2009 in all models except for early-season models of Vesper Sparrow densities.

From behavioural observations, the following prairie birds nested along transmission lines, from most to least abundant: Savannah Sparrows, Clay-coloured Sparrows, Western Meadowlarks, Le Conte's Sparrows, Vesper Sparrows, Killdeer, Sedge Wrens, and Bobolinks (*Dolichonyx oryzivorus*). When Bobolinks and Sedge Wrens were observed, they occurred along unmowed or unhayed, infrequently mowed transmission lines, while Killdeer occurred mainly at sites near croplands. However, the latter three species were only encountered at a few study sites in any year ($n \leq 5$), thus they did not occur frequently enough to be well-modeled (Table 3.2).

Numbers of most prairie birds in this study were better predicted by amounts of land use surrounding transmission lines than by available food, whether or not early-season or late-season data were analyzed (Figures 3.8-3.13). Early-season models predicted that increases of 20 % and 40 % in the amount of urban land within 100 m of lines were associated with 37 % and 60 % fewer Clay-coloured Sparrows, 87 % and 98 % fewer Le Conte's Sparrows (which ranged from 0-4 actual territories), 40 % and 64 % fewer Savannah Sparrows, and 58 % and 71 % fewer

Western Meadowlarks (which ranged from 0-3 actual territories) than along lines with no urban land within 100 m (Figures 3.8-3.9, Table 3.6). Increases of 20 % and 40 % in the amount of grassland within 100 m of lines were associated with 79 % and five times more Le Conte's Sparrows and 25 % and 98 % more Western Meadowlarks than along lines with no urban land within 100 m (Figures 3.8-3.9, Table 3.6). Increases of 20 % and 40 % in the amount of wooded land within 100 m of lines were associated with 47 % and 72 % fewer Savannah Sparrows, two and five times more Le Conte's Sparrows, and 79 % and 93 % fewer Western Meadowlarks than along lines with no wooded land within 100 m (Figures 3.8-3.9, Table 3.6). There were similar-sized effects of urban land, wooded land, and grassland amounts on most prairie birds in the late-season analyses, and for both analyses when the outlier site was excluded from models (Figures 3.11-3.12, Tables 3.6-3.7).

In contrast to the other bird species in the early-season and late-season data sets, Vesper Sparrow densities were best predicted by and increased with biomass per collection along transmission lines (Figures 3.10, 3.13, Table 3.6). Models predicted that sites with 20 and 40 g of dry biomass per June collection (which varied from 0 – 90 g) available to either adult Vesper Sparrows or nestlings would have three and seven times more Vesper Sparrow territories than lines with no food in pitfall traps. If the outlier site was excluded from June analyses, a model with only time effects was the most parsimonious model to predict Vesper Sparrow densities. Sites with 20 and 30 g of dry biomass per July collection (which varied from 0 – 30 g) were predicted to have, respectively, five and 23 times more Vesper Sparrow territories (which ranged from 0-5 actual territories at sites) than lines with no food in pitfall traps. Similar positive effects of biomass per July collection resulted from analyses without the outlier site.

Discussion

Effects of Vegetation and Land Use on Arthropod Prey for Prairie Birds Along Transmission Lines

Strong effects of year and Julian date on arthropods available as potential food for birds are consistent with positive correlations between temperature and Julian date and between temperature and activity of insects (Taylor 1963). Similar fluctuations in weather and insect populations occur in prairie landscapes, but birds are not limited by avaialability of arthropod food in these landscapes (Wiens 1974, Wiens and Innis 1974, Wiens 1977). However, there may be additional reductions of arthropod populations in the landscapes that have replaced much prairie, which may cause grassland habitats in these landscapes to be food-limiting for birds.

After accounting for time effects across and within years, arthropod food availability was usually better predicted by local vegetation structure within study sites than by land use surrounding the sites. Lepidoptera in sweep-nets and on counts increased up to a point with increasing vegetation density, which is consistent with studies where butterflies or other arthropods increased at sites with taller vegetation (Dover 1996, Kruess and Tscharntke 2002). In contrast, grasshoppers declined in sweep-nets and on counts as vegetation density increased, and increased in pitfall traps as bare ground cover increased, perhaps due to their preference for nutritious, recently cut vegetation (Seastedt 1985) and bare ground as egg-laying sites (Onsanger 1996). Total arthropod food in pitfall-trap collections for each bird species also decreased along transmission lines with more dense vegetation, and increased as bare ground cover increased along lines. Total arthropod food in sweep-net collections for each bird species probably increased at sites with more forbs, because forbs serve as nectar-plants for butterflies (Clark *et* *al*. 2007) and as food for grasshoppers (Vickery and Kevan 1993). Some previous studies suggest that reductions in mowing and spraying and a shift to haying will increase plant resources for arthropods and arthropod prey for prairie birds along transmisson lines (Morris and Rispin 1988, Parr and Way 1988, Munguira and Thomas 1992, Erhardt 1995, Kruess and Tscharntke 2002, Leston 2013). Transmission lines could also be managed as a patchwork of hayed and unmowed sections to increase arthropods that use dense vegetation and arthropods that avoid dense vegetation.

Transmission lines with less dense vegetation and more bare ground had higher grasshopper and total arthropod biomass in pitfall traps, but these results might indicate higher arthropod activity levels rather than more arthropod prey for prairie birds at these sites. Pitfall traps might collect greater biomasses at these sites if bare ground or shorter vegetation facilitates arthropod movements and thus increases encounters with pitfall traps (Greenslade 1964). However, carabid biomass increased along transmission lines with more dense vegetation in this study, which contradicts the prediction of greater arthropod activity at sites with less vegetation. Grasshoppers also declined with increasing vegetation density on other surveys in my study, suggesting that their declines in pitfall traps reflected actual lower abundances in dense vegetation. Nonetheless, either higher arthropod activity levels or higher arthropod abundance might increase availability and detectability of arthropod prey by birds (Whittingham and Evans 2004, Atkinson *et al*. 2005), suggesting that these sites provide improved foraging opportunities regardless of the mechanism explaining the patterns we observed.

The unmowed, rural outlier site (“Zora”) with unusually high biomasses in pitfall traps might have influenced my results in the pitfall trap analyses because of its high percentage of bare ground cover and low vegetation density. Vegetation density and bare ground cover only influenced the amounts of grasshoppers and carabids in pitfall traps when Zora was included in pitfall trap analyses. Alternatively, this transmission line may support high arthropod biomass because it was dominated by native prairie rather than by exotic vegetation (McIntyre and Thompson 2003). There was too little native prairie cover along other transmission lines to test for an effect of native prairie cover on arthropod food availability for prairie birds. However, arthropods on other surveys increased at sites with increased forb cover that was dominated by exotic legumes.

After accounting for vegetation as resources for arthropods, arthropods in pitfall traps declined with increasing urban land as in previous studies (Bolger *et al*. 2000, Kitahara *et al*. 2000, Niemela *et al*. 2002). Built-up lands such as roads might have prevented flightless arthropods in pitfall traps from recolonizing urban transmission lines where frequent mowing reduced either their populations or resources such as taller vegetation (Dover 1996, Kruess and Tscharntke 2002). However, in contrast to previous urban studies of insects (Bolger *et al*. 2000), grassland habitats along transmission lines in my study were rarely isolated from the nearest similar habitats by more than individual roads. This minimal physical isolation of grassland habitats along urban transmission lines may explain why other measures of flying arthropods (lepidopterans and grasshoppers in nets and traps) did not decline with the amount of urban land in this study. The results from my study and previous studies imply that if mowing and vegetation are to be altered along transmission lines to increase terrestrial arthropod prey for prairie birds, such changes should be focused along transmission lines that are separated by as few roads as possible from adjacent grassland habitats.

Habitat quality rather than quantity probably explained why arthropods in pitfall traps declined as both urban lands and total amount of grassland increased within 100 m of transmission lines. Total grassland within 100 m consisted of one or more types of managed grassland, each of which had differing amounts of resources and therefore quality for arthropods. Grasslands near urban lines were usually frequently mowed and sprayed, which tend to lead to a lower volume of herbaceous vegetation for lepidopterans (Dover 1996, Kruess and Tscharntke 2002), and had less bare ground and forb cover than hayed grasslands (Vickery and Kevan 1993, Onsanger 1996, Clark *et al*. 2007). Therefore, in future studies, it may be appropriate to model the extent of mowed and unmowed grasslands instead of total grassland as an influence on arthropod food availability for prairie birds along urban transmission lines.

Effects of Arthropod Prey and Land Use on Bird Densities Along Transmission Lines

Prairie birds generally did not settle in larger numbers along transmission lines with more arthropod food for nestlings. If prairie birds actively selected grassland habitats with more arthropod food, they might be expected to decline over the same period of time that arthropods declined along transmission lines. However, most species of prairie birds increased along transmission lines from 2007 to 2009, except for Vesper Sparrows in the early-season models. My study's results differed from previous correlations between grassland birds and arthropods in grasslands outside of native prairie (Bock *et al*. 1986, Flanders *et al*. 2006, Nocera *et al*. 2007), but were consistent with previous conclusions that arthropod food is not normally a limiting resource for prairie birds (Wiens and Rotenberry 1979). My results suggest that changing mowing or vegetation along transmission lines to increase arthropod food for prairie birds will not necessarily attract or benefit prairie birds to those lines, unless those changes occur along lines that attract prairie birds for other reasons, e.g. transmission lines in less urban or wooded landscapes.

Unlike other prairie birds in this study, Vesper Sparrows increased at sites with more arthropod prey for that species, which is consistent with its breeding habits in agricultural landscapes. Vesper Sparrows nest in tilled croplands and may use habitat cues for arthropod food availability during settlement in cropland habitats (Rodenhouse and Best 1983, 1995). Early in the breeding season, Vesper Sparrows are more abundant in fencerows within agricultural landscapes, rather than croplands, perhaps due to greater arthropod abundances or nest cover (Rodenhouse and Best 1983, 1995). As summer progresses, arthropods and nest cover increase in growing cropland vegetation, and Vesper Sparrows shift to nest and forage further within croplands. Vesper Sparrows also nest and forage earlier in croplands with more crop residue, which has been associated with larger numbers of soil and litter-dwelling arthropods (Rodenhouse and Best 1983, 1995). Thus, my results and those from previous studies suggest that Vesper Sparrows may settle in larger numbers along transmission lines where vegetation is managed to increase arthropod prey for Vesper Sparrows.

Prairie birds generally settled in larger numbers along transmission lines with less nearby urban or wooded land, and some species settled in larger numbers along transmission lines with more habitat. Declines of prairie birds have been documented in urban grasslands before (Sodhi 1992, Bock *et al*. 2001, Haire *et al*. 2000) as have declines of prairie birds in grasslands with more wooded lands (Bakker *et al*. 2002, Grant *et al*. 2004). Urban grasslands as habitats for prairie birds may have been lacking in other resources for birds besides arthropod food. Although some prairie birds, such as Savannah Sparrows, use a wide variety of different grassland habitats (Wheelwright and Rising 2008), mowed urban transmission lines had less dense vegetation as nest cover for Le Conte's Sparrows (Lowther 2005), and had less woody plant cover that serves as nesting habitat for Clay-coloured Sparrows (Knapton 1994). Western

Meadowlarks were more affected by grassland amount than by urban land in my study, since Western Meadowlarks might only settle in larger grassland habitats (Davis 2004). If transmission lines are to be managed as prairie bird habitats, such lines should be chosen from those in landscapes with less urban or wooded land, and sufficient grassland to attract species such as Western Meadowlarks. Furthermore, mowing frequency should be reduced to create more nest cover for some species of prairie birds.

Although prairie birds other than Vesper Sparrows were not more abundant in grasslands with more arthropod food, I recommend that mowing and spraying frequencies be reduced and plant resources for arthropods be augmented along existing transmission lines that already attract large numbers of prairie birds. Prairie birds are showing greater overall declines than North American birds that inhabit other ecosystems (Herkert 1994, Peterjohn and Sauer 1999), and some kinds of native prairie are underrepresented in existing protected areas (Hoekstra *et al*. 2005). It will be increasingly important to manage urban lands to support declining species and ecosystems such as these (Young 2000). Doing so will improve habitats for both arthropods and the prairie birds that consume those arthropods. Increasing the abundance of forbs will provide nectar for butterflies and fodder for grasshoppers. Creating patches of taller uncut vegetation will provide shelter for lepidopterans and birds such as Le Conte's Sparrows that nest in taller herbaceous vegetation, while patches of shorter vegetation and bare ground will support more grasshoppers and birds such as Vesper Sparrows. Managing urban transmission lines as habitats for arthropods and prairie birds would be especially appropriate in cities in the North American prairie region, especially those cities with few open grassland spaces as extensive as along transmission lines.

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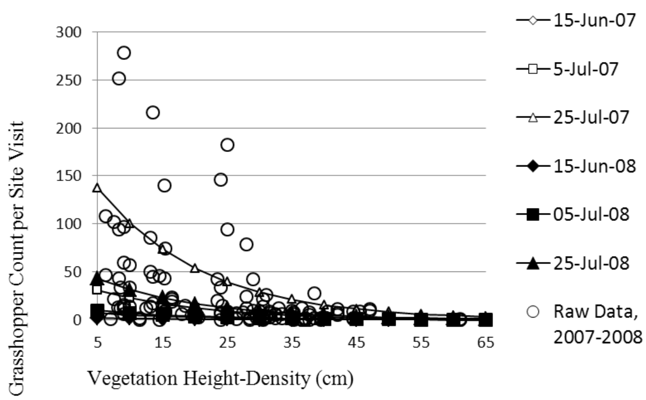


Figure 3.1. Changes in actual and predicted grasshopper counts from transects (n = 103) with changes in year, time of season, and vegetation density the highest-ranking model predicting grasshopper counts along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2008.

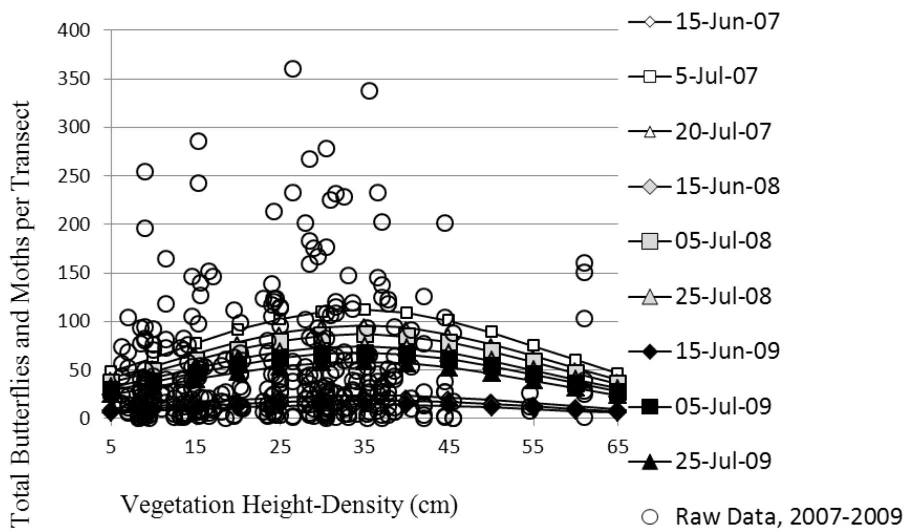


Figure 3.2. Changes in actual and predicted total adult lepidopteran counts from transects (*n* = 367) with changes in year, time of season, and vegetation density from the highest-ranking model of adult lepidopteran counts along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009. Counts were predicted to be highest at intermediate vegetation density.

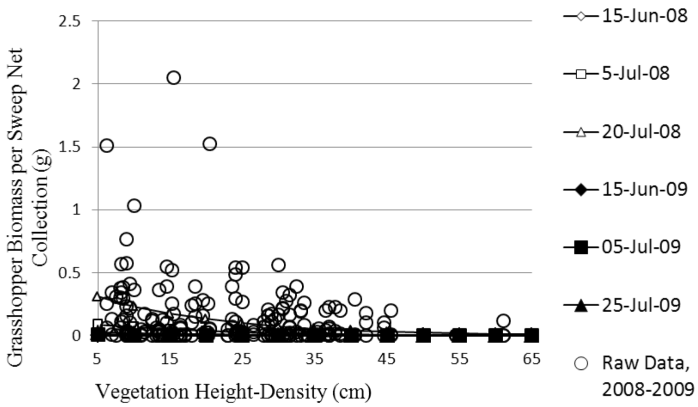


Figure 3.3. Changes in actual and predicted grasshopper biomass per sweep-net collection (*n* = 197) with changes in year, time of season, and vegetation density the highest-ranking model predicting grasshopper biomass along 47 transmission lines within 200 km of Winnipeg, Manitoba, 2008 – 2009.

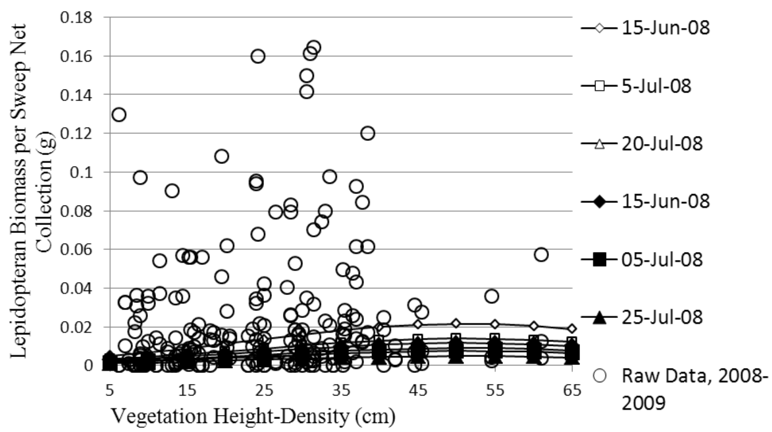


Figure 3.4. Changes in actual and predicted lepidopteran biomass per sweep-net collection (*n* = 197) with changes in year, time of season, and vegetation density the highest-ranking model predicting lepidopteran biomass along 47 transmission lines within 200 km of Winnipeg, Manitoba, 2009 – 2009.

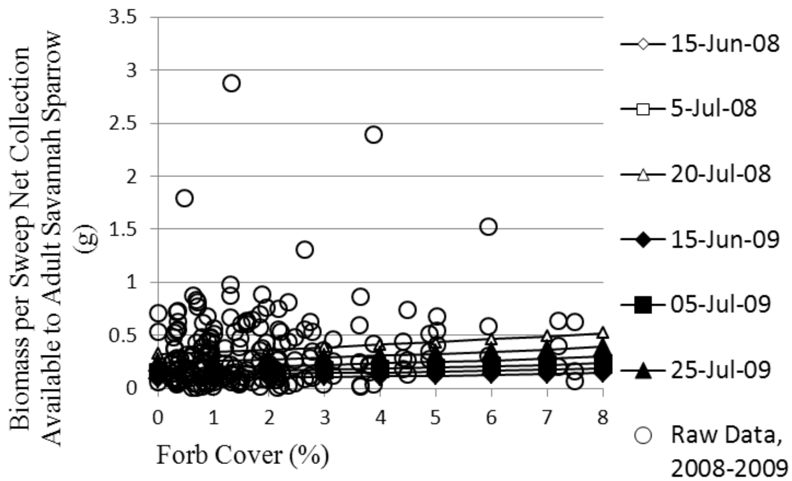


Figure 3.5. Changes in actual and predicted biomass estimated to be available as food for adult Savannah Sparrows per sweep-net collection (*n* = 197) with changes in year, time of season, and vegetation density the highest-ranking model predicting available biomass for Savannah Sparrows along 47 transmission lines within 200 km of Winnipeg, Manitoba, 2008 – 2009.

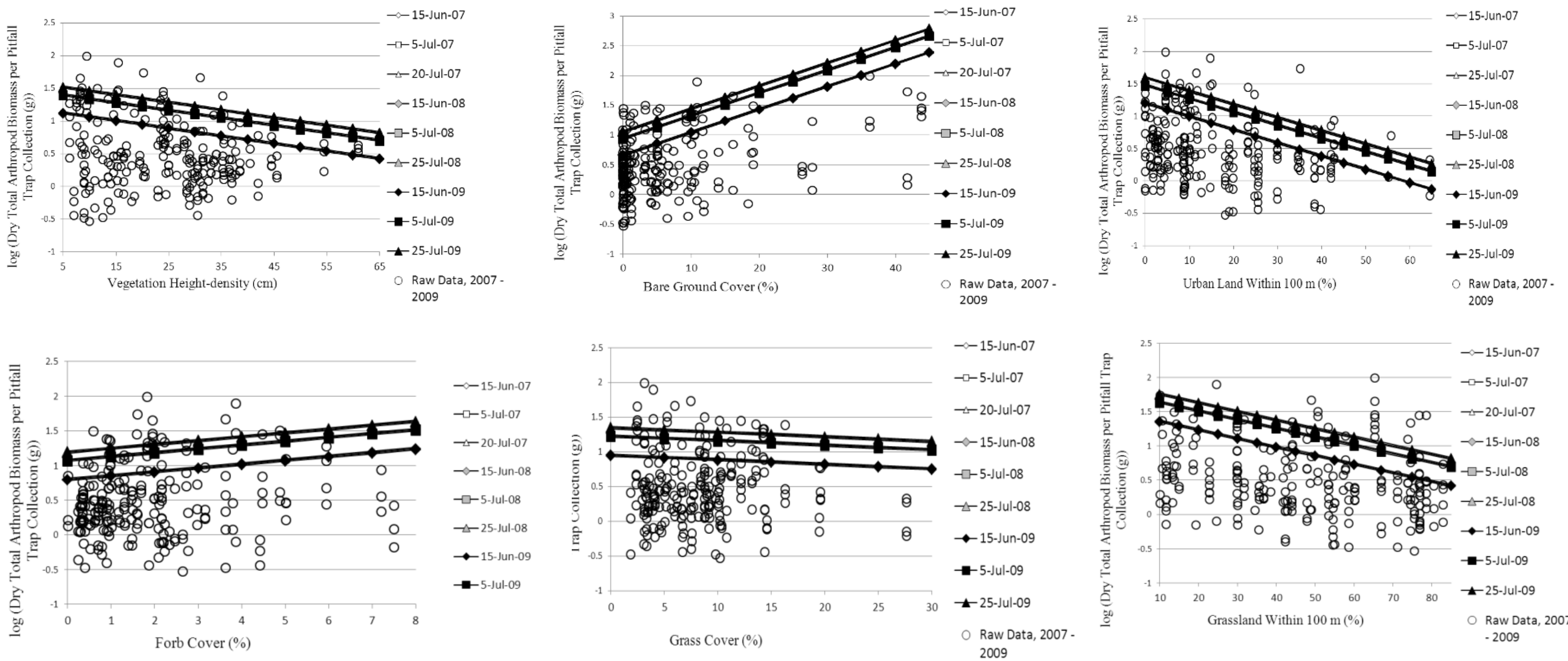


Figure 3.6. Changes in log-transformed actual and predicted dry total arthropod biomass (g) per pitfall trap collection (*n* = 212) with changes in year, time of season, and each vegetation metric from the full vegetation model predicting total arthropod biomass along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009.

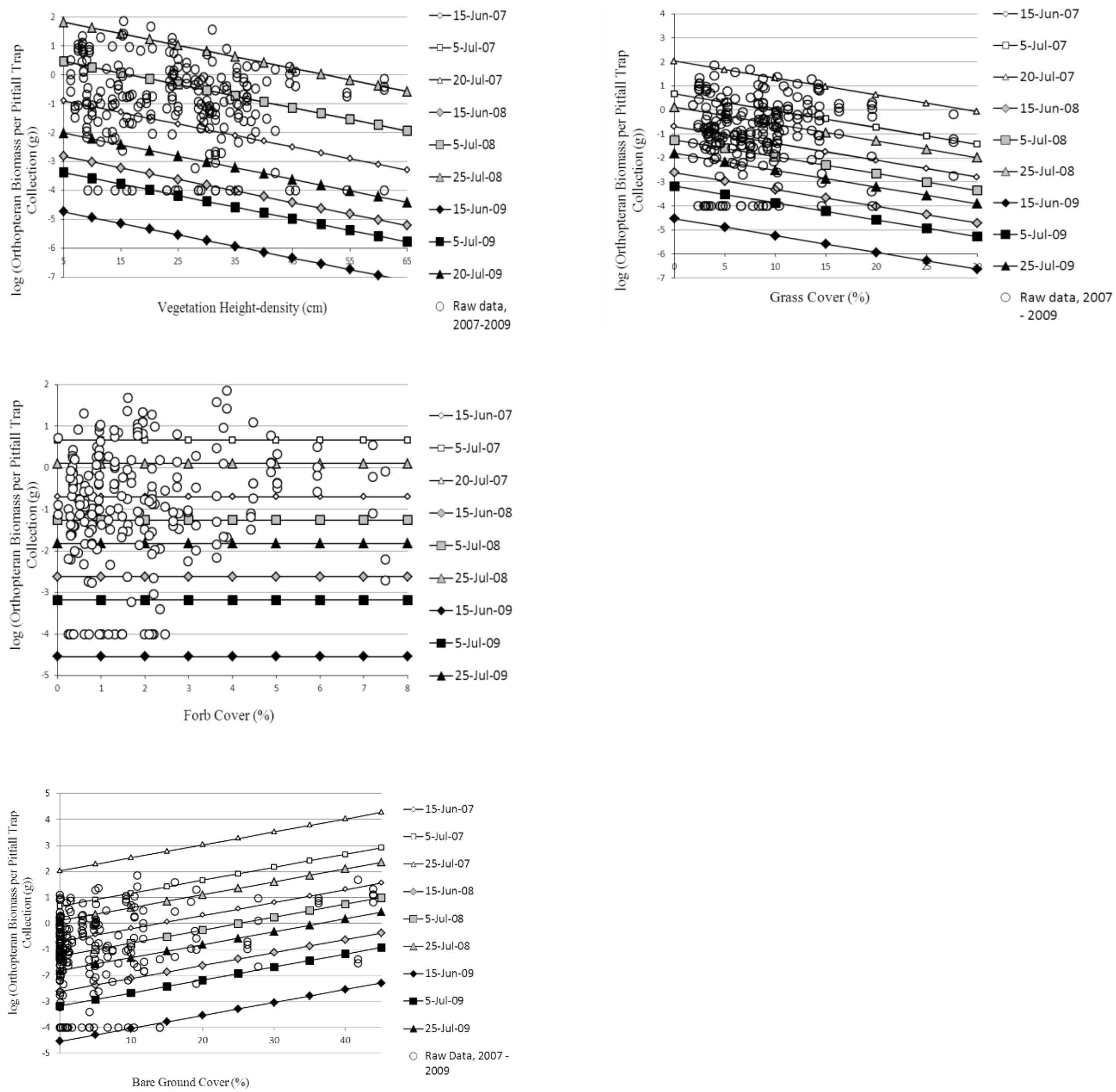


Figure 3.7. Changes in log-transformed actual and predicted dry orthopteran biomass (g) per pitfall trap collection (n = 212) with changes in year, time of season, and each vegetation metric from the full vegetation model predicting orthopteran biomass along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009.

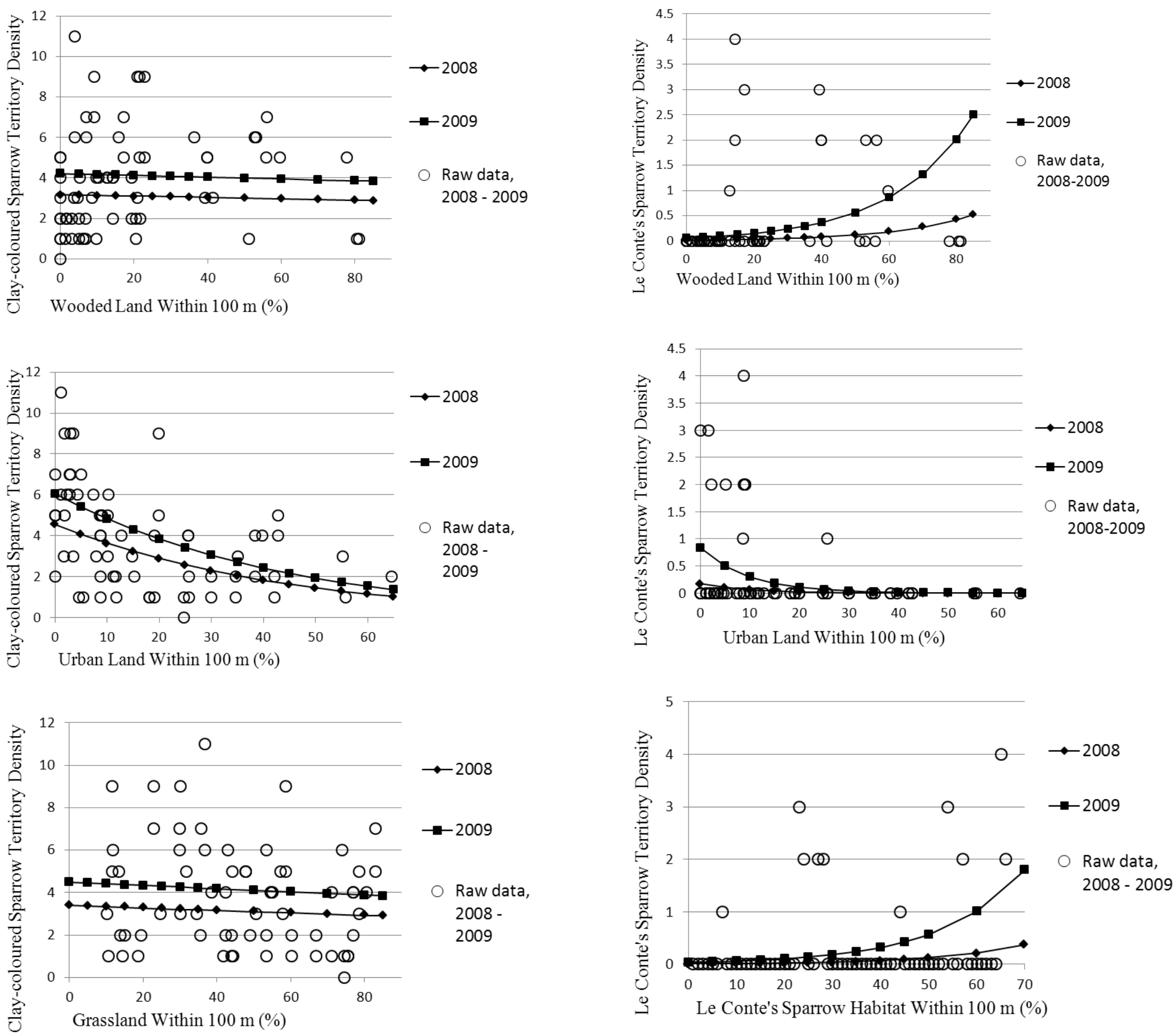


Figure 3.8. Changes in Clay-coloured and Le Conte's Sparrow territory densities with year and every land use variable from the land use model predicting these species along 46 transmission lines within 200 km of Winnipeg, Manitoba, 2008 – 2009 (*n* = 67 site-year density measurements). The data for these analyses came from the early biomass data set of pitfall trap biomasses measured in June, 2008 – 2009.

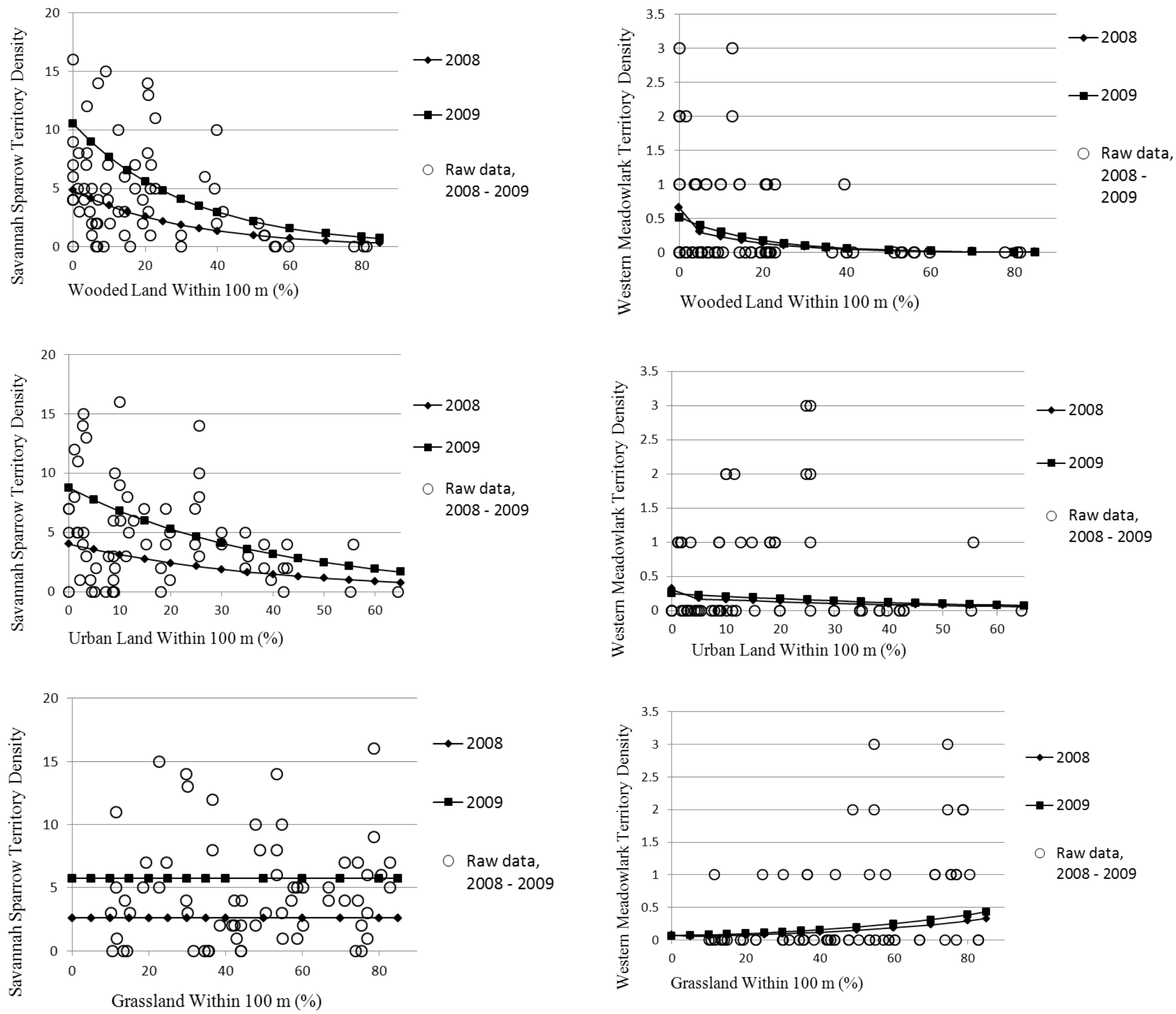
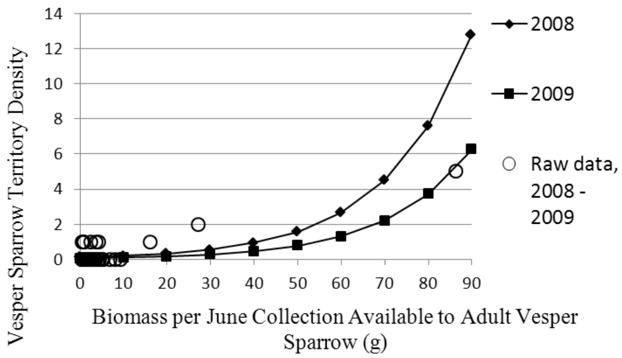


Figure 3.9. Changes in Savannah Sparrow and Western Meadowlark territory densities with year and every land use variable from the land use model predicting these species along 46 transmission lines within 200 km of Winnipeg, Manitoba, 2008 – 2009 (*n* = 67 site-year density measurements). The data for these analyses came from the early biomass data set of pitfall trap biomasses measured in June, 2008 – 2009.



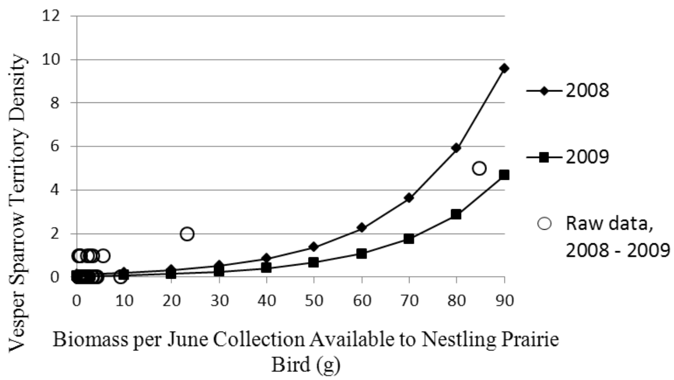


Figure 3.10. Changes in Vesper Sparrow territory densities with year and food availability from each of the two highest-ranking models for predicting Vesper Sparrows along 46 transmission lines within 200 km of Winnipeg, Manitoba, 2008 – 2009 (n = 67 site-year density measurements). The data for these analyses came from the early biomass data set of pitfall trap biomasses measured in June, 2008 – 2009.

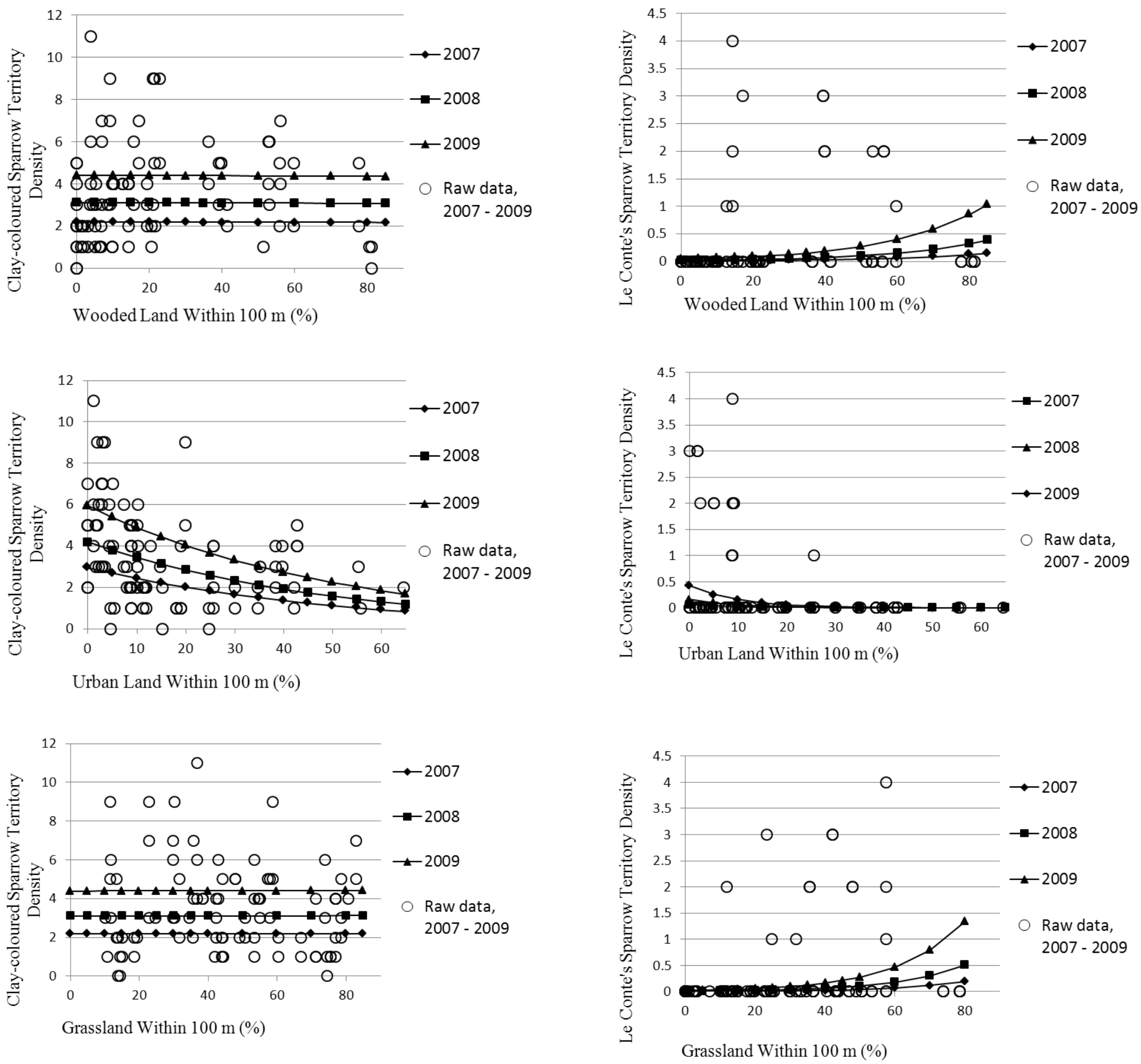


Figure 3.11. Changes in Clay-coloured and Le Conte's Sparrow territory densities with year and every land use variable from the land use model predicting these species along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2008 – 2009 (*n* = 93 site-year density measurements). The data for these analyses came from the late biomass data set of pitfall trap biomasses measured in July, 2007 – 2009.

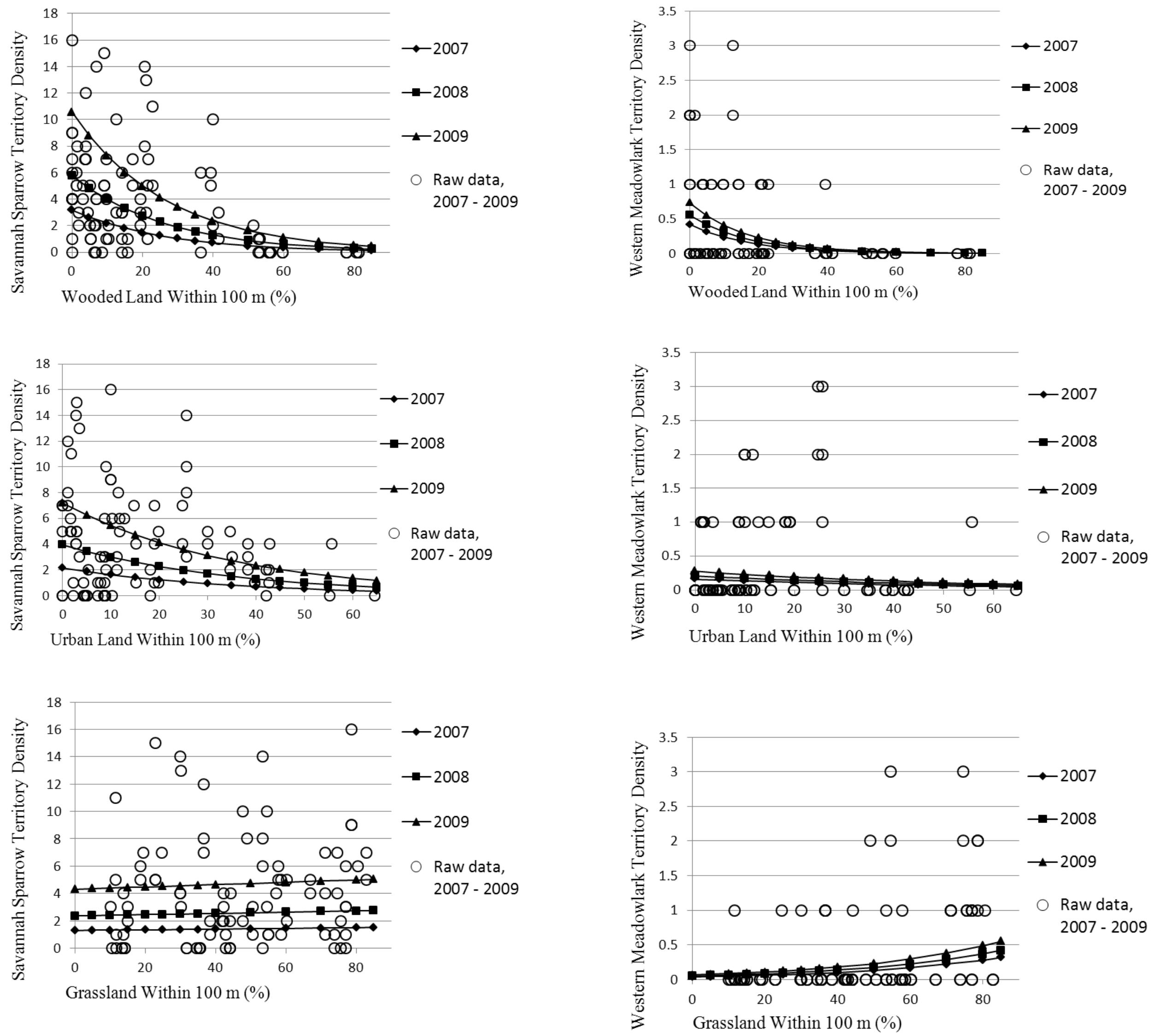


Figure 3.12. Changes in Savannah Sparrow and Western Meadowlark territory densities with year and every land use variable from the land use model predicting these species along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2008 – 2009 (n = 93 site-year density measurements). The data for these analyses came from the late biomass data set of pitfall trap biomasses measured in July, 2007 – 2009.

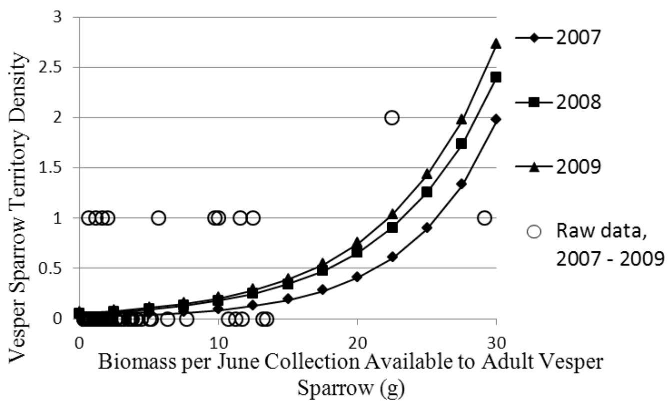


Figure 3.13. Changes in Vesper Sparrow territory densities with year and food availability from the highest-ranking model for predicting Vesper Sparrows along 46 transmission lines within 200 km of Winnipeg, Manitoba, 2008 – 2009 (*n* = 93 site-year density measurements). The data for these analyses came from the late biomass data set of pitfall trap biomasses measured in June, 2007 – 2009.

Table 3.1. The models that were used to predict dependent variables (vegetation structure, abundance of arthropod food for prairie birds, and prairie bird territory densities) along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007-2009.

Dependent Variable (Arthropod Abundance)	Independent Variables in Models Used for Each Dependent Variable
Grasshopper counts (#/both transects)	Local vegetation: year + Julian day + bare ground + grass cover + forb cover + vegetation density
Lepidopteran counts (#/transect)	Bare ground: year + Julian day + bare ground
Total biomass in pitfall traps (g)	Grass cover: year + Julian day + grass cover
Orthopteran biomass in pitfall traps (g)	Forb cover: year + Julian day + forb cover
Lepidopteran biomass in pitfall traps (g)	Vegetation density: year + Julian day + vegetation density
Carabid biomass in pitfall traps (g)	Land use: year + Julian day + urban100 + grassland100
Available biomass in pitfall traps for each species (g)	Global: year + Julian day + bare ground + grass cover + forb cover + vegetation density + urban100 + grassland100
Total biomass in sweep nets (g)	
Orthopteran biomass in sweep nets (g)	Time: year + Julian day
Lepidopteran biomass in sweep nets (g)	Null: no time, land use, or vegetation predictors
Available biomass in sweep nets for each species (g)	

Dependent Variable (Bird Territory Densities)	Independent Variables in Models Used (Early Season Dataset/Late Season Dataset)
Clay-coloured Sparrow (# territories/5 ha)	Biomass: year + available biomass per June or July pitfall trap collection for adult of each species
Le Conte's Sparrow (# territories/5 ha)	Biomass for nestling: year + available biomass per June or July pitfall trap collection for 8-day old Savannah Sparrow nestling
Savannah Sparrow (# territories/5 ha)	Land use: year + urban100 + habitat100 + wooded100
Vesper Sparrow (# territories/5 ha)	Local vegetation: year + bare ground + grass cover + forb cover + vegetation density
Western Meadowlark (# territories/5 ha)	Global: year + biomass for nestling in June (early) or July (late) + forb cover + vegetation density + urban100 + potential habitat100 + wooded100
	Time: year
	Null: no time, biomass, vegetation, or land use predictors

Table 3.2. Summary statistics (mean, standard error of the mean (SE), minimum, maximum) for variables along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009.

	Mean	SE	Min	Max		Mean	SE	Min	Max
Landscape metrics					Arthropod biomass (g)				
% Urban land 100 m	16.80	1.91	0.00	64.54	Per pitfall trap collection per site				
% Mowed, unhayed grassland 100 m	19.95	0.33	0.00	74.55	Total Biomass	6.43	0.06	0.29	98.51
% Total grassland 100 m	47.40	2.66	10.08	82.89	Carabidae	0.80	0.01	0.00	8.50
% Habitat 100 m for most bird spp.	47.40	2.66	10.08	82.89	Lepidoptera	0.07	0.00	0.00	1.16
% Habitat 100 m for Le Conte's Sparrow	25.24	3.17	0.00	78.64	Orthoptera	2.31	0.03	0.00	71.51
% Habitat 100 m for Vesper Sparrow	60.21	3.12	10.63	94.94	For Clay-coloured or LeConte's Sparrow	3.11	0.03	0.05	77.36
% Wooded land 100 m	19.33	0.31	0.00	81.06	For Killdeer	5.21	0.05	0.23	85.77
% Cropland 100 m	15.57	0.39	0.00	71.92	For Savannah Sparrow adult	4.66	0.05	0.16	84.61
					For Savannah Sparrow nestling	5.97	0.05	0.25	91.91
Local Vegetation metrics					For Sedge Wren	2.05	0.02	0.05	23.62
% Bare ground cover	6.04	1.15	0.00	43.85	For Vesper Sparrow	5.54	0.05	0.23	86.23
% Litter cover	72.90	1.90	31.18	95.00	For Western Meadowlark	5.81	0.05	0.28	86.44
% Forb cover	1.79	0.19	0.01	7.50					
% Grass cover	7.77	0.58	1.82	27.65	Arthropod biomass (g)				
% Woody stem cover	0.17	0.03	0.00	0.98	Per sweep net collection per site				
Height-density (cm)	24.20	1.50	4.00	61.00	Total Biomass	0.34	0.00	0.01	2.88
Plant species richness	44.84	1.92	13.00	81.00	Lepidoptera	0.02	0.00	0.00	0.17
					Orthoptera	0.11	0.00	0.00	2.05
Bird territory densities per site (5 ha)					For Clay-coloured or LeConte's Sparrow	0.31	0.00	0.01	2.88
Bobolink	0.03	0.02	0	2	For Savannah Sparrow adult	0.33	0.00	0.01	2.88
Clay-coloured Sparrow	3.50	0.21	0	11	For Savannah Sparrow nestling	0.34	0.00	0.01	2.88
Killdeer	0.18	0.04	0	3	For Sedge Wren	0.29	0.00	0.01	2.88
Le Conte's Sparrow	0.40	0.10	0	7					
Savannah Sparrow	4.25	0.37	0	18	Grasshopper counts per transect	26.66	0.39	0	278
Sedge Wren	0.10	0.03	0	2	Lepidopteran counts per transect	63	0.57	0	827
Vesper Sparrow	0.26	0.06	0	5					
Western Meadowlark	0.43	0.06	0	3					

Table 3.3. Best local vegetation and landscape-level predictors of grasshopper transect count totals over 2 transects per visit (*n* = 48 sites, 102 visits), lepidopteran transect count totals per visit (*n* = 48 sites, 367 visits), and arthropod biomasses per sweep-net collection (*n* = 47 sites, 197 sweep-net collections) along 47-48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Response variables were modeled with negative binomial distributions (butterfly counts, grasshopper counts) or normal distributions after log transformation (biomass in sweep nets and pitfall traps).

Dependent Variable	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Total arthropod biomass in sweep nets	Time effects only	0.44	n/a
Lepidoptera counts per transect	Vegetation density	0.95	Vegetation density (cm): 0.07 (0.03 -- 0.10) Vegetation density^2 (cm^2): -0.001 (-0.0016 -- -0.0003)
Lepidoptera biomass in sweep nets	Vegetation density	0.67	Vegetation density (cm): 0.07 (-0.02 -- 0.16) Vegetation density^2 (cm^2): -0.001 (-0.002 -- 0.001)
Grasshopper counts over 2 transects	Vegetation density	0.93	Vegetation density (cm): -0.06 (-0.10 -- -0.02)
Grasshopper biomass in sweep nets	Vegetation density	0.57	Vegetation density (cm): -0.06 (-0.08 -- -0.03)
Food in sweep nets for Clay-coloured Sparrow	Forb cover	0.95	Forb cover (%): 0.06 (-0.02 -- 0.14)
Food in sweep nets for Le Conte's Sparrow	Forb cover	0.95	Forb cover (%): 0.06 (-0.02 -- 0.14)
Food in sweep nets for nestling Savannah Sparrow	Forb cover	0.93	Forb cover (%): 0.08 (-0.001 -- 0.15)
Food in sweep nets for adult Savannah Sparrow	Forb cover	0.79	Forb cover (%): 0.06 (-0.02 -- 0.13)
Food in sweep nets for adult Sedge Wren	Time effects only	0.44	n/a

Table 3.4. Best local vegetation and landscape-level predictors of arthropod biomasses per pitfall-trap collection (*n* = 212) along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Response variables were log-transformed before being modeled with the normal distribution.

			Model Parameter Effect Size (95 % Confidence Interval)					
Dependent Variable	Best Model	Model Weight	Bare ground (%)	Vegetation density (cm)	Forb cover (%)	Grass cover (%)	% Urban	% Grassland
Total arthropod biomass	Global	0.99	0.04 (0.02 -- 0.06)	-0.01 (-0.03 -- 0.00)	0.06 (-0.05 -- 0.16)	-0.01 (-0.04 -- 0.03)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- -0.00)
Lepidoptera biomass	Global	0.99	0.06 (0.02 – 0.11)	0.01 (-0.03 – 0.04)	0.20 (-0.06 – 0.46)	0.06 (-0.03 – 0.15)	-0.03 (-0.06 – 0.00)	-0.01 (-0.03 – 0.01)
Grasshopper biomass	Full vegetation model	0.62	0.05 (0.01 -- 0.09)	-0.04 (-0.07 -- -0.01)	0.00 (-0.23 -- 0.23)	-0.07 (-0.15 -- -0.01)	n/a	n/a
Carabid biomass	Time effects only	0.26	n/a	n/a	n/a	n/a	n/a	n/a
Food for Clay-coloured Sparrow	Global	0.85	0.04 (0.02 -- 0.06)	-0.02 (-0.03 -- -0.00)	-0.02 (-0.13 -- 0.09)	0.00 (-0.03 -- 0.04)	-0.01 (-0.02 -- 0.00)	-0.01 (-0.02 -- -0.00)
Food for Killdeer	Global	0.99	0.04 (0.02 -- 0.06)	-0.01 (-0.03 -- -0.00)	0.05 (-0.05 -- 0.16)	-0.01 (-0.04 -- 0.03)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- -0.00)
Food for Le Conte's Sparrow	Global	0.85	0.04 (0.02 -- 0.06)	-0.02 (-0.03 -- -0.00)	-0.02 (-0.13 -- 0.09)	0.00 (-0.03 -- 0.04)	-0.01 (-0.02 -- 0.00)	-0.01 (-0.02 -- -0.00)
Food for nestling Savannah Sparrow	Global	0.98	0.04 (0.02 -- 0.06)	-0.01 (-0.03 -- 0.00)	0.05 (-0.05 -- 0.16)	-0.01 (-0.04 -- 0.03)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- -0.00)
Food for adult Savannah Sparrow	Global	0.97	0.04 (0.02 -- 0.06)	-0.01 (-0.03 -- 0.00)	0.05 (-0.05 -- 0.15)	-0.01 (-0.04 -- 0.03)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- -0.00)
Food for Sedge Wren	Global	0.69	0.03 (0.02 -- 0.05)	-0.01 (-0.03 -- 0.00)	-0.03 (-0.14 -- 0.08)	0.00 (-0.03 -- 0.04)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- -0.00)
	Bare ground	0.28	0.04 (0.02 -- 0.06)	n/a	n/a	n/a	n/a	n/a
Food for Vesper Sparrow	Global	0.98	0.04 (0.02 -- 0.06)	-0.01 (-0.03 -- 0.00)	0.05 (-0.05 -- 0.15)	-0.01 (-0.04 -- 0.03)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- -0.00)
Food for Western Meadowlark	Global	0.99	0.04 (0.02 -- 0.06)	-0.01 (-0.03 -- 0.00)	0.05 (-0.07 -- 0.14)	-0.01 (-0.04 -- 0.03)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- -0.00)

Table 3.5. Best predictors of arthropod biomasses per pitfall-trap collection (*n* = 205) along 47 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009, after removing from analysis one site ("Zora") with unusually high pitfall-trap biomasses and statistical influence. Response variables were log-transformed before being modeled with the normal distribution.

			Model Parameter Effect Size (95 % Confidence Interval)					
Dependent Variable	Best Model	Model Weight	Bare ground (%)	Vegetation density (cm)	Forb cover (%)	Grass cover (%)	% Urban	% Grassland
Total arthropod biomass	Global	0.99	0.03 (0.02 -- 0.04)	-0.01 (-0.03 -- 0.00)	0.06 (-0.05 -- 0.15)	-0.01 (-0.04 -- 0.03)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- - 0.01)
Lepidoptera biomass	Time effects only	0.18	n/a	n/a	n/a	n/a	n/a	n/a
Grasshopper biomass	Time effects only	0.47	n/a	n/a	n/a	n/a	n/a	n/a
Carabid biomass	Time effects only	0.26	n/a	n/a	n/a	n/a	n/a	n/a
Food for Clay-coloured Sparrow	Global	0.72	0.03 (0.02 -- 0.05)	-0.02 (-0.03 -- -0.00)	-0.02 (-0.10 -- 0.11)	0.00 (-0.03 -- 0.04)	-0.02 (-0.03 -- 0.00)	-0.01 (-0.02 -- - 0.00)
Food for Killdeer	Global	0.96	0.03 (0.02 -- 0.05)	-0.01 (-0.03 -- -0.00)	0.05 (-0.04 -- 0.16)	-0.01 (-0.04 -- 0.03)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- - 0.00)
Food for Le Conte's Sparrow	Global	0.72	0.03 (0.02 -- 0.05)	-0.02 (-0.03 -- -0.00)	-0.02 (-0.10 -- 0.11)	0.00 (-0.03 -- 0.04)	-0.02 (-0.03 -- 0.00)	-0.01 (-0.02 -- - 0.00)
Food for nestling Savannah Sparrow	Global	0.9	0.03 (0.02 -- 0.05)	-0.01 (-0.03 -- 0.00)	0.05 (-0.05 -- 0.16)	-0.01 (-0.04 -- 0.03)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- - 0.00)
Food for adult Savannah Sparrow	Global	0.94	0.03 (0.02 -- 0.05)	-0.01 (-0.03 -- 0.00)	0.04 (-0.06 -- 0.15)	-0.01 (-0.04 -- 0.03)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- - 0.00)
Food for Sedge Wren	Global	0.5	0.03 (0.02 -- 0.05)	-0.01 (-0.03 -- 0.00)	-0.03 (-0.13 -- 0.08)	0.00 (-0.03 -- 0.04)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- - 0.00)
	Bare ground	0.21	0.03 (0.02 -- 0.05)	n/a	n/a	n/a	n/a	n/a
Food for Vesper Sparrow	Global	0.97	0.03 (0.02 -- 0.05)	-0.01 (-0.03 -- 0.00)	0.04 (-0.05 -- 0.14)	-0.01 (-0.04 -- 0.02)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- - 0.00)
Food for Western Meadowlark	Global	0.96	0.03 (0.02 -- 0.05)	-0.01 (-0.03 -- 0.00)	0.05 (-0.05 -- 0.15)	-0.01 (-0.04 -- 0.02)	-0.02 (-0.03 -- -0.01)	-0.01 (-0.02 -- - 0.00)

Table 3.6. Best landscape, local vegetation and food availability models for predicting prairie songbird densities along transmission lines within 200 km of Winnipeg, Manitoba, 2007-2009. Models for the early biomass data set used 67 site-year measurements of biomass from pitfall traps in June, 2008 - 2009 along 46 transmission lines. Models that used the late biomass data set used 93 site-year measurements of biomass from pitfall traps in July, 2007 - 2009 from 48 transmission lines.

Species	Data Set	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Clay-coloured Sparrow	Early	Landscape	0.99	Woodland (%): -0.00 (-0.01 -- 0.01) Urban (%): -0.02 (-0.04 -- -0.01) Grassland (%): -0.00 (-0.01 -- 0.00)
	Late	Landscape	0.77	Woodland (%): -0.00 (-0.01 -- 0.01) Urban (%): -0.02 (-0.03 -- -0.01) Grassland (%): 0.00 (-0.01 -- 0.01)
Le Conte's Sparrow	Early	Landscape	0.89	Woodland (%): 0.05 (0.01 -- 0.09) Urban (%): -0.10 (-0.21 -- 0.02) Grassland (%):0.05 (0.02 -- 0.09)
	Late	Landscape	0.71	Woodland (%): 0.04 (0.00 -- 0.08) Urban (%): -0.10 (-0.23 -- 0.02) Grassland (%):0.05 (0.01 -- 0.09)
Savannah Sparrow	Early	Global	0.88	Biomass available to adult nestling (g): -0.04 (-0.07 -- -0.00) Veg Density (cm): -0.00 (-0.02 -- 0.01) Forb cover (%): 0.04 (-0.07 -- 0.00) Grass cover (%): -0.03 (-0.07 -- 0.00) Woodland (%):-0.03 (-0.04 -- -0.01) Urban (%):-0.03 (-0.04 -- -0.02) Grassland (%):-0.00 (-0.01 -- 0.01)
	Late	Landscape	0.96	Woodland (%):-0.04 (-0.05 -- -0.02) Urban (%):-0.03 (-0.04 -- -0.01) Grassland (%):0.00 (-0.01 -- 0.01)
Vesper Sparrow	Early	Food	0.41	Biomass available to adult nestling (g): 0.05 (0.03 -- 0.07)
	Early	Food	0.39	Biomass available to adult Vesper Sparrow (g): 0.05 (0.03 -- 0.07)
	Late	Food	0.84	Biomass available to adult Vesper Sparrow (g): 0.16 (0.09 -- 0.23)
Western Meadowlark	Early	Landscape	0.75	Woodland (%):-0.04 (-0.08 -- -0.00) Urban (%):-0.01(-0.04 -- 0.02) Grassland (%): 0.03 (0.01 -- 0.05)
	Late	Landscape	0.96	Woodland (%):-0.06 (-0.10 -- -0.01) Urban (%):-0.02 (-0.05 -- 0.02) Grassland (%): 0.03 (0.00 -- 0.05)

Table 3.7. Best landscape, local vegetation and food availability models for predicting prairie songbird densities along 47 transmission lines within 200 km of Winnipeg, Manitoba, 2007-2009, after removing from analysis one site ("Zora") with unusually high pitfall-trap biomasses and statistical influence. Models for the early biomass data set used 65 site-year measurements of biomass from pitfall traps in June, 2008 - 2009 along 46 transmission lines. Models that used the late biomass data set used 90 site-year measurements of biomass from pitfall traps in July, 2007 - 2009 from 48 transmission lines.

Species	Data Set	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Clay-coloured Sparrow	Early	Landscape	0.74	Woodland (%):-0.00 (-0.01 -- 0.01) Urban (%):-0.02 (-0.04 -- -0.01) Grassland (%):-0.00 (-0.01 -- 0.00)
	Late	Landscape	0.77	Woodland (%):-0.00 (-0.01 -- 0.01) Urban (%):-0.02 (-0.03 -- -0.01) Grassland (%):0.00 (-0.01 -- 0.01)
Le Conte's Sparrow	Early	Landscape	0.84	Woodland (%):1.60 (0.36…2.85) Urban (%):-0.10 (-0.21 -- 0.02) Grassland (%):0.05 (0.01 -- 0.09)
	Late	Landscape	0.71	Woodland (%):0.04 (0.00 -- 0.07) Urban (%):-0.10 (-0.22 -- 0.02) Grassland (%):0.05 (0.01 -- 0.09)
Savannah Sparrow	Early	Landscape	0.54	Woodland (%):-0.03 (-0.04 -- -0.02) Urban (%):-0.03 (-0.04 -- -0.01) Grassland (%):-0.00 (-0.01 -- 0.01)
	Late	Landscape	0.94	Woodland (%):-0.35 (-0.36 -- -0.34) Urban (%):-0.03 (-0.04 -- -0.02) Grassland (%): -0.06 (-0.18 -- 0.06)
Vesper Sparrow	Early	Landscape	0.53	Woodland (%): -0.09 (-0.24…0.06) Urban (%): -0.19 (-0.37…-0.02) Grassland (%):-0.06 (-0.18…0.06)
	Early	Time only	0.21	n/a
	Late	Food	0.67	Biomass available to adult Vesper Sparrow (g): 0.13 (0.06…0.20)
Western Meadowlark	Early	Landscape	0.59	Woodland (%):-0.05 (-0.10…-0.01) Urban (%):-0.01(-0.05 -- 0.02) Grassland (%): 0.02 (0.00…0.04)
	Early	Food	0.27	Biomass available to adult meadowlark (g): -0.40 (-0.79…-0.00)
	Late	Landscape	0.95	Woodland (%):-0.06 (-0.10 -- -0.01) Urban (%):-0.01 (-0.05…0.02) Grassland (%):0.02 (0.00…0.05)

Chapter 4. Managing Vegetation Along Urban Transmission Lines to Increase Food Plants and Shelter Habitat for Butterflies

Abstract

Many species of prairie butterflies along with their tall-grass prairie habitats are declining and are poorly protected by existing reserves. It will be increasingly important to manage underused urban grassy spaces such as transmission lines as habitats for butterflies of threatened ecosystems such as tall-grass prairies. However, these habitats might not currently be suitable for many grassland butterflies, because frequent mowing and spraying to control weeds along lines might remove shelter habitat and food plants, preventing butterflies from being established. Urban land surrounding lines might also prevent butterflies and resource plants from settling along restored prairie habitats along lines; however, because transmission lines often run for kilometres, they might facilitate movement from other, similar habitats by which they run close. To determine if mowing regime or surrounding urbanization reduced butterflies or resource plants along lines, I analyzed transects of butterfly abundance and resource plant data from 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009. Lines varied in mowing regime and amount of surrounding urban land. Those lines with 40 and 80 species of plants within plots had 30 and 85 % more butterfly species per visit than lines with 10 species of plants per plot. Forb cover of 3 and 5 % was predicted to have 51 – 100 % more butterflies of some species than lines without forb cover, dense vegetation 20 and 40 cm high were predicted to have 34 – 112 % more butterflies of some species than vegetation 5 cm high. Forb cover increased with haying while shelter habitat declined with mowing, but plant species richness declined with urbanization, suggesting that introducing some resource plant species along lines might benefit

some butterflies. If mowing and spraying are reduced to increase resource plants for butterflies along lines, most butterflies will increase along these lines regardless of surrounding urbanization. Thus, urban transmission lines present a promising opportunity for creating habitat for butterflies that historically inhabited tall-grass prairies.

Keywords*: tall-grass prairie, restoration, transmission line, butterflies, resource plants*

1. Introduction

Urban transmission lines occupy vast areas that could be restored as low-growing, threatened ecosystems such as tall-grass prairies (Samson and Knopf 1994) to contribute to the conservation of declining populations of prairie butterflies (Shuey *et al*. 1987, Orwig 1990, Schlict *et al*. 2009). Prairie butterflies would benefit from such restoration in Manitoba, because less than 0.1 % of that province's tall-grass prairies remain from two centuries ago (Samson and Knopf 1994), and more urban lands need to be restored for wildlife to complement existing wildlife reserves (Young 2000, Dearborn and Kark 2010). Transmission lines have been successfully managed as habitats for threatened butterflies elsewhere (Smallidge *et al*. 1996, Lowell and Lounsbury 2002, Forrester *et al*. 2005). Before expensive prairie restorations proceed, ecologists must determine whether or not the surrounding urban landscape will prevent butterflies from reaching and benefiting from new resource plants and habitats along transmission lines (e.g. Kitahara *et al*. 2000, Clark *et al*. 2007, Bergerot *et al*. 2010). Most urban wildlife habitats are small and isolated from each other for large distances by surrounding urban land (McDonald *et al*. 2008), which might prevent colonization of urban tall-grass prairies; however, transmission lines provide kilometres of potential habitats that are close to each other, often being isolated from similar habitats by no more than single roads. By understanding which mechanisms affect butterfly species richness and abundance along transmission lines, urban wildlife managers can plan how and where to restore butterfly habitats and prairie vegetation along transmission lines to attract and benefit the most butterflies.

Frequent mowing and spraying to reduce weeds and litter (McKinney 2002) can decrease habitat quality for butterflies. Mowing can reduce insect populations via mortality (Bulan and Barrett 1971, Munguira and Thomas 1992) and remove taller vegetation that is shelter habitat for butterflies and their caterpillars (Dover 1996, Kruess and Tscharntke 2002, Collinge *et al*. 2003). Frequent mowing and spraying reduce species richness of butterfly resource plants (e.g. Munguira and Thomas 1992, Valtonen *et al*. 2007, Öckinger *et al*. 2009); however, infrequent mowing and spraying may increase forb cover and plant species richness by removing taller, competitive species (Parr and Way 1988, Munguira and Thomas 1992). Butterflies with larvae that eat fewer than ten plant species may decline with frequent mowing more than generalist butterflies, whose larvae feed on more species of plants (Kitahara *et al*. 2000, Clark *et al*. 2007). Frequent mowing and spraying may have more negative effects for butterflies whose larvae feed on forbs rather than species whose larvae feed on grasses, because herbicidal sprays in urban green spaces typically are used to control weedy forbs while having little effect on turfgrasses (United Agri Products 2010).

Urban lands near butterfly habitats may contribute to declines of butterflies in those habitats, but not necessarily so. First, mean size of discrete wildlife habitat areas (“patches”) usually declines as habitats are replaced by built-up urban lands (e.g. buildings, roads, concrete) (McKinney 2002). As habitat patch size decreases, distance to the nearest habitat patch usually increases (Fahrig 2003). Built-up lands may prevent butterflies from moving between habitats, because roads serve as barriers or sources of mortality for butterflies (Forman and Alexander 1998, Ries *et al*. 2001). Thus, sedentary butterfly species decline in isolated habitats (Hill *et al*. 1996, Sutcliffe *et al*. 1996, Polus *et al*. 2007), and specialist butterfly species are more likely than generalists to decline to local extinction in smaller habitats (Hill *et al*. 1996, Kraus *et al*. 2003, Polus *et al*. 2007). However, transmission line corridors provide many hectares of potential habitat for butterflies and resource plants (Morgan *et al*. 1995) with individual sections isolated from each other by no more than single roads. Alternatively, butterflies might decline or increase in urban landscapes if their resource plants decline due to habitat loss or isolation (Leon-Cortes *et al*. 2000), or because of increases in exotic resource plants in urban landscapes (Reichard *et al*. 2001, Tooker *et al*. 2002, Graves and Shapiro 2003).

I determined whether resource plant abundance or the amount of urban land along transmission lines affected butterfly species richness and numbers and resource plants for butterflies. I predicted that butterfly species richness and numbers would increase along transmission lines with greater plant species richness, more shelter habitat, and greater cover of nectar-plants for adult butterflies, and larval host-plants. Second, I predicted that butterfly species richness and numbers would generally decline along transmission lines as amount of nearby urban land increased. Third, I predicted that resource plants for butterflies would decline along frequently mowed and sprayed transmission lines, but that infrequently mowed transmission lines might have greater plant species richness than unmowed transmission lines. I also predicted that resource plants for butterflies would decline along transmission lines as amount of nearby urban land increased.

2. Methods

2.1. Study Area

I surveyed butterflies and their plant resources along transmission lines within 200 km of Winnipeg, Manitoba (49.90˚ N, 97.14˚ W), within a region that was historically occupied by tall-grass prairie (Koper *et al*. 2010). Surveys occurred over three years (2007 – 2009), and were conducted along 48 transmission lines with grassy rights-of-way that were at least 30 m wide and 500-m long. As there were limited numbers of suitable transmission lines available within the study area, I used all suitable sites. Sites were at least 500 m apart to reduce the likelihood that butterflies from a given site were also recorded in the sample at nearby sites, and to minimize spatial autocorrelation among sites.

Common butterfly species within the study area included exotic species such as the Cabbage White (*Pieris rapae* Linnaeus), Common Sulfur (*Colias philodice* Godart), and European Skipper (*Thymelicus lineola* Ochsenheimer); native skippers such as the Long Dash (*Polites mystic* W. H. Edwards) and the Hobomok (*Poanes hobomok* Harris); the Monarch (*Danaus plexippus* Linnaeus); Great-spangled (*Speyeria cybele* Fabricius), Silver-bordered (*Boloria selene* Dennis and Schiffermüller), Meadow (*B. bellona* Fabricius), and Variegated Fritillaries (*Euptoieta claudiae* Cramer); Northern Pearl (*Phyciodes morpheus* Fabricius) and Pearl Crescents (*Ph. Tharos* Drury); Common Wood-nymph (*Cercyonis pegala* Fabricius); Ringlet (*Coenonympha tullia* Müller); Silvery Blue (*Glaucopsyche lygdanus* Doubleday).

2.2 Local Vegetation Management and Surrounding Land Use

My sites varied in mowing regime. Urban sites within Winnipeg's Perimeter Highway are mowed and sprayed at least once or twice a year with a broadleaf herbicide (2,4 –D) to kill weeds such as dandelion (*Taraxacum officinale*) and Canada thistle (*Cirsium arvense*), and incidentally other broadleaf, non-target plants. Cut vegetation is left as mulch along urban lines. In contrast, rural transmission lines in Manitoba are typically cropped, hayed (mowed once a year, with cut vegetation baled and removed), or left unmanaged except for tree removal. Transmission lines in 2007 – 2008 were mowed and sprayed twice annually without haying (n = 13), mowed and sprayed once annually without haying (n = 9), mowed once annually with haying (n = 7), and unmowed except for tree removal (n = 19). Hayed lines had visibly greater forb cover than other lines, primarily introduced legumes such as bird's-foot trefoil (*Lotus corniculatus*), alfalfa (*Medicago sativa*), sweet clover (*Melilotus alba*, *M. officinale*), Alsike clover (*Trifolium hybridum*), and red clover (*T. praetense*).

A caveat for this study was that effects of mowing and spraying were confounded with each other since they co-occurred at frequently mowed and sprayed sites and infrequently mowed, unhayed sites. Spraying did not occur at hayed or unmowed sites. Therefore, when effects of mowing and spraying were noted on wildlife, I could not identify a distinct effect of mowing or lack of mowing separate from spraying in this study.

To measure the amounts of habitat and non-habitat within 100 m of my study sites for butterflies, I imported GPS waypoints for a 500-m transect at each study site and land cover data for southern Manitoba into ArcGIS 8.3 (ESRI 2002). Land cover data consisted of digital orthophotos and LANDSAT data (Manitoba Conservation Data Centre 2006). In combination with ground-truthing on-site and overhead maps in Google Earth, I used land cover data to create shape-files of polygons representing different land uses within a 100-m buffer around each study site transect. Most polygons were classified as grasslands (mowed, hayed, fallow, or pastured, including forage crops), croplands (tilled crops), built-up urban lands (roads, concrete, buildings), and wooded lands (forests, shrublands). Water bodies, marshes, and quarries occupied negligible amounts of land. I then calculated the cumulative proportions of grasslands, croplands, built-up urban lands, and wooded lands within 100 m of each transect as measures of habitat and non-habitat area (McIntyre and Barrett 1992). Habitat for butterflies along transmission lines was modeled as grassland within 100 m of transmission lines.

2.3. Surveys

2.3.1. Butterflies Along Transmission Lines

I surveyed butterflies along 48 transmission lines where I established a straight 500-m transect, from 10:30 to 1:30 on warm days (>13 ° C) without strong wind (≥ 15 $kmhr^{-1}$) or precipitation (Pollard 1977). There were 3 - 11 butterfly surveys per site in 2007 – 2009, with up to four surveys per site in a given year. I looked for butterflies while walking along the 500-m transect (~30 minutes per transect). I counted individuals of all species within 5 m of the transect during visits and noted their locations and behaviors (flying, mating, feeding) at the time on survey maps. Where possible, I captured butterflies that could not be identified on the wing and examined them in the hand prior to release, or collected them as voucher specimens. While I tentatively identified crescent butterflies on the surveys as Northern Pearl Crescents (*Phyciodes morpheus*) based on the voucher specimens, it is plausible that some individual crescents during the surveys were similar-looking Pearl Crescents (*P. tharos*). Voucher specimens were deposited at the J.B. Wallis/R.E. Roughley Museum of Entomology, Department of Entomology, University of Manitoba.

2.3.2 Butterfly Resource Plants Along Transmission Lines

I conducted vegetation surveys along 48 transmission lines in either 2007 or 2008 (mid-July to mid-August). Sites with butterfly surveys in 2007 had vegetation surveys in 2007 while sites with butterfly surveys that began in 2008 had vegetation surveys in 2008. I assumed that vegetation on sites in 2007 did not significantly change in 2008, and I used vegetation measurements from 2007 as independent variables for butterfly models at the same sites in 2008. In 2009, I repeated vegetation surveys at 20 of the 48 sites as part of another study (Leston 2013). Mowing frequency was experimentally altered along eight of the 20 transmission lines in this other study, but the change had no effects on resources for butterflies except for vegetation density (Leston 2013), and thus I did not model effects of this change in mowing in the present study.

I recorded plant species richness and abundance of butterfly resource plants within two 1000–m^2 vegetation survey plots (mid-July to late August) along each transmission line. There were ten 0.1-m^2 systematically spaced subplots (for 20 subplots per site) in each larger survey plot, within which I measured cover of individual plant species (Kalkhan and Stohlgren 2000). I ranked cover of individual species in a subplot on a scale where numbers represented a range of percent covers (0%, trace = one or two stems or < 0.5 % of plot; 1 = 0.5 - 0.9%; 2 = 1-3%; 3 = 4-10%; 4 = 11-25%; 5 = 26-50%; 6 = 51-74%; 7 = 75-89%; 8 = 90-99%; 100%). I used this scale because it produces more consistent estimates of plant cover by different field technicians (Daubenmire 1959). For analyses, this ranking was converted to the mid-range values for each number range.

I used four metrics from vegetation surveys to assess the abundance of butterfly resource plants along transmission lines. First, I measured cumulative plant species richness from both survey plots along each transmission line as a measure of larval host-plant availability for butterfly species in general. Second, I used mean total cover by all forb species from all subplots per site as an estimate of abundance of nectar plants for adult butterflies, because grassland butterflies take nectar from many species of flowers (Tooker *et al*. 2002, Tudor *et al*. 2004). Third, I measured shelter habitat for butterflies (Kruess and Tscharntke 2002, Dover 1996) as mean height-density of herbaceous vegetation (cm) from all subplots per site with a Robel pole (Robel *et al*. 1970). I then calculated mean larval host-plant cover from all subplots per site, for each butterfly species' or species-group's caterpillars, from all species of the following plants: violets for fritillary butterflies (Klassen *et al*. 1989); milkweeds and dogbanes for Monarchs (Klassen *et al*. 1989); asters for Northern Pearl and Pearl Crescents (Klassen *et al*. 1989); timothy and redtop grasses for European Skippers (Klassen *et al*. 1989); mustards for Cabbage Whites (Klassen *et al*. 1989); and legumes for Common Sulfurs (Klassen *et al*. 1989) and Silvery Blues (Klassen *et al*. 1989). Total grass cover represented larval host-plant cover for Common Wood-nymphs, Ringlets, and native skippers as a group, because Common Wood-nymphs and Ringlets feed on a wide variety of grasses and sedges (Klassen *et al*. 1989). Furthermore, most native skippers I detected on the surveys - even those that are thought to be host-plant specialists (Clark *et al*. 2007) - will consume abundant grasses like Kentucky Bluegrass (*Poa pratensis*) (Klassen *et al*. 1989) (Appendix II).

2.4. Analyses

I conducted exploratory data analyses before modeling to determine how to model the effects of mowing regime and land use on dependent variables appropriately. It was apparent from scatter plots and loess plots that some dependent variables were nonlinearly related to independent variables of interest (e.g. Julian date, mowing frequency, vegetation density, forb cover). In such cases, I modeled those dependent variables as a quadratic or cubic function of Julian date and as a quadratic function of mowing frequency or vegetation density, in which case dependent variables reached maximum values at intermediate values of the independent variables. Normality statistics and quantile-quantile plots indicated that continuously distributed dependent variables (total forb cover, larval host-plant cover) were best modeled as normally distributed after log-transformation. Other dependent variables that consisted of counts (plant and butterfly species richness, butterfly numbers) were modeled with generalized linear models as either Poisson or negative binomial distributions, with the preferred distribution having a lower model deviance. I calculated Pearson correlation coefficients to identify redundant variables or pairs of land use predictor variables that were strongly correlated with each other ($|r| > 0.6$). In such cases, the variable in the pair considered to be less biologically relevant in explaining butterfly numbers was excluded from subsequent models, to minimize issues within modeling.

I then tested for potential outliers by examining histograms and percentiles of distributions of each species for counts larger than the 95th percentile of each distribution. Three sites had extremely high cover of host-plants for European Skippers relative to cover by these host plants at other sites (< 0.5 %), which gave these sites high leverage and statistical influence (DFFITTs values) on the outcome of models. Similarly, for most butterfly species, a small number of visits produced very large counts for each species. To evaluate the impact of statistical outliers or influential sites (i.e. sites with extremely high values for independent variables) on my results, I did analyses with 1) all visits for European Skippers; 2) all visits minus the one with the largest count (724 skippers in one visit); 3) all visits minus the largest count and all counts from three sites with unusually high host-plant cover (> 0.5 %). Similarly, for other butterfly species, I removed visits from analysis for each species if their counts were larger than the 95th percentile of each distribution.

I used generalized linear and non-linear mixed modeling (for both modeling types, PROC NLMIXED, SAS 9.3) (SAS 2011) to assess the effects of mowing, vegetation, and surrounding land use on butterflies and their resource plants after accounting for time effects of each visit and repeated measurements at the same sites (Bolker *et al*. 2008). Mixed modeling also enabled me to account for changes in mowing frequency and vegetation density that occurred along eight of my sites in 2009 as part of another study (Leston 2013). I used generalized linear models (PROC GENMOD, SAS 9.3) (SAS 2011) to generate starting parameter estimates of time, management, vegetation, and land use parameters for mixed models.

I included year as a time effect in all models except the null model because I predicted annual differences in weather would have effects on vegetation, and in turn butterflies. I also included Julian date (the number of days since January 1st) in models of butterfly abundance because I predicted that butterflies would increase in abundance and/or activity as temperatures increased (Taylor 1963). Julian date of butterfly surveys was strongly, positively correlated (r > 0.60) with weather data for the Winnipeg region during the 2007-2009 field seasons (mean and minimum weekly temperatures), suggesting that Julian date was a reasonable index for several different weather variables.

I used an information theoretic approach to rank the best model for predicting each dependent variable (Burnham and Anderson 2002). The best (most parsimonious) model was the model with the smallest value of Akaike's Information Criterion modified for small sample size (AIC_c) in the set of *a priori* models for each response variable (Burnham and Anderson 2002). Models whose AIC_c values differ from the best model's by two units or less ($\Delta AIC_c \leq 2$) are considered to be more or less equivalent (Burnham and Anderson 2002), in which case the highest-ranking model with the fewest parameters is considered to be the most parsimonious (Arnold 2010). I calculated model weights (ω) to express the relative likelihood that a given model best predicted each dependent variable (Burnham and Anderson 2002).

2.4.1. Effects of Resources and Urban Land on Butterflies Along Transmission Lines

I used the following models to determine if butterfly abundance and species richness along transmission lines were affected more by the amounts of urban land and grassland habitat within 100 m of transmission lines, or by the abundance of resource plants along transmission lines:

1) *year + Julian date + host-plant cover + vegetation density + forb cover* (full vegetation model)
2) *year + Julian date + host-plant cover*
3) *year + Julian date + vegetation density*
4) *year + Julian date + forb cover*
5) *year + Julian date + urban 100 m + grassland 100 m* (land use model)

6a) year + Julian date + *host-plant cover + vegetation density + forb cover + urban 100 m + grassland 100 m* (global model)

6b) year + Julian date + *vegetation density + forb cover + urban 100 m + grassland 100 m* (global model for Common Sulfurs and Silvery Blues)

7) *year + Julian date* (time effects model)

8) null model

Dependent variables for these models consisted of: 1) Common Wood-nymphs per visit; 2) Ringlets per visit; 3) native skippers of all species per visit; 4) European Skippers per visit; 5) Common Sulfurs per visit; 6) Silvery Blues per visit; and 7) Cabbage Whites per visit; 8) Monarchs per visit; 9) fritillaries of all species per visit; 10) crescents of all species per visit.

The preferred host-plants of Common Sulfurs and Silvery Blues were excluded from the global models for those species, because legume cover was strongly positively correlated with total forb cover along transmission lines ($r = 0.84$).

I used a similar set of models (1-5, 6a, 7, 8) to predict butterfly species richness per transect. However, instead of using larval host-plant cover as a predictor, I used the cumulative plant species richness from both vegetation surveys per site as a predictor of butterfly species richness in models 1 and 2.

I compared the results of models with and without outliers (i.e. visits with atypically large numbers of a given butterfly species or species-group). Where outliers affected the selection of the best-fitting model, results with and without outliers are presented.

2.4.2. Effects of Mowing and Urban Land on Butterfly Resources Along Transmission Line

To determine how mowing regime and proportions of different land uses within 100 m (urban lands, grassland habitat) affected resource plants for butterflies, I compared the following models:

1) *year + mowing frequency + mowing frequency*^{2} + *hayed* (mowing regime model)

2) *year + urban 100 m + grassland 100 m* (land use model)

3) *year + mowing frequency + mowing frequency*^{2} + *hayed + urban 100 m + grassland 100 m* (global model).

4) year (time effects model)

5) null model

Dependent variables in this suite of models consisted of 1) mean vegetation height-density (cm), 2) mean per cent total forb cover, 3) mean percent larval host-plant cover for each butterfly species or species-group, and 4) and cumulative plant species richness per site.

3. Results

3.1. Effects of Resources and Urban Land on Butterflies Along Transmission Lines

Effects of year and time of season were important in all models, with butterfly species richness and abundances of most species declining from 2007 to 2009, except for increases in Cabbage Whites, Silvery Blues, and Ringlets. Species richness and abundances of most species increased from June to August. However, Ringlets, Silvery Blues and Monarchs declined from June to August while European Skippers peaked in early July.

Butterfly species richness per visit (46 species over all visits) was lower along frequently mowed transmission lines, but was best predicted by plant species richness along transmission lines (Figure 4.1, Tables 4.1-4.3). Transmission lines with 40 and 80 species of plants (which varied from 10 – 85 species per site) were predicted to have respectively 30 % and 85 % more species of butterflies per visit than lines with only 10 species of plants (Figure 4.1, Table 4.3). The most common species were European Skippers, Common Sulfurs, Cabbage Whites, Common Wood-nymphs, crescents (Pearl, Northern Pearl), fritillaries (Great-spangled, Meadow, Silver-bordered, Variegated), Monarchs, Ringlets, and Silvery Blues (Table 4.1). Native skippers were dominated by species such as the Hobomok and Long Dash, which typically inhabit woodland edges (pp. 42-43, 47, 120-122, 132-133, 199- 200 *in* Klassen *et al*. 1999).

Numbers per visit of Cabbage Whites and butterflies with grass-eating caterpillars were best predicted by forb cover or abundance of shelter habitat (Figures 4.2-4.6, Tables 4.3-4.4). Transmission lines with 3 % and 5 % total forb cover (which varied from 0 – 7.5 %) were predicted to have 51 % and 100 % more Common Wood-nymphs per visit than lines with no forb cover (Figure 4.2). Models predicted that lines with 20 and 40-cm-tall vegetation height-density (which varied from 5 – 65 cm) had 34 % and 100 % more Common Wood-nymphs and 38 % and 112 % more Cabbage Whites per visit than lines where vegetation height-density was 5 cm (Figure 4.6). Ringlets per visit were best predicted by a quadratic function of vegetation height-density, reaching a predicted maximum number along transmission lines where dense vegetation was 20 cm high (Figure 4.3). Native skippers declined along transmission lines with greater forb cover (Figure 4.5). Depending on the model used, European Skippers were either best predicted by the global model (all visits; all visits minus the top outlier), or increased with vegetation height-density (all visits minus top outlier and visits at three sites with > 0.5 % host-plant cover).

In the global model, European Skippers declined with greater forb cover and increased with timothy and redtop cover, vegetation density, and the amount of urban land within 100 m of transmission lines (Figure 4.6, Tables 4.3-4.4).

Butterflies with legume-eating caterpillars increased along transmission lines with more forb cover (Figures 4.7-4.8, Tables 4.3-4.4). Models predicted that transmission lines with 3 % and 5 % total forb cover had, respectively, two and four times more Common Sulfurs and five and 13 times more Silvery Blues per visit than lines than along lines with no forb cover (Figures 4.7- 4.8). Silvery Blues were best predicted by the global model, where in addition to forb cover, increases of 20 % and 40 % in the amount of land within 100 m that was urban (which varied from 0 – 65 %) were associated with two and five times more Silvery Blues per visit than along lines with no urban land within 100 m (Figure 4.8). When outliers were removed from analysis, both Common Sulfurs and Silvery Blues were best predicted by forb cover alone, increasing at sites either as a linear (Silvery Blue) or quadratic function of forb cover (Common Sulfur). Common Sulfurs were predicted to peak at sites where ground cover in forbs was approximately 4 % (Table 4.4).

Larval host-plant specialists with forb-eating caterpillars generally responded negatively to urbanization, but some species also increased along transmission lines with more resources (Figures 4.9-4.11, Tables 4.3-4.4). Models predicted that increases of 20 % and 40 % in the amount of land within 100 m that was urban (which varied from 0 – 65 %) were associated with 86 % and 98 % fewer crescents, 71 % and 91 % fewer fritillaries, and 35 % and 57 % fewer Monarchs per visit than along lines with no urban land within 100 m (Figures 4.9-4.11, Tables 4.3). Crescents were best predicted by the global model, in which lines with 20 and 40-cm-tall vegetation height-density had respectively two and five times more crescents per visit than lines where density was 5 cm (Figure 4.11, Tables 4.3-4.4). Monarchs also increased as vegetation height-density increased along transmission lines, but a model with just time effects explained Monarch abundance as well as models with urban land or shelter habitat. After outliers were removed, Monarch abundance increased with forb cover along transmission lines, although the effect size was small (Table 4.4).

3.2. Effects of Mowing and Urban Land on Butterfly Resources Along Transmission Lines

Mowing regime either partially or best predicted the abundance of nectar plants, shelter habitat for butterflies, and larval host-plants for butterflies with legume-eating or grass-eating caterpillars (Figure 4.12, Tables 4.5-4.6). Hayed transmission lines on average had three times more forb cover for adult butterflies, six times more legume cover, 39 % less grass cover, and six times more timothy and redtop cover than unhayed transmission lines. Vegetation height-density decreased by an average of 9.6 cm with a change in mowing from none to once a year, but changed by much smaller amounts either with further increases in mowing frequency or with haying of cut vegetation (Figure 4.12, Tables 4.5-4.6).

In contrast, surrounding land use either partially or best predicted total plant species richness and larval host-plants for butterflies with forb-eating caterpillars (Figure 4.13, Table 4.6). Plant species along transmission lines consisted of 177 species of forbs, including 130 species of butterfly nectar-plants and larval host-plants; 47 species of grasses, rushes, and sedges; and 49 species of woody shrubs and trees (Appendices II-IV). The land use model predicted that increases of 20 % and 40 % in the amount of land within 100 m that was urban (which varied from 0 – 65 %) were associated with 20 % and 35 % fewer plant species than along lines with no urban land within 100 m (Figure 4.13, Table 4.6). Similarly, increases from 10 % in the amount of land within 100 m that was grassland (which varied from 10 – 85 %) to 20 % and 40 % grassland were associated with 13 % and 24 % fewer species of plants than along lines where 10 % of land within 100 m was grassland (Figure 4.13, Table 4.6). Cover by asters and violets also declined with increasing urban land and grassland within 100 m, whereas legume cover increased along transmission lines with more urban land within 100 m (Figure 4.13, Table 4.6).

A model with only year effects and no land use or mowing effects best explained abundance of host-plants for Cabbage Whites (i.e. mustards) and Monarchs (i.e. milkweeds and dogbanes) (Table 4.6). However, cover by these host-plants was negligible along most transmission lines in the study.

4. Discussion

4.1. Effects of Resources and Urban Land on Butterflies Along Transmission Lines

Strong effects of year and Julian date on abundance of butterflies in general are consistent with positive correlations between temperature and Julian date and between temperature and activity of insects (Taylor 1963). Individual species of butterflies also had specific flight seasons timed to coincide with availability of resource plants, which was when these butterflies were most likely to be active and detected on surveys (Klassen *et al*. 1989).

After accounting for time effects, butterfly species richness and numbers per species (except for skippers) generally increased with plant species richness and general resource plant cover (shelter habitat, total forb cover) along transmission lines. This pattern was consistent with previously documented increases in butterfly species richness with increasing plant species richness (Ries *et al*. 2001, Munguira and Thomas 1992, Valtonen *et al*. 2005), increases in butterfly numbers with shelter habitat (Kruess and Tscharntke 2002, Collinge *et al*. 2003), and increases in butterfly abundance with increasing nectar-plant cover (e.g. Munguira and Thomas 1992, Shepherd and Debinski 2005, Clark *et al*. 2007). Some butterflies in my study increased as their larval host-plants increased along transmission lines (Common Sulfurs, Silvery Blues, European Skippers, crescents), as in previous studies of butterflies and their host-plants (Leon-Cortes *et al*. 2000, Auckland *et al*. 2004, Krauss *et al*. 2003). Other butterflies in my study were not more common at sites with more host-plants, but the cover of these plants was negligible at all study sites (milkweeds for Monarchs, mustards for Cabbage Whites, violets for fritillaries). Alternatively, host-plants for butterflies with grass-eating caterpillars (Common Wood-nymphs, Ringlets, native skippers) were common enough to not be a limiting resource. However, skippers declined with increasing forb cover at sites, even though skippers use and compete with each other for patches of forbs as nectar sources (Layberry *et al*. 1998). Forb cover happened to be greatest along hayed transmission lines in this study, and haying of host-grasses with skipper eggs probably reduced the numbers of skippers that would otherwise be found along these lines (Layberry *et al*. 1998). Apart from skippers, increasing resource plants will increase butterfly species richness and abundance along most transmission lines in spite of surrounding urbanization.

Urban land surrounding transmission line sections in my study did not prevent most butterflies from colonizing urban transmission lines. Most of the common butterfly species in the study are relatively mobile (Wood and Pullin 2002, Pywell *et al*. 2004, Burke *et al*. 2011), even including some species that declined along urban transmission lines in my study (e.g. Monarchs, fritillaries) (Neve *et al*. 1996, Haddad 1999, Stasek *et al*. 2008). It is therefore unlikely that roads or other built-up lands prevented relatively mobile butterflies from settling along urban transmission lines. Even some sedentary species such as Silvery Blues (Thomas *et al*. 1992, Pywell *et al*. 2004) can disperse along roadsides, as long as appropriate host-plants are present (Dirig and Cryan 1991). Most transmission lines in my study consisted of linear grassy habitats that were hundreds of metres long between roads, and were separated from the nearest similar habitat by no more than a single road. Thus, other sedentary butterflies like skippers and crescents (Thomas *et al*. 1992, Pywell *et al*. 2004, Stasek *et al*. 2008) would only have to cross built-up lands over a small distance (< 30 m) to reach my study sites from other habitats. In another study (Bergerot *et al*. 2010), butterflies were unable to take advantage of resource-rich habitats in highly urban landscapes; however, the habitats in that study were small, isolated urban gardens, unlike the large, long habitats along transmission lines in my study. The difference between habitats in the studies explains why built-up lands will probably not prevent sedentary butterflies from settling along new butterfly habitats along urban transmission lines.

4.2. Effects of Mowing and Urban Land on Butterfly Resources Along Transmission Lines

Frequently mowed and sprayed transmission lines had equivalent or fewer resources than unmowed lines (e.g. grass cover, shelter habitat) and hayed lines (forb cover, legume cover, and redtop and timothy cover). Hayed lines had greater forb cover because leguminous forbs were deliberately introduced to such lines. Since mowing and haying do not affect all butterfly resources in the same way, mowing and spraying frequency along transmission lines should be reduced but not necessarily eliminated to increase butterfly resource plants. A patchwork of hayed and unmowed grasslands might support a broader variety of resources (shelter habitat, larval host-plants, adult nectar-plants, e.g. Dover 1996, Dennis *et al*. 2003) than using one mowing and spraying regime along transmission line butterfly habitats.

Reduction or elimination of mowing and spraying to enable resource plants for butterflies to thrive along transmission lines may produce spaces that are perceived by the public as being unmanaged and disorderly (Byrne 2005). However, frequently mowed buffer strips along the edges of these habitats and signs stating the purpose of unmowed transmission lines may increase the acceptability of unmowed areas to the public (Saskatchewan Watershed Authority 2012).

Although surrounding urban land was a stronger predictor of plant species richness than mowing and spraying, plant species declined with frequent mowing and spraying as in previous studies (Parr and Way 1988, Munguira and Thomas 1992). In these studies, roadsides that were mowed and sprayed at intermediate frequencies had more plant species than unmowed and frequently mowed and sprayed roadsides, perhaps because occasional mowing and spraying prevented the most competitive plant species from taking over roadsides (Parr and Way 1988, Munguira and Thomas 1992, Hobbs and Huenneke 1992). However, the effects of mowing, spraying, and surrounding urbanization on plant species richness were also confounded. Infrequently mowed transmission lines in my study occurred in landscapes with few nearby built-up lands, while most urban transmission lines were frequently mowed and sprayed. Therefore, land use may have predicted plant species richness more strongly than mowing and spraying because the variable for urbanization accounted for both negative effects of increasing mowing frequency and increasing amount of built-up lands on plant species richness.

The negative relationship between urbanization and plant species richness was consistent with some previous studies (McKinney 2002, 2008). Plant species richness may decline with increasing built-up lands because urbanization prevents plant species from recolonizing green spaces where those plant species have been reduced or eliminated (McKinney 2002). Alternatively, plant species richness may peak at intermediate levels of urbanization due to the presence of deliberately introduced species of plants in parks and gardens (McKinney 2008) or due to the spread of disturbance-adapted exotic plants in frequently disturbed urban environments (Reichard *et al*. 2001). The major implication for butterfly habitats along urban transmission lines is that host-plants may need to be actively reintroduced to attract and benefit certain butterflies, because surrounding urban lands may prevent these host-plants from naturally recolonizing transmission line habitats.

5. Conclusion

Changes in mowing and spraying and reintroductions of butterfly resource plants can improve habitat for butterflies. Transmission lines are already managed elsewhere as habitats for endangered butterflies like the Karner Blue (*Lycaeides melissa samuelis*) (Smallidge *et al*. 1996, Lowell and Lounsbury 2002, Forrester *et al*. 2005). In Manitoba, restoring tall-grass prairies on transmission corridors might instead be restored and managed as critically endangered tall-grass prairie (Samson and Knopf 1994, Koper *et al*. 2010) to create habitat for declining prairie butterflies (Shuey *et al*. 1987, Orwig 1990, Schlict *et al*. 2009), threatened prairie plants like the Western Silvery Aster (*Symphyotrichium sericeum*) (Robson 2010), and important pollinators such as bees, which are also declining in many ecosystems (Kearns *et al*. 1998). In addition, the lack of isolation between most transmission line sections in this study suggests that new butterfly habitats along transmission lines will contribute to networks of existing wildlife protected areas (Young 2000, Dearborn and Kark 2010).

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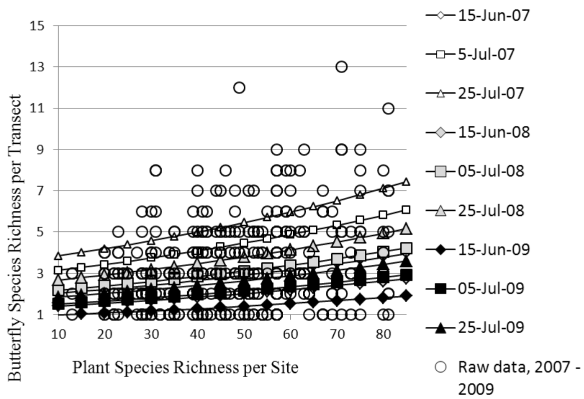

Figure 4.1. Changes in raw and predicted values for butterfly species richness per visit (*n* = 367) (*y* axis) with changes in year, time of season, and plant species richness along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009, from the highest-ranking model (plant species richness) for predicting butterfly species richness.

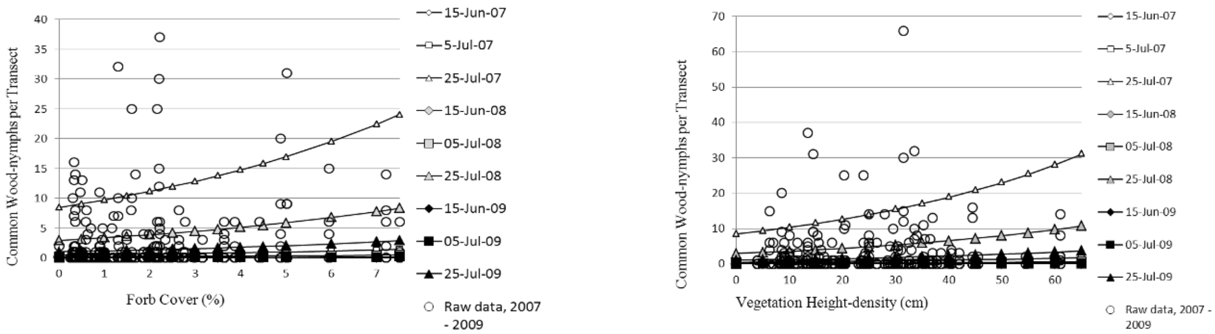

Figure 4.2. Changes in raw and predicted numbers of Common Wood-nymphs per visit (*n* = 367) (*y* axis) with changes in year, time of season, and either forb cover or vegetation density along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009, from the two highest-ranking models (forb cover, vegetation density) for predicting Common Wood-nymph abundance.

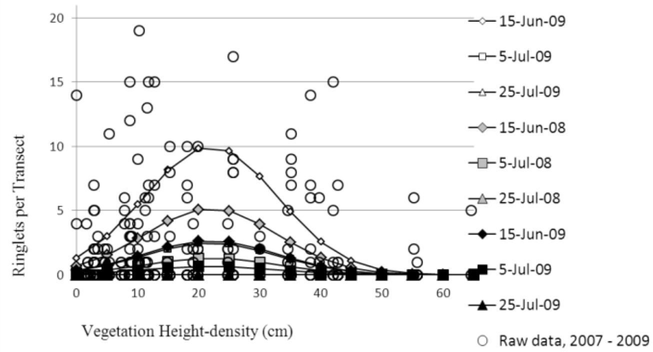

Figure 4.3. Changes in raw and predicted numbers of Ringlets per visit (*n* = 367) (*y* axis) with changes in year, time of season, and vegetation density (*x* axis) along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009, from the highest-ranking model (vegetation height-density) for predicting Ringlet abundance.

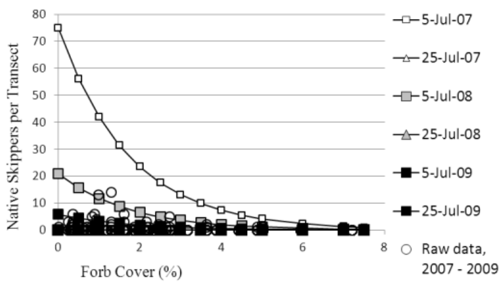

Figure 4.4. Changes in raw and predicted numbers of native skippers per visit (*n* = 367) (*y* axis) with year, time of season, and changes in forb cover (*x* axis) along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009, from the highest-ranking model (forb cover) for predicting native skipper abundance.

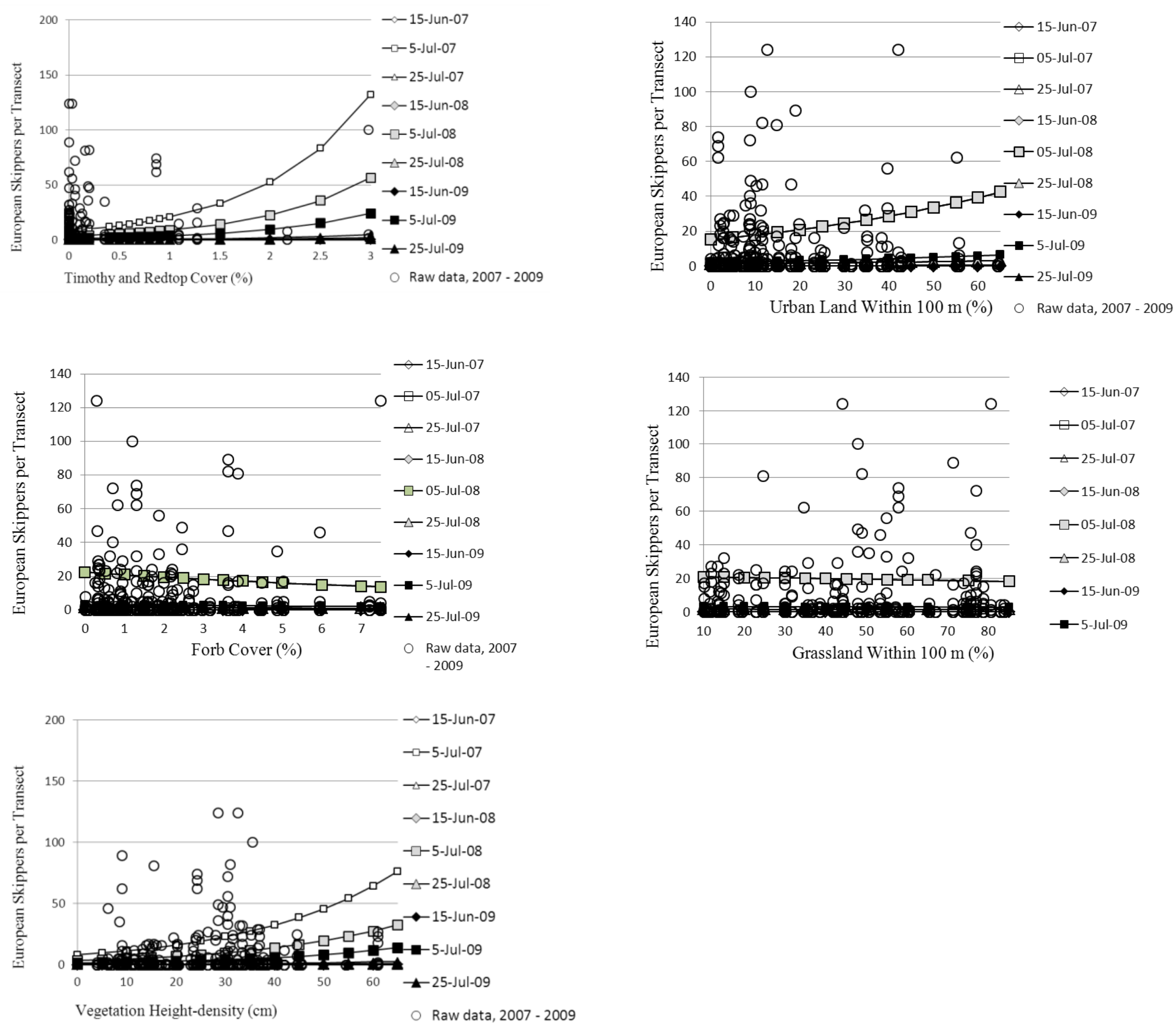

Figure 4.5. Changes in raw and predicted numbers of European Skippers per visit (*n* = 366) (*y* axis) with changes in year, time of season, vegetation, and land use variables from the global model (*x* axis) for predicting European Skippers along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009.

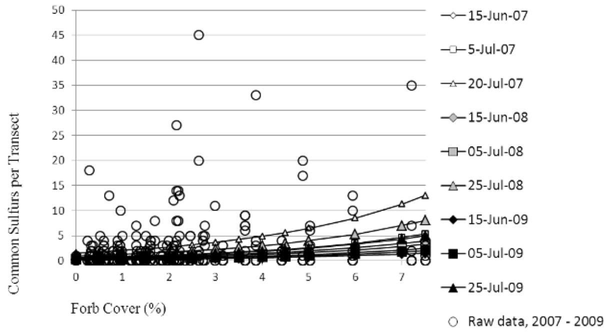

Figure 4.6. Changes in raw and predicted numbers of Common Sulfurs per visit (n = 367) (y axis) with changes in year, time of season, and total forb cover (x axis) along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009, from the highest-ranking model (forb cover) for predicting Common Sulfur abundance.

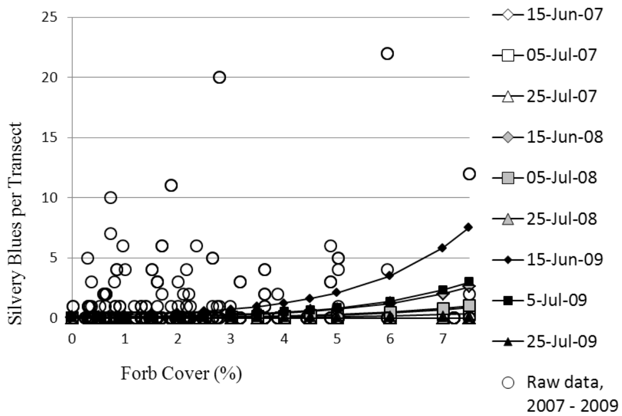

Figure 4.7. Changes in raw and predicted numbers of Silvery Blues per visit (n = 367) (y axis) with changes in year, time of season, and total forb cover (x axis) along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009, from the highest-ranking model (forb cover) for predicting Silvery Blue abundance.

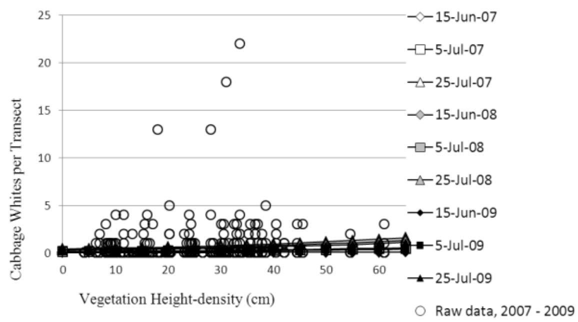

Figure 4.8. Changes in raw and predicted numbers of Cabbage Whites per visit (*n* = 367) (*y* axis) with changes in year, time of season, and vegetation density (*x* axis) along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009, from the highest-ranking model (vegetation height-density) for predicting Cabbage White abundance.

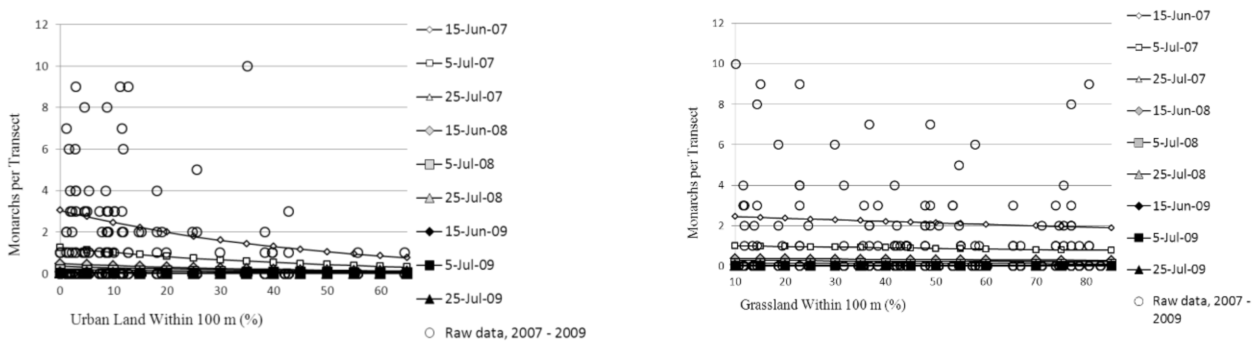

Figure 4.9. Changes in raw and predicted numbers of Monarchs per visit (n = 367) (y axis) with changes in year, time of season, and land use from the landscape model for predicting Monarchs along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009.

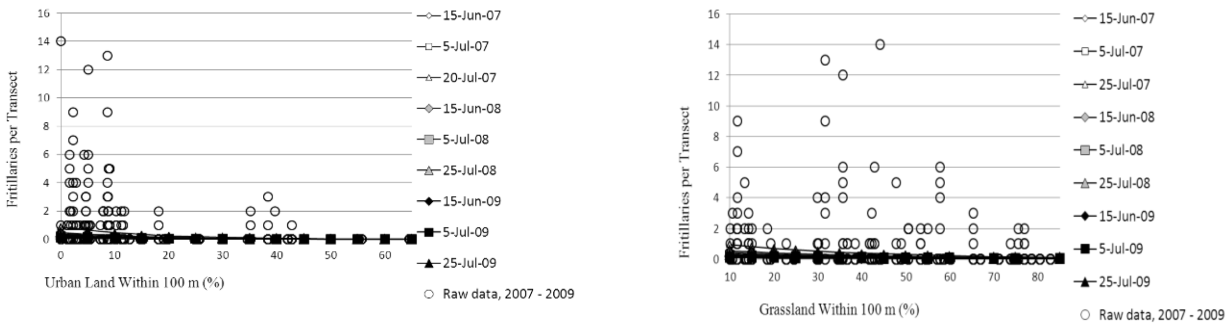

Figure 4.10. Changes in raw and predicted numbers of fritillaries per visit (*n* = 367) (*y* axis) with changes in year, time of season, and land use from the landscape model for predicting fritillaries along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009.

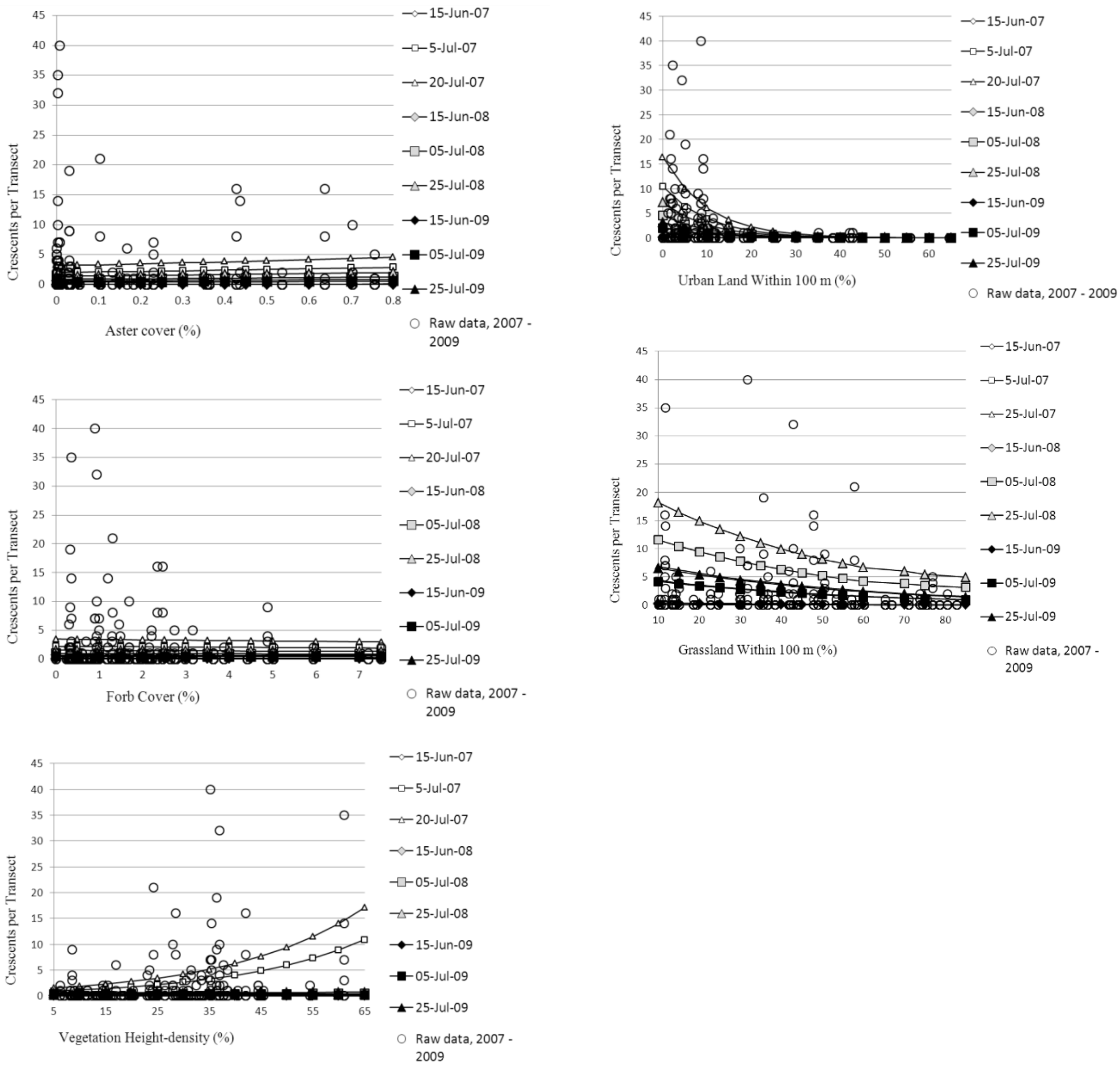

Figure 4.11. Changes in raw and predicted numbers of crescents per visit (n = 367) (y axis) with changes in year, time of season, vegetation, and land use variables from the global model (x axis) for predicting European Skippers along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009.

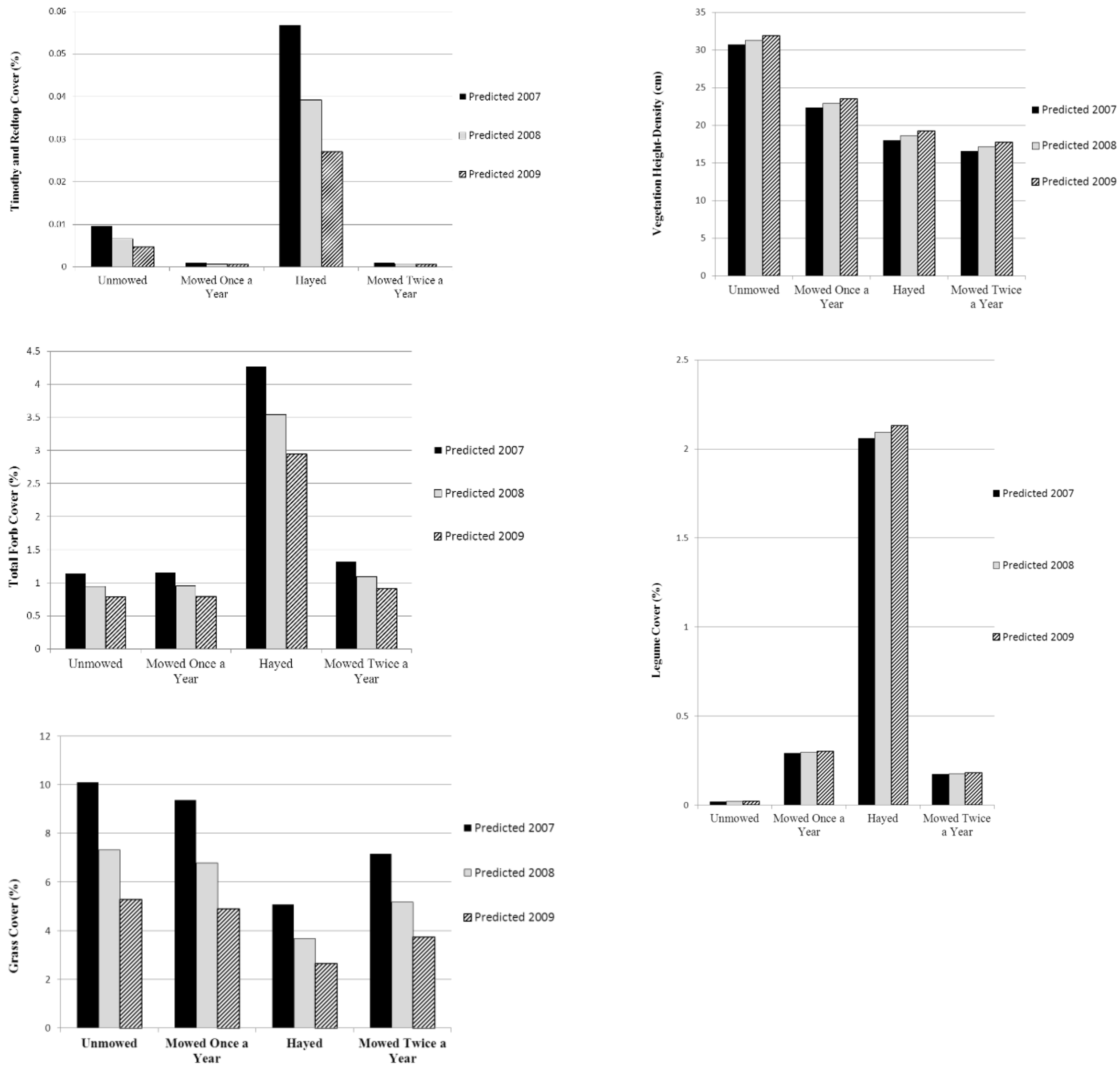

Figure 4.12. Differences in vegetation structure under different mowing regimes along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009. Columns in each bar graph = predicted mean of each type of vegetation structure in different years under each type of mowing regime in the study, based on effect sizes of mowing frequency and haying (yes or no) in the management model.

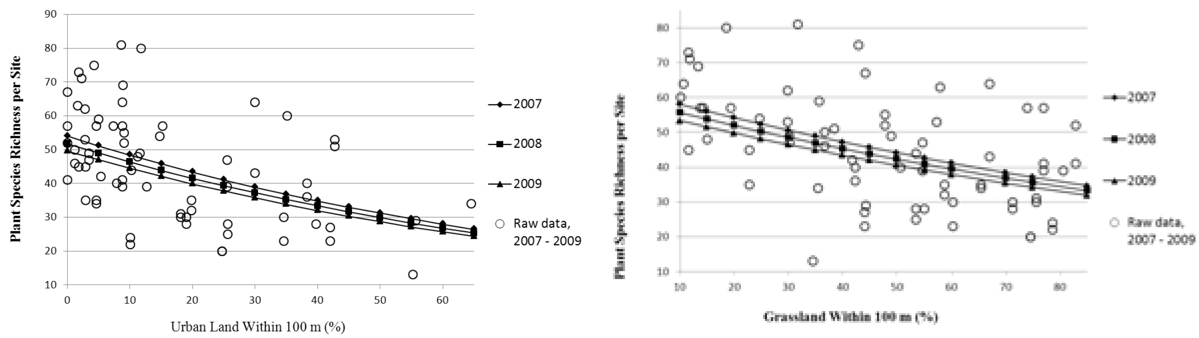

Figure 4.13. Changes in raw and predicted plant species richness with changes in year and land use variables from the land use model predicting plant species richnessalong 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009.

Table 4.1. Butterflies observed along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007-2009. Host-plant specialists (*) in this table are based on Clark *et al*. (2007), and refer to species with larvae that feed on ≤ 10 plant species. Number in brackets after each name indicates number of individuals for that species that were observed over all surveys at 48 sites.

Family		Species Over Three Years
Danaeidae		*Danaus plexippus** (422)
Hesperidae	Hesperinae	*Ancycloxipha numitor* * (2), *Euphyes vestris** (36), *Hesperia comma* *(1), *Poanes hobomok* *(77), *Polites corus** (1), *Polites mystic** (27), *Polites themistocles** (6), *Thymelicus lineola* *(4638)
	Pyrginae	*Epargyreus clarus*(1), *Erynnis* spp.*(5)
Lycaenidae	Lycaeninae	*Lycaena helloides** (4), *Lycaena hyllus** (3), *Lycaenus* spp.* (1)
	Melitinae	*Feniseca tarquinius** (17)
	Polyommatinae	*Everes comyntas* (7), *Glaucopsyche lygdanus* (401)
Nymphalidae	Argynninae	*Boloria bellona** (12), *Boloria selene** (10), *Boloria* spp. *(51), *Euptoieta claudiae* (17), *Speyeria cybele* *(163)
	Limenitinae	*Limenitis archippus* *(43), *Limenitis arthemis* (11)
	Melitaeinae	*Chlosyne nycteis** (2), *Phyciodes morpheus/tharos** (749)
	Nymphalinae	*Junonia coenia* (2), *Nymphalis antiope* (39), *Nymphalis milberti** (60), *Vanessa atalanta** (32), *Vanessa cardui* (1)
Papilionidae		*Papilio glaucus* (18), *Papilio machaon** (1), *Papilio polyxenes* (10)
Pieridae	Anthocharinae	*Euchloe ausonides* *(2)
	Coliadinae	*Colias eurytheme* (45), *Colias interior** (6), *Colias philodice* (882)
	Pierinae	*Pieris protodice* (1), *Pieris rapae* (265)
Satyridae	Elymninae	*Satyrodes eurydice* *(158)
	Satyrinae	*Cercyonis pegala* *(1117), *Coenonympha tullia* *(1114), *Megisto cymela* *(1), *Satyrium acadica** (9)
Unknown		42
Total		10512

Table 4.2. Summary statistics for butterflies (mean, standard error (SE), minimum, maximum) per visit along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009, separated by management regime along the lines.

	Mowed twice a year			Mowed once a year, unhayed			Hayed once a year			Unmowed		
Butterfly numbers per visit per site	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
Butterfly species richness	2.68	0.15	0-8	3.69	0.23	0-9	3.53	0.30	1 - 12	3.24	0.18	0-13
Cabbage White	0.49	0.14	0-13	0.81	0.28	0-22	0.50	0.31	0-18	0.42	0.10	0-13
Common Sulfur	2.41	0.64	0-45	1.33	0.26	0-14	3.43	0.76	0-33	1.06	0.21	0-18
Common Wood-nymph	1.49	0.41	0-37	2.06	0.59	0-32	2.28	0.69	0-31	1.92	0.50	0-66
Crescent spp.	0.17	0.07	0-6	1.34	0.44	0-21	0.62	0.19	0-9	2.42	0.49	0-40
European Skipper	3.58	1.08	0-89	12.28	3.13	0-211	8.77	2.95	0-124	10.95	4.70	0-746
Fritillary spp.	0.08	0.04	0-3	0.62	0.20	0-14	0.25	0.07	0-2	0.82	0.16	0-13
Monarch	0.34	0.09	0-5	0.84	0.23	0-10	0.65	0.21	0-9	0.49	0.10	0-9
Native skipper spp.	0.15	0.06	0-5	0.79	0.24	0-14	0.12	0.05	0-2	0.30	0.07	0-6
Ringlet	2.53	0.57	0-43	2.06	0.38	0-15	1.87	0.51	0-19	2.23	0.74	0-76
Silvery Blue	0.97	0.30	0-20	0.24	0.07	0-3	2.93	0.69	0-22	0.54	0.12	0-10

Table 4.3. Best landscape and vegetation predictors of butterfly species richness and abundances of common butterflies and species-groups along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009 (*n* = 367 visits). Response variables were modeled with negative binomial distributions except for butterfly species richness (Poisson).

Response Variable	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Butterfly species richness	Plant species richness	0.85	Plant species richness: 0.01 (0.00 -- 0.01)
Cabbage White	Vegetation density	0.45	Vegetation density: 0.02 (-0.00 -- 0.04)
Common Sulfur	Forb cover	0.55	Forb cover: 0.28 (0.28 -- 0.28)
	Global	0.32	Forb cover: 0.26 (0.26 -- 0.26) Vegetation density: -0.01 (-0.03 -- 0.01) Urban: 0.01 (-0.00 -- 0.03) Grassland: 0.00 (-0.01 -- 0.01)
Common Wood-nymph	Forb cover	0.29	Forb cover: 0.14 (-0.03 -- 0.31)
	Full vegetation model	0.27	Grass cover: 0.02 (-0.00 -- 0.05) Forb cover: 0.21 (0.02 -- 0.39) Vegetation density: 0.02 (-0.00 -- 0.05)
	Vegetation density	0.2	Vegetation density: 0.02 (-0.01 -- 0.04)
Crescents	Global	0.76	Aster cover: 0.45 (-1.29 -- 2.19) Forb cover: -0.02 (-0.28 -- 0.24) Vegetation density: 0.04 (0.01 -- 0.07) Urban: -0.09 (-0.12 -- -0.05) Grassland: -0.02 (-0.03 -- 0.00)
European Skipper	Global	0.85	Timothy cover: 0.97 (0.97 -- 0.97) Forb cover: -0.07 (-0.07 -- -0.07) Vegetation density: 0.03 (0.01 -- 0.05) Urban: 0.02 (0.00 -- 0.04) Grassland: 0.00 (-0.01 -- 0.01)
Fritillaries	Land use	0.90	Urban: -0.06 (-0.10 -- -0.03) Grassland: -0.03 (-0.05 -- -0.01)
Monarch	Land use	0.30	Urban: -0.02 (-0.03 -- -0.00) Grassland: -0.00 (-0.01 -- 0.01)
	Vegetation density	0.36	Vegetation density: 0.02 (0.00 -- 0.04)
	Time effects only	0.15	n/a
Native Skippers	Forb cover	0.84	Forb cover: -0.58 (-0.90 -- -0.26)
Ringlet	Vegetation density	0.99	Vegetation density: 0.18 (0.05 -- 0.31) Vegetation density^2: -0.004 (-0.01 -- -0.00)
Silvery Blue	Global	0.73	Forb cover: 0.52 (0.26 -- 0.77) Vegetation density: 0.02 (-0.01 -- 0.06) Urban: 0.04 (0.01 -- 0.07) Grassland: 0.00 (-0.02 -- 0.03)

Table 4.4. Best landscape and vegetation predictors of butterfly species richness and abundances of common butterflies and species-groups along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 - 2009, after removing statistical outliers (unusually large counts per species per visit) and statistically influential points (sites with extremely large values for predictor variables). Response variables were modeled with negative binomial distributions. European Skipper$_{366}$ = only largest count removed; European Skipper$_{338}$ = largest count + all sites with host plant cover > 0.5 % removed.

Response Variable	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Cabbage White$_{363}$	Vegetation density	0.49	Vegetation density: 0.02 (-0.00 -- 0.04)
Common Sulfur$_{350}$	Forb cover	0.55	Forb cover: 0.70 (0.28 -- 1.12) Forb cover^2: -0.07 (-0.13 -- -0.02)
Common Wood-nymph$_{350}$	Forb cover	0.35	Forb cover: 0.11 (-0.03 -- 0.25)
Crescents$_{337}$	Global	0.98	Aster cover: -0.34 (-0.34 -- -0.34) Forb cover: 0.13 (0.13 -- 0.13) Vegetation density: 0.04 (0.02 -- 0.06) Urban: -0.07 (-0.09 -- -0.05) Grassland: -0.02 (-0.03 -- -0.01)
European Skipper$_{366}$	Global	0.77	Timothy cover: 0.97 (0.97 -- 0.97) Forb cover: -0.07 (-0.07 -- -0.07) Vegetation density: 0.03 (0.01 -- 0.05) Urban: 0.02 (0.00 -- 0.04) Grassland: 0.00 (-0.01 -- 0.01)
European Skipper$_{338}$	Vegetation density	0.64	Vegetation density: 0.03 (0.01 -- 0.05)
Fritillaries$_{349}$	Land use	0.90	Urban: -0.03 (-0.06 -- -0.01) Grassland: -0.02 (-0.03 -- -0.00)
Monarch$_{351}$	Forb cover	0.85	Forb cover: 0.06 (0.06 -- 0.06)
Native Skippers$_{359}$	Forb cover	0.64	Forb cover: -0.46 (-0.72 -- -0.21)
Ringlet$_{350}$	Vegetation density	0.99	Vegetation density: 0.14 (--) Vegetation density^2: -0.003 (-0.003 -- -0.003)
	Forb cover	0.28	Forb cover: 0.32 (0.09 -- 0.56)
Silvery Blue$_{359}$	Global	0.41	Forb cover: 0.39 (0.15 -- 0.62) Vegetation density: 0.00 (-0.03 -- 0.03) Urban: 0.04 (0.01 -- 0.06) Grassland: 0.00 (-0.02 -- 0.02)

Table 4.5. Summary statistics (mean, standard error of the mean (SE), minimum, maximum) for landscape-level and local vegetation metrics along 48 transmission line sites within 200 km of Winnipeg, Manitoba, 2007 - 2009, separated by management regime along the lines.

	Mowed twice a year			Mowed once a year			Hayed once a year			Unmowed		
Landscape or local vegetation metrics	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
Landscape metrics												
% Urban land 100 m	29.82	4.13	2.79 - 64.54	10.59	3.10	0 - 35.10	9.22	1.83	0 - 14.79	12.66	2.28	0 - 42.05
% Total grassland 100 m	49.22	3.68	22.79 - 75.53	33.82	8.74	10.08 - 76.97	50.19	8.59	19.36 - 80.56	49.95	3.95	11.59 - 82.89
Local Vegetation metrics												
Forb cover (%)	1.94	0.40	0-7.21	1.28	0.23	0-2.73	4.61	0.73	0 - 7.50	1.25	0.15	0 - 3.16
Grass cover (%)	6.32	0.80	1.82-12.14	10.59	2.25	0-27.65	4.98	0.45	0 - 6.77	8.35	0.82	0 - 19.56
Shelter habitat (cm)	16.18	1.96	7 - 40.50	21.67	3.45	4 - 37	18.11	3.86	6.25 - 32.50	31.09	2.06	8.25 - 61.00
Plant species richness	35.32	2.61	13 - 53	59.20	3.46	39 - 80	48.57	2.92	39 – 57	45.19	3.05	20 - 81
Larval host plants:												
for Blues, Sulfurs (%)	0.57	0.18	0 - 2.94	0.39	0.09	0.12 - 0.93	3.38	0.68	0 - 5.24	0.23	0.07	0 - 1.46
for Cabbage White (%)	0.00	0.00	0.00	0.00	0.00	0 - 0.00	0.00	0.00	0.00	0.00	0.00	0.00
for rescents (%)	0.05	0.02	0 - 0.22	0.06	0.03	0 - 0.36	0.17	0.08	0 - 0.54	0.11	0.04	0 - 0.76
for European Skipper (%)	0.02	0.01	0 - 0.19	0.14	0.10	0 - 0.87	0.21	0.09	0 - 0.71	0.41	0.16	0 - 3.64
for fritillaries (%)	0.00	0.00	0 - 0.03	0.00	0.00	0 - 0.05	0.00	0.00	0 - 0.03	0.00	0.00	0 - 0.05
for Monarch (%)	0.04	0.02	0 - 0.33	0.01	0.01	0 - 0.08	0.01	0.01	0 - 0.06	0.00	0.00	0 - 0.03
for native skippers (%)	6.32	0.80	0 - 12.14	10.59	2.25	0 - 27.65	4.98	0.45	0 - 6.77	8.35	0.82	0 - 19.56
for Ringlets, Wood-nymphs (%)	6.32	0.80	1.82 - 12.14	10.59	2.25	2.38 - 27.65	4.98	0.45	3.12 - 6.77	8.35	0.82	2.37 - 19.56

Table 4.6. Best landscape and management predictors of total plant species richness, shelter habitat, and cover of adult nectar-plants and larval host-plants for butterflies along 48 transmission lines within 200 km of Winnipeg, Manitoba, 2007 – 2009 (*n* = 68 survey-years). Response variables were modeled with negative binomial distributions (plant species richness) or lognormal distributions (everything else).

Dependent Variable	Best Model	Model Weight	Model Parameter Effect Size (95 % Confidence Interval)
Aster cover	Full management	0.30	Mowing frequency: 3.34 (-0.69 -- 7.37) Mowing^2: -1.58 (-3.62 -- 0.46) Hayed (yes/no): 2.06 (-0.84 -- 4.96)
	Landscape	0.23	Urban: -0.06 (-0.11 -- -0.01) Grassland: -0.02 (-0.06 -- -0.02)
	Time effects only	0.11	n/a
Legume cover	Global	0.99	Mowing frequency: 5.93 (2.61 -- 9.24) Mowing^2: -2.52 (-4.76 -- -0.28) Hayed (yes/no): 1.16 (1.12 -- 1.20) Urban: 0.02 (-0.01 -- 0.05) Grassland: 0.05 (-0.33 -- 0.43)
Milkweed cover	Time effects only	0.82	n/a
Mustard cover	Time effects only	0.99	n/a
Plant species richness	Landscape	0.90	Urban: -0.01 (-0.015 -- -0.005) Grassland: -0.01 (-0.010 -- -0.004)
Timothy and redtop cover	Full management	0.50	Mowing frequency: -3.52 (-8.17 -- 1.13) Mowing^2: 1.22 (-1.13 -- 3.57) Hayed (yes/no): 4.08 (0.81 -- 7.35)
Forb cover	Haying	0.82	Hayed (yes/no): 1.28 (0.52 -- 2.04)
Grass cover	Full management	0.84	Mowing frequency: 0.03 (-0.64 -- 0.68) Mowing^2: -0.10 (-0.34 -- 0.32) Hayed (yes/no): -0.61 (-1.07 -- -0.15)
Vegetation density	Mowing frequency	0.80	Mowing frequency: - 7.19 (-9.66 -- - 4.72)
Violet cover	Landscape	0.91	Urban: -0.00 (0.00 -- 0.00) Grassland: -0.02 (-0.03 -- -0.01)

Chapter 5. Ecological and Economic Arguments for Converting Urban Transmission Lines into Prairie Wildlife Habitats

Abstract

Reductions in mowing and spraying to control weeds along urban transmission lines and other rights-of-way would have many economic and ecological benefits. Ecological benefits include fewer greenhouse gas emissions from mowing and spraying equipment, increased sequestration of atmospheric carbon, reduced pollution from herbicides, and less destruction of birds' nests and resource plants for butterflies. Transmission lines could also be restored and managed as endangered, low-growing ecosystems like tall-grass prairies, which could enable wildlife to use these lines as corridors between other urban wildlife habitats. Prairie restoration can be expensive in the short term, but can be funded by savings in management costs from reducing or eliminating mowing and spraying elsewhere along transmission lines. Long-term economic benefits include lower costs of labour, fossil fuels and chemicals used during mowing and spraying. These costs might decline further after prairie establishment because restored prairies might be invaded by fewer weeds. Although weed control will continue to be necessary, mowing and spraying reductions and habitat restoration can be focused along wider, longer transmission lines. This strategy will maximize ecological benefits and minimize social concerns because there is more space on such lines for wildlife habitat and frequently managed buffer strips.

Keywords*: tall-grass prairie, restoration, transmission line, rights-of-way, weeds, costs, benefits*

Introduction

Urban lands continue to expand and encroach upon wildlife habitats worldwide, threatening many species at risk (McDonald *et al*. 2008). Although some organisms adapt to, and may benefit from urban lands as habitat, species richness generally declines as urbanization increases (McKinney 2002). This pattern has been observed in butterflies (e.g. Kitahara *et al*. 2000, Clark *et al*. 2007), other arthropods (Bolger *et al*. 2000), and birds (Chace and Walsh 2006). Urban lands may have greater plant diversity due to weedy or deliberately introduced species, but plant diversity usually declines in highly urbanized landscapes (McKinney 2008). These declines are due to a variety of mechanisms that operate at a range of spatial scales, from vegetation management within wildlife habitat patches to habitat fragmentation, edge effects, exotic organisms, and physical isolation of wildlife habitat patches by other land uses at larger spatial scales (McKinney 2002). To maintain biodiversity in expanding cities, especially for ecosystems that are poorly protected in existing reserves, it will become increasingly important to restore underused urban lands as wildlife habitats that complement existing wildlife reserves (Young 2000).

Underused grassy urban spaces such as transmission lines for distributing electricity are spaces where mowing and spraying could be reduced or eliminated to restore endangered low-growing habitats like tall-grass prairies for wildlife. Urban spaces such as these are frequently mowed and sprayed to control weeds and create tidy open areas free of litter; however, these efforts to acheive human aesthetic objectives make such spaces less habitable for many species of wildlife (McKinney 2002). Elsewhere, transmission lines have been managed as as low-growing ecosystems for endangered species (Baker 1999). I suggest endangered ecosystems such as tall-grass prairies, which provide habitat for many declining and threatened species, could also benefit from habitat restoration along transmission lines and other rights-of-way.

Ecological Benefits of Reducing Mowing and Restoring Prairie along Urban Transmission Lines

Reducing or eliminating mowing and spraying would improve habitat for wildlife along urban transmission lines. Heavily managed urban lawns can have high primary production and benefit a small number of species such as weedy plants and smaller arthropods (Falk 1976) and infrequently mowed roadsides may support more plant and butterfly species than completely unmowed roadsides (Parr and Way 1988, Munguira and Thomas 1992). However, frequent mowing prevents taller plant species from being established along urban transmission lines (e.g. Fenner and Palmer 1988, Schippers and Joenje 2002, Hovd and Skogen 2005), removes shelter habitat for butterflies and other arthropods (Kruess and Tscharntke 2002), and destroys nesting habitat and nests of prairie birds (Kershner and Bollinger 1996). Frequent herbicidal spraying reduces species of forbs along roadsides (Parr and Way 1988), which results in fewer species of butterflies (e.g. Munguira and Thomas 1992, Valtonen *et al*. 2005, Öckinger *et al*. 2009).

Transmission lines provide an ideal opportunity to increase the extent of highly endangered low-growing ecosystems such as tall-grass prairies. North American prairie grasslands are among the most critically reduced and the least protected of ecosystems worldwide (Hoekstra *et al*. 2005). In Manitoba, for example, over 99 % of the tall-grass prairies that occurred in this province 200 years ago have been replaced by urban and agricultural lands (Samson and Knopf 1994). The extensive anthropogenic development across this region means that there are now few opportunities for protecting remnant tall-grass prairie in Manitoba; however, space along transmission lines and other rights-of-way could provide opportunities for restoration. Many of Winnipeg's transmission line sections between roads are at least 30 m wide and 500 or more m long, and there are thousands of hectares of other rights-of-way along roadsides in Manitoba (Morgan *et al*. 1995). If these rights-of-way were managed as tall-grass prairie habitats, some transmission line sections between roads would be at least as large as Winnipeg's largest existing remnant tall-grass prairie, the 16-hectare Living Prairie Museum (City Naturalist 2007; Figure 5.1). Some of these rights-of-way have similar numbers of plant and animal species to those in urban remnant prairies (Appendices I-III). Therefore, reducing mowing and spraying and restoring prairie along transmission lines could enable these lines to complement tall-grass prairies in existing protected areas (Young 2000).

Besides greatly increasing habitat area, restoring tall-grass prairie along transmission lines would increase connectivity of urban habitats for wildlife. Most wildlife habitat remnants in many cities are small and isolated from each other by roads and other built-up lands (McDonald *et al*. 2008); however, transmission line corridors run for kilometres with sections between roads being hundreds of metres long (Morgan *et al*. 1995). In theory, transmission lines that lie close to adjacent wildlife habitats may serve as conduits for wildlife moving between those habitats (Figure 5.2), enabling individuals of a given species to move from source populations of that species to declining populations in other habitats (Levins 1969). Prairie organisms are likely to use transmission lines with restored prairies to move between remnant prairies, because roadsides with restored prairies have more species and numbers of butterflies that remain for longer periods of time than unrestored roadsides (Ries *et al*. 2001).

Reductions in mowing and spraying during prairie restoration along transmission lines would also lower ecological costs to humans and species outside of transmission lines. Grassy urban spaces that are dominated by turf grasses have to be frequently mowed, sprayed with herbicides to control weeds, irrigated and fertilized (Byrne 2005). Excess nutrients from fertilizers may enter streams as runoff and increase water pollution (Byrne 2005), while herbicides may have adverse effects on non-target organisms (Rohr and Crumrine 2005). There are smog and noise pollution from combustion of gasoline by mowing and spraying equipment, as well as greenhouse gas contributions to global warming from the production and consumption of gasoline, herbicides, and fertilizers (Byrne 2005).

Restoring native prairie plants along transmission lines may reduce ecological costs of mowing and spraying further by reducing the need for weed control. Native prairie plants can subsist on soils with fewer nutrients and less watering than many exotic turf grasses, due to the efficient C4 photosynthetic pathway and mycorrhizal fungi of some prairie grasses and forbs (Hetrick *et al*. 1987). Restored prairies with high species richness may also be more resistant to reinvasion by exotic plants (e.g. Tilman 1997, Kennedy *et al*. 2002), although exotic plants may invade species-rich restored prairie on nutrient-rich soils (Stohlgren *et al*. 2002). Restoration activities that lower soil productivity may favour native prairie plants over exotic weeds (Morgan 1994, Stohlgren *et al*. 2002). Ultimately, by reducing the need for and frequency of weed control, large-scale native prairie restoration along transmission lines would reduce total consumption of gasoline and other chemicals and emissions of air and water pollution.

Planting native prairie grasses like Switch-grass (*Panicum virgatum*) along transmission lines could provide ecological services such as a source of biofuels (Jensen *et al*. 2007). Switch-grass can be harvested without tilling and releasing soil carbon back to the atmosphere as greenhouse gases (Jensen *et al*. 2007), sequesters more carbon underground, and requires fewer inputs of fertilizers or pesticides than other biofuel crops during establishment (McLaughlin and Walsh 1998, Zan *et al*. 2001). Finally, harvested and unharvested stands of Switch-grass provide habitat for many different species of prairie birds (Roth *et al*. 2005), and harvesting can be done in late summer or fall to avoid destroying nests (Kershner and Bollinger 1996).

Economic Benefits of Reducing Mowing and Restoring Prairie along Urban Transmission Lines

Prairie restoration can be expensive in the short-term due to costs of high-quality prairie seed (Egan 1994, Harrington 1994), which is often in short supply and must normally be harvested in large quantities (Morgan and Collicut 1994). Larger prairie restorations use more seed than smaller restorations and incur expenses including rented or purchased machinery and contractors, which smaller prairie restorations may not require (Morgan *et al*. 1995). However, as mechanization and the scale of harvesting and processing seeds increase, efficiency of seed collection increases while production costs decrease (Morgan and Collicut 1994). Furthermore, as more prairie areas are restored, they may become seed sources that reduce or eliminate the need to purchase additional seed from suppliers (Morgan *et al*. 1995). Thus, native prairie seed costs per unit area may decline for larger prairie restorations.

Other short-term prairie restoration costs apart from seed are variable and may be reduced in several ways. Activity and material costs of restoring prairie are dependent on site-specific environmental conditions and on the species of prairie plants that are well-adapted for those conditions (Morgan *et al*. 1995). Besides collecting and processing prairie seed, typical restoration stages include propagating individual plants from seeds or sprigs, removing exotic vegetation from restoration sites, planting cover crops, and reintroducing native plants (Morgan *et al*. 1995). The best options for executing each of these restoration stages depend on site-specific conditions and species that are to be restored (Morgan *et al*. 1995). Activity costs of prairie restoration can also be reduced by employing volunteer labour such as school groups to reintroduce seeds or individual prairie plants at restored prairies (Morgan *et al*. 1995).

Short-term costs of prairie restoration may be offset by reductions in long-term management costs along transmission lines after prairie restoration, or at least after reductions in mowing and spraying. For example, Manitoba Hydro paid $135,000 in 2009 for 360 ha of transmission lines in Winnipeg to be mowed 1-10 times in that year (Wayne Ortiz, *personal comm*.). Based on the Manitoba Hydro contract in 2009, if 50 % of that area was left unmowed for one year, immediate savings in management costs (up to $77,500) could be used to fund prairie restorations along other sections of Winnipeg's transmission lines. Restored prairies still have to be subsequently managed by haying or controlled burns to prevent exotic weeds from proliferating (Morgan *et al*. 1995) or prevent some species from outcompeting others (Parr and Way 1988, Hobbs and Huenneke 1992). However, haying or burning would be less frequent and costly current mowing and spraying (Morgan *et al*. 1995).

If a prairie restoration with many plant species is still considered too costly to be offset by lower long-term management costs, a biofuel crop of Switch-grass could be reseeded relatively cheaply along Winnipeg's transmission lines for $80 Cdn. /acre (Iowa State University Extension 2008). A patchwork of harvested and fallow Switch-grass stands along transmission lines could still provide habitat for different prairie birds, while possibly serving as an alternative energy source (Murray and Best 2003, Roth *et al*. 2005). As with prairie restorations, Switch-grass establishment could be funded by immediate management savings from leaving other areas completely unmanaged. Given relative costs, a larger proportion of urban transmission lines and other rights-of-way could be managed as Switch-grass habitats than prairies. Once planted, Switch-grass may be harvested for ten or so years before it needs to be reseeded (Jensen *et al*. 2007), and reseeding may not be necessary after ten years of good management (Fike *et al*. 2006).

Selecting Locations for Reducing Mowing and Restoring Prairies along Urban Transmission Lines

Despite the benefits of unmowed and restored prairie areas, restoration costs and public concerns about unmanaged urban vegetation will determine where these areas occur along transmission lines. To maximize ecological and economic benefits relative to the cost of prairie restoration, and to alleviate concerns about unmowed, unsprayed vegetation, there are several reasons why prairie restoration efforts should focus on relatively long, wide transmission line sections.

One reason to focus restoration activities on relatively wide transmission lines is to minimize public concerns about weeds proliferating near buildings after reductions in mowing and spraying. Tall-grass prairies are not as frequently mowed or sprayed as turf grasses, and might be perceived as "weedy" in public perception. In Winnipeg, municipal and provincial agencies are obligated to control weeds on their properties by Manitoba's Noxious Weeds Act (Noxious Weeds Act, 2012). Elsewhere in North America, there are laws and strong social pressures to maintain tidy, weed-free grassy spaces in cities, especially near residences and buildings (Byrne 2005). The aesthetic behind these laws and social pressures is associated with higher social status and values like establishment of order and human control of nature (Byrne 2005). However, if mowing and spraying are reduced or prairie is restored along larger transmission lines, then there is more room to maintain an obvious buffer strip of managed grass along the edge of the restored or unmowed area. Interpretive signs describing the purpose of restored prairies and unmowed areas may then increase the acceptability of restorations to the public (Figure 5.3) (Saskatchewan Watershed Authority 2012).

Focusing prairie restoration along wider transmission lines may also enable the use of controlled burns to manage restored prairies (City Naturalist 2007). Controlled burns may not be publically acceptable in some residential areas (Morgan *et al*. 1995), but have been used to manage remnant prairies in Winnipeg under an existing Controlled Burn Policy, which can be used to minimize negative aspects of controlled burns (City Naturalist 2007). Burns that are conducted at different times of year benefit different species of plants (Howe 1994), while a patchwork of burned and unburned areas maintains insect species richness in restored prairies (Panzer and Schwartz 2000). A patchwork of small burned patches within wider transmission lines might be publically acceptable, because wider lines provide more space for unburned areas to serve as buffer zones between burns and adjacent housing (Figure 5.3).

Reducing mowing and restoring prairies along larger sections of transmission lines would also create larger habitat areas for wildlife that prefers taller grass or prairie vegetation. Larger restored prairie patches can theoretically support larger populations of individual species of prairie plants, which makes those populations less vulnerable to inbreeding or local extinction in the near future (Drobney 1994, Harrington 1994). Larger grassland patches support larger numbers of arthropods (Thomas and Harrison 1992, Hill 1996, Bolger *et al*. 2000) and restored prairies along wider, longer transmission lines would have fewer nearby urban or wooded lands to discourage use by prairie birds (Chace and Walsh 2006).

Longer transmission lines are as also more likely to function as effective wildlife corridors. During habitat fragmentation by urbanization, physical distance between remnant habitats increases as former habitat is converted to urban lands (Fahrig 2003). Smaller populations of prairie plants and arthropods within smaller, more isolated grassland patches might be more vulnerable to local extinction (Drobney 1994, Harrington 1994, Bolger *et al*. 2000), because they are less likely to be reached and recolonized by individuals from other grassland patches (Levins 1969). However, unmowed wildlife habitats or restored prairies along transmission lines may extend for kilometres and be separated from similar habitats along other line sections by as little as a single-lane road (Morgan *et al*. 1995). Tall-grass prairie could be restored along line sections that are adjacent to each other to minimize the distance that emigrants have to travel between restored habitat patches.

In special cases, prairies might be restored as isolated patches along transmission lines to insulate species at risk from environmental factors (e.g. an insect pest or competitor) that occur in other habitats (Levins 1969). For example in Manitoba, the Small White Lady-slipper Orchid (*Cypripedium candidum*) is threatened by hybridization with its more common relative, the Small Yellow Lady-slipper Orchid (*C. parviflorum*) (Worley *et al*. 2009). Therefore, *C. candidum* could be reintroduced along transmission line sections that previously lacked *C. parviflorum*, with adjacent sections of line continuing to be frequently mowed and sprayed to discourage incursion by *C. parviflorum*.

Managing Unmowed and Restored Prairie Patches along Urban Transmission Lines

Unmowed vegetation along urban transmission lines still needs to be sprayed to control weeds if there are public complaints. For example in Winnipeg, Manitoba Hydro and the City of Winnipeg are obligated by Section 3(1) of the Noxious Weeds Act of Manitoba to control noxious weeds as often as necessary to prevent their spread, or face fines (Noxious Weeds Act 2012). However, Section 3(1) does not specify the frequency or extent of spraying to be conducted, only that it is "as often as may be necessary to prevent the growth, ripening and scattering of weeds or weed seeds" (Noxious Weeds Act 2012). To that end, concentrations of weeds might be spot-sprayed with backpack sprayers instead of broadcast-spraying entire transmission lines with a boom sprayer.

If transmission lines are restored as prairie habitats, they must be periodically hayed or burned to maintain high plant species richness and prevent weeds from reinvading (Parr and Way 1988). Either haying or burning removes decomposing litter, which prevents weedy exotic plants from benefiting from the nutrients that are returned to soils by decomposition (Schippers and Joenje 2002, Hovd and Skogen 2005). While weedy, rapidly growing exotic plants thrive in nutrient-rich soils, impoverishing soils of nutrients may favour native prairie plants (Morgan *et al*. 1995). After prairie restoration, management by haying or burning can be less frequent than typical urban mowing and spraying rates (Morgan *et al*. 1995). As with mowing, haying should be delayed until after the summer to avoid destroying nests and nestlings of ground-nesting prairie birds (Kershner and Bollinger 1996). Controlled burns may be used at different times of the year to favour different species of prairie plants (Howe 1994).

To support more species, transmission line sections with prairie may be managed as a patchwork of burned, unburned, hayed, and unhayed areas rather than be burned or hayed entirely. Reasons for this are that prairie bird species use a variety of vegetation heights for nesting (Murray and Best 2003, Roth *et al* 2005), and prairie butterflies exhibit species-specific responses to controlled burns (Panzer and Schwartz 2000). In other studies, heterogeneous agricultural landscapes with many different habitats support more species of plants and arthropods (Benton *et al*. 2003, Gabriel *et al*. 2010), and a patchwork of burned and grazed areas supports more species of prairie birds (Fuhlendorf 2006). Given that both burns and haying remove vegetation from restored prairies, burning or haying an entire restored prairie patch could wipe out all individuals of a species in that patch. There are concerns that many prairie butterfly species are declining and disappearing from fire-managed prairie reserves (Shepherd and Debinski 2005).

Conclusion

Prairie restoration, and reducing mowing and spraying along transmission lines, would not only have many ecological and economic benefits, but could also be used in combination to address challenges like the need for urban weed control and the expense of prairie restoration. Reducing mowing and spraying along larger transmission lines may reduce public concerns about weed proliferation and increase management savings that can be directed towards prairie restoration elsewhere. In turn, restoring prairie along larger transmission lines will increase the persistence and connectivity of populations of prairie organisms, and may reduce the frequency of and need for weed control, further reducing management costs. A patchwork of unmowed grasslands and restored prairies may also support greater biodiversity. Some successful examples of restored urban prairies and management reduction along transmission lines could increase public interest in managing other underused urban lands besides transmission lines for wildlife.

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Figure 5.1.Restored tall-grass prairie at the XS49 / YH33 - VH1 / VH2 transmission line along Taylor Street Winnipeg, Manitoba (a) and remnant prairie at the Living Prairie Museum, Winnipeg, Manitoba (b). So far, only a portion (1 ha) of this otherwise frequently mowed and sprayed section has been restored. This transmission line section (8 ha) is comparable in size to the Living Prairie Musuem (16 ha) and offers more space that could be restored as tall-grass prairie.

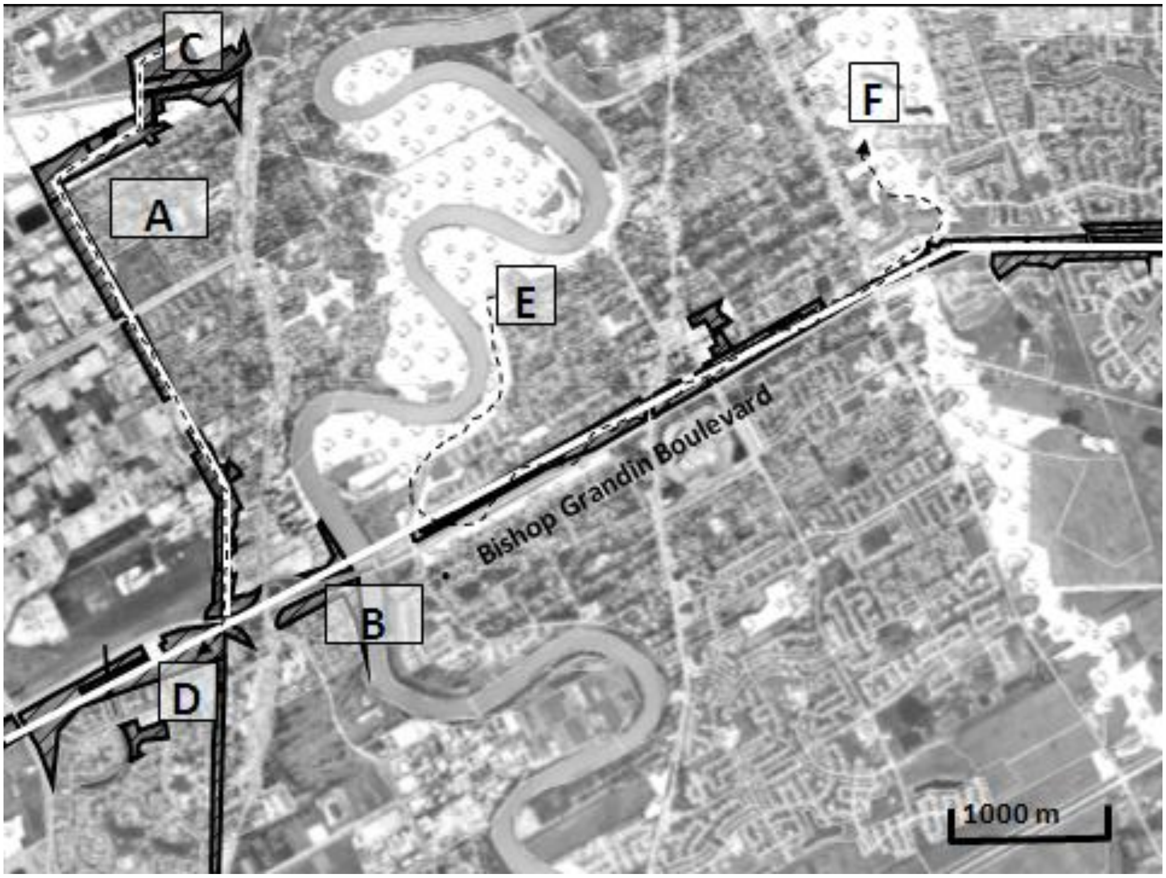

Figure 5.2. The XS49 / YH33 and VH1 / VH2 (A) and VH1 / VH2 and YV5 / XV39 (B) transmission lines (white) along Bishop Grandin Boulevard, Winnipeg potentially enable prairie organisms to move from point C to point D and woodland-dwelling organisms to move from point E to point F along the surrounding rights-of-way (black stripes). Wildlife may be more likely to use these transmission lines as corridors if tall-grass prairie was restored along these lines. Digital overhead: Manitoba Conservation (2006). Digitized polygons: ArcGIS 8.3 (ESRI 2002).

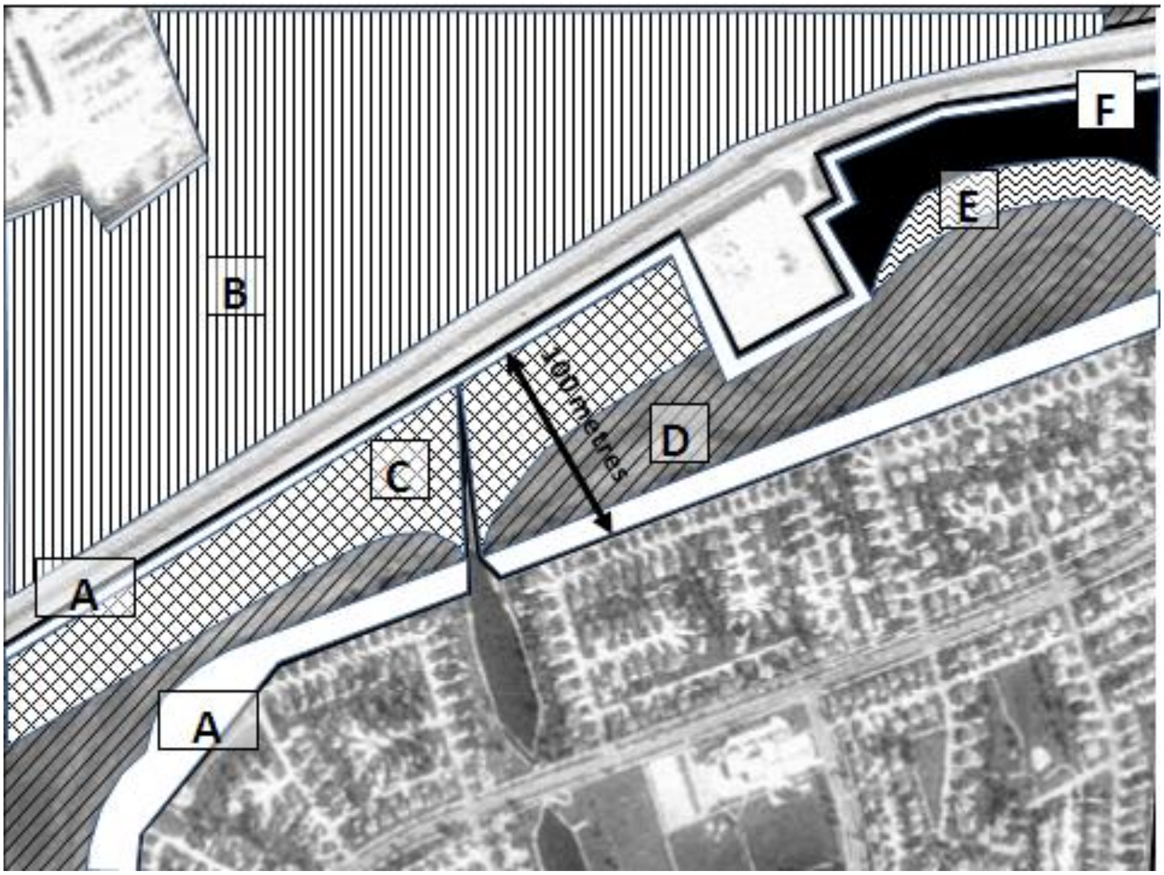

Figure 5.3. Hypothetical patchwork of different grassland habitats along a wider urban transmission line right-of-way in Winnipeg: frequently mowed and sprayed grass strips adjacent to houses and infrastructure (A); large grassy expanses that are seeded with a biofuel crop of switchgrass (B); unmowed grass further away from buildings, only spot-sprayed with herbicides when necessary (C); restored prairie managed by infrequent haying (D); unhayed restored prairie (E), a portion of which is managed with controlled burns once every few years (F). Unmowed grass and controlled burn areas have been deliberately located as far away from houses as possible along this transmission line to alleviate public concerns about weeds and fires. Digital overhead: Manitoba Conservation (2006). Digitized polygons: ArcGIS 8.3 (ESRI 2002).

Chapter 6. Conclusions

When I began this study, I was interested in the idea that transmission lines might be managed as alternative habitats where tall-grass prairie could be restored, just because there is so little of that ecosystem left in Manitoba or Canada. Some transmission line sections, if restored as tall-grass prairie would be larger than most tall-grass prairie tracts in southern Manitoba. However, many of the animals and plants that I observed along transmission lines are not limited to tall-grass prairie and use several different ecosystems as habitat. The effects of mowing and spraying on plants and animals, for example lower plant species richness along frequently mowed and sprayed transmission lines, were similar to those effects of mowing and spraying in previous studies in other habitats similar to transmission lines, e.g. roadsides. For these reasons, the scope of my study extends beyond transmission lines and tall-grass prairie, and could be applied to restoring and managing for other underprotected ecosystems within manmade, underused grassy urban spaces in general.

Since undertaking this thesis, I have prepared a strategy for how and where to manage lines to benefit the most species, and how to restore tall-grass prairie or other critically endangered ecosystems economically while reducing concerns about weed proliferation if mowing and spraying occurs less frequently. Because surrounding urbanization was strongly negatively associated with plant species richness (Chapter 2), densities of prairie birds (Chapters 2, 3, 5), larval host-plants for some species of butterflies (Chapter 4), and food available to prairie birds as represented by arthropod biomass in pitfall traps (Chapter 2), it is unlikely that these aforementioned organisms will increase along urban transmission lines, even if mowing and spraying are reduced. Given that butterfly species richness and some individual species of butterflies along transmission lines depended on a site's plant species richness or larval host-plant abundance, many species of plants have to be reintroduced to urban transmission lines before they will be used by butterflies. Therefore, urban wildlife managers should focus habitat management along transmission lines with less nearby built-up lands, which will make it likelier that such lines are settled by plants and prairie birds that decline with increasing urban land. Transmission lines that are managed for prairie birds should also have as little wooded land nearby as well.

In contrast to plant species richness and prairie birds, some butterflies and other arthropods were best predicted by and declined with frequent mowing and spraying (Chapter 2) and increased with resource plants along transmission lines (Chapter 4). Transmission lines in urbanized landscapes may be managed for butterflies or other arthropods, as long as mowing and spraying are reduced and appropriate resource plants are available. Alternatively, mowing and spraying can be reduced along lines that are selected to be managed as prairie bird habitats, to increase arthropods along those lines. Except for Vesper Sparrows, increasing arthropod prey for birds may not attract most prairie birds to use those habitats; however, increasing arthropods as food for birds could still be a management objective along lines that do attract many birds (Chapter 3).

Some butterfly species and other arthropods reached their highest numbers along infrequently mowed transmission lines (Chapters 2, 4) or responded to vegetation features that were associated with infrequently hayed transmission lines. Many infrequently mowed transmission lines in this study had comparable plant, butterfly, carabid beetle and prairie bird species richness to remnant prairies that were also surveyed in 2007 - 2009 (Table 6.2). Some insects showed opposing responses to mowing extent or vegetation density. Grasshopper counts increased with mowing extent and declined with vegetation density, while lepidopterans increased with a short-term halt in mowing (Chapter 2) or increasing vegetation density (Chapter 3) or declined with increasing mowing frequency (Chapters 2). Thus, mowing and spraying should not be eliminated entirely from new wildlife habitats along transmission lines, and a mixture of mowed and unmowed habitats should support a greater variety of species. Some transmission lines serve as important reservoirs of biodiversity, and that some mowing and spraying is still compatible with high species richness and resources for wildlife along transmission lines.

Restoring prairie and reducing mowing and spraying along less-urban transmission lines will also reduce public concerns about proliferation of weeds after reducing or eliminating mowing and spraying (Chapter 5). There will be fewer home-owners or businesses that require maintenance of orderly green spaces near their properties near the transmission lines. Having fewer buildings near transmission lines will also make it likely that restored prairie along these lines can be managed with controlled burns, because the risk of property damage to homes from runaway fires is lower (Chapter 5).

Although I did not find strong relationships between amount of grassland habitat and species richness or numbers of plants and animals in this study, some prairie birds increased as potential grassland habitat increased (Chapters 2, 3). Thus, longer, wider transmission lines should be preferred as sites to manage for prairie birds (Table 6.1). Longer, wider transmission lines have other ecological and economic benefits as sites for mowing and spraying reductions and prairie restoration (Chapter 5). Reducing mowing and spraying over larger areas will reduce management costs of transmission lines, which may free up funds for restoration. Prairie restorations cost less per unit area for larger-scale restorations. Larger unmowed wildlife habitats and prairie restoration areas are likelier to support larger populations of butterflies, other arthropods or reintroduced plants that are less likely to be extirpated. Longer transmission lines that support wildlife habitat or restored prairie are more likely to pass near to other wildlife habitats, enabling the use of transmission lines as wildlife corridors. If there still are public concerns about weeds or controlled burns along unmowed lines, wider transmission lines still enable large wildlife habitats to be surrounded by buffer zones where weeds can be frequently controlled without burning.

Ultimately, why put effort into reconfiguring transmission lines and other underused grassy urban spaces as tall-grass prairie or other endangered ecosystems? Not simply because we can, but because in a world of expanding human populations and shrinking wildlife habitats outside of cities, we need to reconsider the purposes of various urban landscapes and features, to see if they can serve an additional purpose: to replace the habitats that are lost to expanding cities. We need to stop thinking of nature as something in reserves far from cities. We need to realize that humans and their cities don't only have to be part of the problem of ecosystem and species endangerment. Humans and their cities are a part of nature as well, and should be part of the solution to restore endangered habitats and species.

Table 6.1. Urban transmission lines that could be restored and managed as tall-grass prairie or other habitats for wildlife. Most sites are currently frequently mowed and sprayed, but there are some large unmanaged grasslands (*) that are dominated by exotic plants as well. Higher-priority sites have more grassland habitat within 100-1000 m of transmission lines and tend to have less non-habitat (urban or wooded lands) within 400-1000 m.

Site Name	Line Name	Northing	Easting	Nonhabitat 400	Nonhabitat 1000	Grassland 100	Grassland 400	Grassland 1000
Bishop Grandin I	VH1 / VH2; YV5 / XV39	5526583	200463	33.77	50.86	74.55	65.05	43.04
Plessis Station	SV24; TV1; TV2	5532007	210898	20.68	37.72	54.64	54.59	31.66
Wilkes*	Old Portage line	5529683	190209	16.43	14.83	76.97	53.21	22.72
Sugar Factory	XS49 / YH33; VH1 / VH2	5527635	201082	57.52	64.23	75.53	42.48	30.81
Dogpark	XS49 / YH33; VH1 / VH2	5530810	201092	58.44	76.30	82.89	41.56	23.70
Southside*	VJ50; VT63	5522707	210251	22.35	20.62	78.64	39.24	30.44
Mailhot*	VJ50; VT63	5526183	209465	20.91	24.14	41.81	34.08	17.13
Bishop Grandin J	VH1 / VH2; YV5 / XV39	5526583	200463	56.06	50.55	53.42	33.12	24.69
McGillivray	XS49 / YH33; VH1 / VH2	5528961	200524	68.48	88.05	11.94	31.52	11.94
Shorehill	VH1 / VH2; YV5 / XV39	5526583	200463	62.48	75.41	58.67	22.82	22.85
Bishop Grandin D	VH1 / VH2; YV5 / XV39	5529008	207240	78.49	74.94	42.26	21.51	20.09
Dakota	VH1 / VH2; YV5 / XV39	5526583	200463	78.02	86.58	44.01	20.86	12.95
Bradley	adjacent to Regent Park	5532007	210898	72.38	66.21	35.46	19.10	10.78
Leila	south and west of Leila and McPhillips	5541883	202083	77.71	75.38	44.30	18.46	7.67
St. Mary*	VH1 / VH2; YV5 / XV39	5528036	204026	83.26	90.14	60.22	15.86	7.68
Whyte Ridge	YX48	5526848	197065	82.93	77.90	38.48	14.19	7.73
Bud	VH1 / VH2; YV5 / XV39	5528036	204026	85.47	80.39	34.52	12.73	10.91
Lagimodière*	SV24; TV1; TV2	5528741	210475	1.35	3.81	36.69	8.42	6.74
Bishop Grandin E*	VH1 / VH2; YV5 / XV39	5528036	204026	83.43	89.62	54.97	8.38	7.87
Scurfield	YX48	5526848	197065	55.80	46.50	57.22	7.86	8.49

Table 6.2. Biodiversity along 52 transmission lines, three remnant prairies (italics), and one restored prairie (at Manitoba Hydro's former 830 Taylor Street headquarters) (italics) in Winnipeg, Manitoba, 2007 - 2009. "-" = no carabid surveys at a site.

	Species Richness Over All Visits					Species Richness Over All Visits			
Site Name	Plants	Butterflies	Carabids	Birds	Site Name	Plants	Butterflies	Carabids	Birds
206 East	45	8	15	3	Marchand A	73	9	-	0
206 South	49	13	14	4	Marchand B	61	13	-	0
206 West	73	11	11	5	McGillivray	30	11	5	3
207 South	39	9	3	4	MC18	67	10	4	2
Anola	81	14	5	2	*Oak Hammock*	42	11	-	4
Bishop Grandin D	40	7	6	2	Oakbank	49	8	15	4
Bishop Grandin E	28	8	3	2	Pleasant	75	14	9	2
Bishop Grandin I	20	7	5	3	Plessis Station	47	8	5	4
Bishop Grandin J	28	8	9	3	Portage A	57	10	14	4
Bradley	34	8	4	2	Portage B	44	11	9	6
Brady	57	6	5	4	Portage D	40	14	11	5
Bud	13	6	2	1	*Prime Meridian Trail*	78	10	4	3
Cooks creek	62	12	13	3	*Rotary Prairie*	44	8	-	5
Dakota	27	8	3	2	Sapton	69	11	10	1
Dogpark	52	5	7	3	Scurfield	53	7	12	4
Eastdale	59	13	5	2	Shorehill	35	7	2	2
Fairview	64	7	6	1	Southside	24	6	14	3
Garven B	57	18	11	1	Spruce	63	12	11	5
Garven D	74	9	5	1	St. Mary	30	6	5	2
Garven F	55	12	9	3	Stoneridge	71	16	8	3
Gros Isle	60	12	10	2	Sugar Factory	31	13	5	4
Heatherdale	54	10	8	4	W2W	80	11	10	4
Lagimodière	50	8	13	4	W3E	57	8	14	3
Leila	29	6	10	3	W5E	48	11	6	3
Living Prairie Museum	36	8	-	3	Whyte Ridge	51	9	9	3
Mailhiot	42	8	4	2	Wilkes	41	10	6	5
Manitoba Hydro	53	8	9	3	Willowdale	57	9	6	6
Maple Grove	64	6	12	2	Zora	35	7	12	3

APPENDIX I. Carabid beetle, butterfly, grasshopper, and prairie bird species that occurred along transmission lines in Winnipeg, Manitoba (2007-2009).

Carabid beetles: *Acupalpus carus;Agonum cupreum, A. cupripenne, A. errans, A. placidum, A. trigeminum; Amara avida, A. cupreolata, A. farcta, A. impuncticollis / littoralis?, A. musculis, A. obesa, A. quenseli, A. scitula, A. torrida; Anisodactylus harrissi, A. merula, A. pitychrous, A. sanctaecrucis; Badister neopulchellus, B. obtusus, B. transversus; Bembidion* spp.*; Blethisa multipunctata; Brachinus cyanochroaticus, Bradycellus lecontei; Calleida punctate; Calosoma calidum; Carabus granulatus, C. meander, C. serratus; Chlaenius alternatus, C. impunctifrons, C. lithophilus, C. pensylvanicus, C. purpuricollis, C. sericeus, C. tomentosus, C. tricolor; Cicindela punctulata nebraskana, C. scutellaris; Cymindis* spp.*; Dicaelus politus, D. sculptilis; Diplocheila obtusa, D. oregona, D. striatopunctata, D. undulata; Elaphrus fuliginosus; Harpalus affinis, H. opacipennis; H. pensylvanica, H. seclusus; Microlestes brevilobus; Notiophilus aquaticus; Oxypselaphus puncticeps; Poecilus corvus, P. lucublandus; Pterostichus adstrictus, P. femoralis, P. leconteianus, P. luctuosus, P. melanarius; Selenophorus planipennis; Sphaeroderus lecontei; Stenolophus comma, S. conjunctus; Syntomus americanus; Synuchus impunctatus; Tachys anceps.*

Butterflies: *Ancycloxipha numitor; Boloria bellona, B. selene*; *Cercyonis pegala*; *Chlosyne nycteis*; *Coenonympha tullia; Colias eurytheme, C. interior, C. philodice*; *Danaus plexippus; Epargyreus clarus*; *Erynnis* spp.; *Euchloe ausonides; Euphyes vestris; Euptoieta claudiae*; *Everes comyntas; Feniseca tarquinius; Glaucopsyche lygdanus; Hesperia comma; Junonia coenia*; *Limenitis archippus, L. arthemis; Lycaena helloides, L. hyllus*; *Megisto cymela; Nymphalis antiope, N. milberti*; *Papilio glaucus, P. machaon, P. polyxenes; Phyciodes morpheus, Ph. tharos; Pieris protodice, P. rapae; Poanes hobomok; Polites corus, Po. mystic, Po. themistocles; Satyrium acadica; Satyrodes eurydice; Speyeria cybele; Thymelicus lineola; Vanessa atalanta, V. cardui*.

Grasshoppers: *Aeropodellus clavatus; Ageneotettix deorum; Arphia conspersa, A. pseudonietana; Bruneria brunnea; Camnula pellucida; Chloealtis conspersa; Chorthippus curtipennis; Chortophaga viridifasciata; Dissosteira carolina; Encoptolophus costalis; Melanoplus bivittatus, M. borealis, M. confusus, M. dawsoni, M. femurrubrum, M. sanguinipes; Metator pardalinus; Neopodismopsis abdominalis; Nomotettix cristatus; Orphulella pelidna; Pardalophora haldemanni; Spharagemon collare; Stethoprymna gracile; Tetrix arenosa, T. ornata, T. subulata; Tettigidea lateralis.*

Prairie birds: Bobolink (*Dolichonyx oryzivorus*), Clay-coloured Sparrow (*Spizella pallida*), Killdeer (*Charadrius vociferus*), Le Conte’s Sparrow (*Ammodramus lecontei*), Savannah Sparrow (*Passerculus sandwichensis*), Sedge Wren (*Cistothorus platensis*), Vesper Sparrow (*Pöoecetes gramineus*), Western Meadowlark (*Sturnella neglecta*).

APPENDIX II. Nectar-plants and larval host plants that grew in survey plots at the study sites in 2007-2009. * = nectar-plants that serve as larval host-plants for unlisted butterfly species and species-groups in this appendix (Klassen *et al*. 1999).

Nectar-plants (mostly forbs): *Achillea millefolium*, Amorpha fruticosa, Antennaria aprica *, Aquilegia canadensis*, Artemisia* * (*biennis, campestris, frigida, ludoviciana*), *Campanula rotundifolia* *****, *Castilleja coccinea *, Centaurea maculosa *, Cicuta maculata *, Cirsium (arvense, flodmannii)*, Corylus cornuta, Doellingeria umbellata *, Epilobium angustifolium, Erigeron (caespitosus, canadense, glabellus, lonchophyllus, philadelphicus, strigosus), Fragia virginica *, Gaillardia aristata, Helianthus (annuus, laetiflorus, maximillianii, petiolaris) *, Hieracium umbellatum*, *Humulus lupulus *, Liatris ligulostylis, Linaria dalmatica *, Lithospermum canescens, Lysimachia ciliata *, Lythrum salicaria, Mentha arvensis *, Monarda fistulosa, Pedicularis canadensis *, Penstemon nitidus *, Petasites sagittatus, Polygonum (amphibious, convolvulus, lapathiflorum), Potentilla (anserina, arguta), Ratibida columnifera, Rudbeckia (hirta, laciniata), Rumex acetosella *, Senecio aureus *, Shepherdia argentea, Sium suave *, Solidago (canadense, spathulata, graminifolia, mollis, rigida), Sonchus arvense, Spiraea alba, Taraxacum officinale, Urtica dioica *, Zizia (aptera, aurea) *, Zygadenus elegans.*

Cabbage White host-plants: *Brassica* (*kaber, napus*), *Capsella bursapastoris, Thlaspi arvense.*

Common Sulfur (+ Silvery Blue) host-plants: *Astragalus* (*agrestis, canadensis, missouriensis, striatus*), *Glycirhyza lepidota, Lathyrus pratensis, Lotus corniculatus, Medicago (lupulina, sativa), Melilotus (alba, officinale), Oxytropis splendens, Trifolium (album, hybridum, pratense), Vicia (cracca, sativa).*

Common Wood-nymph (+ Ringlet, + native skipper) host-plants: *Agropyron repens*, *Agrostis stolonifera, Andropogon gerardii, Carex* spp., *Echinochloa crusgalli, Festuca ovina*, *Koeleria macrantha, Phleum alpinum, Poa pratensis, Schyzachirium scoparium, Stipa* (*spartea, viridula*).

Crescent host-plants: *Symphyotrichum (ciliolatum, ericoides, laeve, lanceolatum, nova-angliae, praealtum).*

European Skipper host-plants: *Agrostis stolonifera, Phleum alpinum.*

Fritillary host-plants: *Plantago major, Viola (adunca, nephrophylla, nuttallii, petadifida, rugulosa).*

Monarch host-plants: *Apocynum* (*androsaemniflorum, cannabinum*), *Asclepias* (*incarnata, speciosa, syriaca, verticillata*).

Other larval host-plants for other butterfly and skipper species (shrubs and trees): *Amelanchier alnifolia, Arctostaphylos uva-ursi, Chamaedaphne calyculata, Cornus stolonifera, Potentilla fruticosa, Ribes* spp., *Rosa* spp., *Acer negundo, Crataegus* spp., *Fraxinus pennsylvanicus, Pinus banksiana, Populus (balsamifera,tremuloides), Prunus* spp., *Salix* spp., *Ulmus* spp.

APPENDIX III. Forb species that were encountered along transmission lines in Winnipeg, Manitoba (2007-2009).

Achillea millefolium; Agastache foeniculum; Agoseris glauca; Alisma plantago-aquatica, A. triviale; Allium stellatum; Androsace septentrionalis; Anemone canadensis, A. cylindrica, A. multifida, A. patens, A. quinquefolia; Antennaria aprica; Apocynum androsaemnifolium, A. cannabinum; Aquilegia canadensis; Arabis divaricarpa; Artemisia biennis, A. campestris, A. frigida, A. ludoviciana; Asclepias incarnata, A. speciosa, A. syriaca, A. verticillata; Astragalus agrestis, A. canadensis, A. missouriensis, A. striatus; Atriplex nuttalli; Brassica kaber, B. napus; Caltha palustris; Campanula rotundifolia; Capsella bursapastoris; Cardamine pensylvanica; Cardaria draba; Castilleja coccinea; Centaurea maculosa; Cerastium arvense; Chenopodium album; Cicuta maculata; Cirsium arvense, C. flodmannii; Comandra pallida; Convolvulus spp.*; Dalea candida, D. purpurea; Descurania pinnata, D. sophia; Diosporum trachycarpum; Doellingeria umbellata; Epilobium angustifolium; Equisetum arvense, E. hyemale; Erigeron caespitosus, E. canadense, E. glabellus, E. lonchophyllus, E. philadelphicus, E. strigosus; Fragia virginica; Gaillardia aristata; Galeopsis tetrahit; Galium boreale, G. triflorum; Gentiana andrewsii, G. macounii; Geum aleppicum, G. triflorum; Glycirhyza lepidota; Grindelia squarrosa; Hedeoma hispidum; Helenium autumnale; Helianthus annuis, H. laetiflorus, H. maximillianii, H. petiolaris; Heterotheca villosa; Heuchera richardsonii; Hieracium umbellatum; Humulus lupulus; Iris versicolor; Lactuca pulchella, L. scariola; Lathyrus pratensis; Lepidium densiflorum; Leucanthemum vulgare; Liatris ligulostylis; Lilium philadelphicum; Linaria dalmatica; Lithospermum canescens; Lobelia kalmii; Lotus corniculatus; Lycopus americanus; Lysimachia ciliate; Lythrum salicaria; Matricaria chamomilla, M. matricarioides; Medicago falcata, M. lupulina, M. sativa; Melilotus alba, M. officinalis; Mentha arvensis; Mirabilis hirsuta; Monarda fistulosa; Neslia paniculata; Oenothera biennis; Oxytropis splendens; Packera paupercula; Parthenocissus quinquefolia; Pedicularis canadensis; Penstemon nitidus; Petasites sagittatus; Physalis minima; Physostegia parviflora; Plantago major; Plantanthera dilatata; Polygonum amphibious, P. convolvulus; Potentilla anserina, P. arguta, P. norvegica; Psoralea agrophylla; Ranunculus abortivus, R. acris, R. cymbalaria, R. macounii; Raphanus sativus; Ratibida columnifera; Rhus radicans; Rudbeckia hirta, R. laciniata; Rumex acetosella; Scutellaria galericulata; Senecio aureus; Silene* spp.*; Sisyrhynchium montanensis; Sium suave; Smilacina stellata; Smilax herbacea; Solanum dulcamara; Solidago canadense, S. decumbens/spathulata?, S. graminifolia, S. missouriense, S. mollis, S. rigida; Sonchus arvense; Spiraea alba; Stachys palustris; Symphyotrichium ciliolatum, S. ericoides, S. laeve, S. lanceolatum, S. nova-angliae, S. praealtum; Taraxacum officinale; Thalictrum pubenscens; Thlaspi arvense; Tragopogon dubius; Trifolium album, T. hybridum, T. pretense; Urtica dioica; Vicia cracca, V. sativa; Viola adunca, V. nephrophylla, V. nuttallii, V. petadifida, V. rugulosa; Xanthium strumarium; Zizia aptera, Z. aurea; Zygadenus elegans.*

APPENDIX IV.Woody plant species and graminoid species (grasses and related plants) that were encountered along transmission lines in Winnipeg, Manitoba (2007-2009).

Woody plants: *Acer negundo; Amelanchier alnifolia; Amorpha fruticosa; Arctostaphylos uva-ursi; Betula pumila; Chamaedaphne calyculata; Cornus stolonifera; Corylus cornuta; Crataegus* spp.*; Diervillea lonicera; Fraxinus pensylvanicus; Lonicera* spp.*; Juniperus scoparius; Picea glauca; Pinus banksiana; Populus balsamifera, P. tremuloides; Potentilla fruticosa; Prunus pensylvanicus, P. virginianus; Quercus macrocarpa; Rhamnus alnifolia; Ribes* spp.*; Rosa acicularis, R. arkansana; Rubus pubescens; Salix bebbiana, S. candida, S. discolor, S. exigua, S. lasiandra, S. lucida, S. maccaliana, S. mackenziana, S. pedicellaris, S. planifolia, S. pyrifolia, S. serissima; Sambucus racemosa; Shepherdia argentea; Symphoricarpos alba; Ulmus americana.*

Grasses and related plants: *Agropyron dasystachyum, A. repens, A. pectiniforme, A. smithii, A. spicatum, A. subsecundum, A. trachycaulum; Agrostis scabra, A. stolonifera; Andropogon gerardii; Beckmannia syzigachne; Bouteloua curtipendula; Bromus ciliatus, B. inermis; Calamogrostis inexpansa; Calamovilfa longifolia; Carex* spp.*; Cinna arundinacea; Deschampsia caespitosa; Distichlis stricta; Echinochloa crusgallii; Eleocharis acicularis, E. palustris; Elymus Canadensis; Festuca ovina, F. scabra; Hordeum jubatum; Juncus balticus, J. compressus, J. nodosus; Koeleria macrantha; Muhlenbergia asperifolia; Oryzopsis hymenoides; Phalaris arundinaceus; Phleum pretense; Phragmites australis; Poa pratensis; Puccinellia nuttalliana; Schyzachyrium scoparium; Scirpus validus; Setaria viridis; Spartina alternifolia; Sporobolus heterolepis; Stipa spartea, S. viridula, Triticum aestivum; Typha latifolia; Zea mays.*